Fig. 23.34 Computer-simulated smiles used to evaluate the response to incisal embrasure form. (A) Natural embrasures. (B) Reduced embrasures. In an Internet survey with 1934 responses, (A) was much preferred by 25% and preferred by 36%, and (B) was much preferred by 9% and preferred by 19%. Ten percent expressed no preference. (From Rosenstiel SF, Rashid RG. Public preferences for anterior tooth variations: a Web-based study. *J Esthet Restor Dent*. 2002;14:97.)

SUMMARY

An understanding of the science of color and color perception is crucial for success in the ever-expanding field of esthetic restorative dentistry. Although limitations in materials and techniques may make a perfect color match impossible, a harmonious restoration can almost always be achieved. Shade matching should be approached in a methodical and organized manner. This enables the practitioner to make the best choice and communicate it accurately to the laboratory. Newly developed shade systems and instruments may help the practitioner achieve a reliable restoration match.

The size and shape of restorations are equally important when a highly esthetic result is sought. Knowledge of the optimal proportion and the relative position of the teeth to each other and the soft tissues is essential.

Fig. 23.35 Computer-simulated images used to evaluate the effect of incisor angulation on anterior esthetics. Three-degree distal inclination of the central incisor (A) is preferred to 3-degree mesial inclination (B). Three-degree distal inclination of the lateral incisor (C) is preferred to 3-degree mesial inclination (D). (From Rosenstiel SF, Rashid RG. Dentists' perception of anterior esthetics: a Web-based survey [Abstract no. 1481]. *J Dent Res*. 2004;83[Special Issue A].)

STUDY QUESTIONS

1. Discuss the relationship of the visible spectrum to the electromagnetic energy spectrum, color, and invisible waves.
2. What is the Munsell color order system? Define the individual measures used.
3. What is the CIELAB color system? Define the individual measures used.
4. How does the human eye function? How does it recognize color, light, and dark?
5. What is metamerism? How can it be avoided or minimized? What is color adaptation? Color blindness? Fluorescence? The Benham disk is an example of which phenomenon?
6. How should a shade be selected?
7. Explain the differences between the VITA classical (Lumin Vacuum) shade guide and the VITA Toothguide 3D-MASTER.

Text continues on page 28.

Fig. 23.36 Pretreatment photographs. (A) Smile at rest. (B) Animated smile. (C) Profile assessment of lips at rest. (D) Lateral view of animated smile. (E) 12 o'clock view. (From Jreige CS, Kimura RN, Segundo ARTC, et al. Esthetic treatment planning with digital animation of the smile dynamics: a technique to create a 4-dimensional virtual patient. *J Prosthetic Dent*. 2021, in press.)

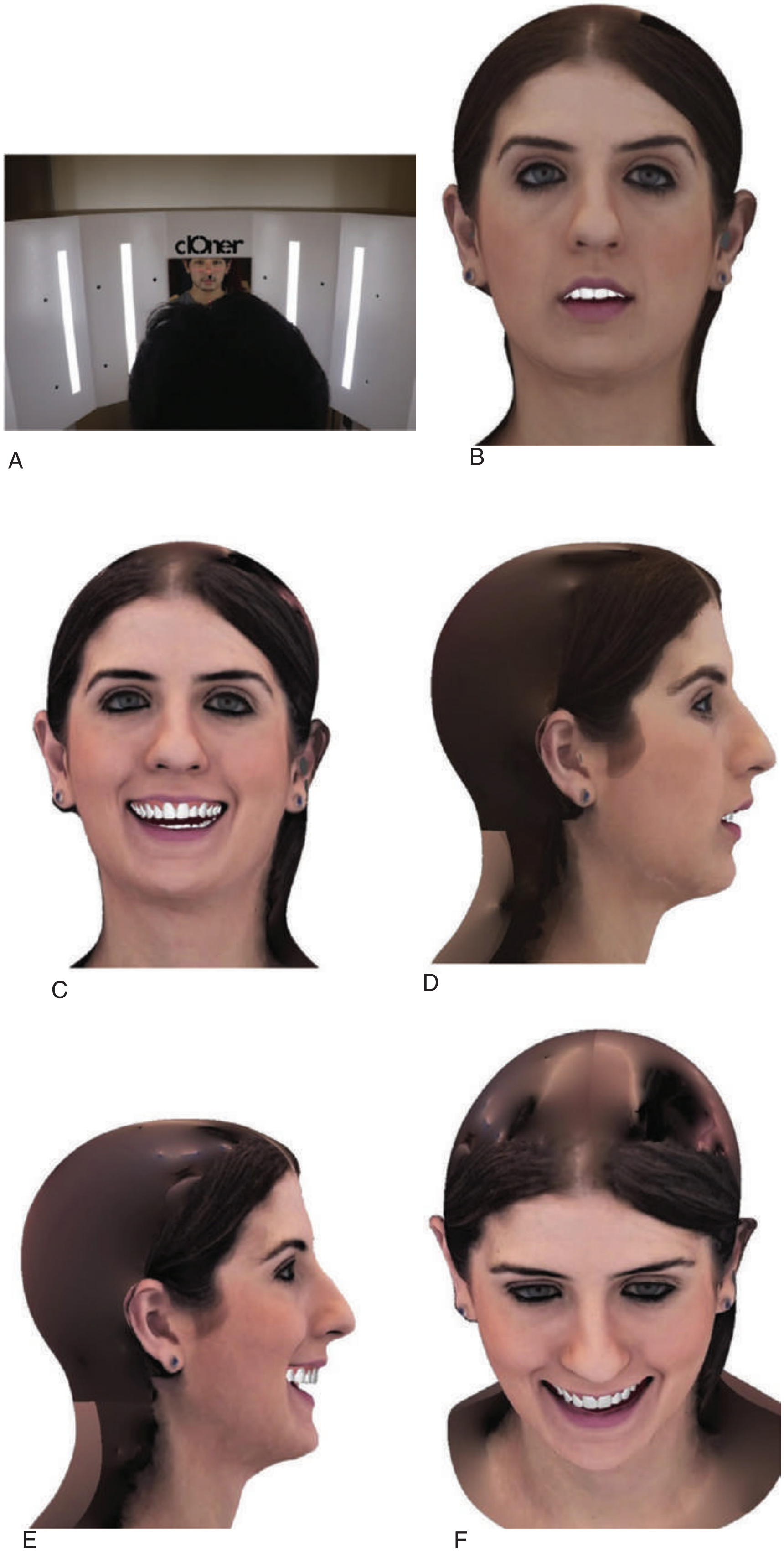

Fig. 23.37 Facial scan obtained by postprocessing images in software program (3DF Zephyr; 3DFLOW). (A) Stereophotogrammetry cabin (clOner; dOne 3D). (B) Smile at rest. (C) Animated smile. (D) Lateral aspect of lips at rest. (E) Profile outlook of animated smile. (F) 12 o'clock view. (From Jreige CS, Kimura RN, Segundo ARTC, et al. Esthetic treatment planning with digital animation of the smile dynamics: a technique to create a 4-dimensional virtual patient. *J Prosthetic Dent*. 2021, in press.)

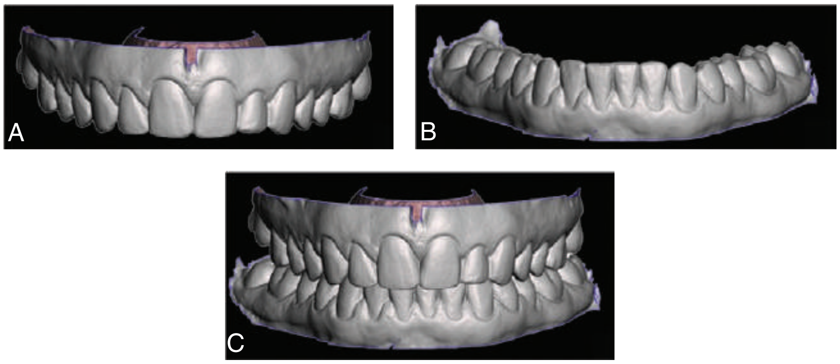

Fig. 23.38 Intraoral scanner 3-dimensional casts. (A) Virtual maxillary cast. (B) Virtual mandibular cast. (C) Occlusion record. (From Jreige CS, Kimura RN, Segundo ARTC, et al. Esthetic treatment planning with digital animation of the smile dynamics: a technique to create a 4-dimensional virtual patient. *J Prosthetic Dent*. 2021, in press.)

Fig. 23.39 Esthetic smile planning with DSD app. (A) DSD software program and facial photograph of animated smile. (B) Maxillary digital cast merged with 2D frontal photograph. (C) Intraoral scan digital cast integrated with profile photograph. (D) Facial scan imported into software program and superimposed on front view photograph. (E) Merging intraoral and facial scans. (F) Smile design guided by anatomic references. (G) Before and after project simulation. *DSD*, Digital smile design. (From Jreige CS, Kimura RN, Segundo ARTC, et al. Esthetic treatment planning with digital animation of the smile dynamics: a technique to create a 4-dimensional virtual patient. *J Prosthetic Dent*. 2021, in press.)

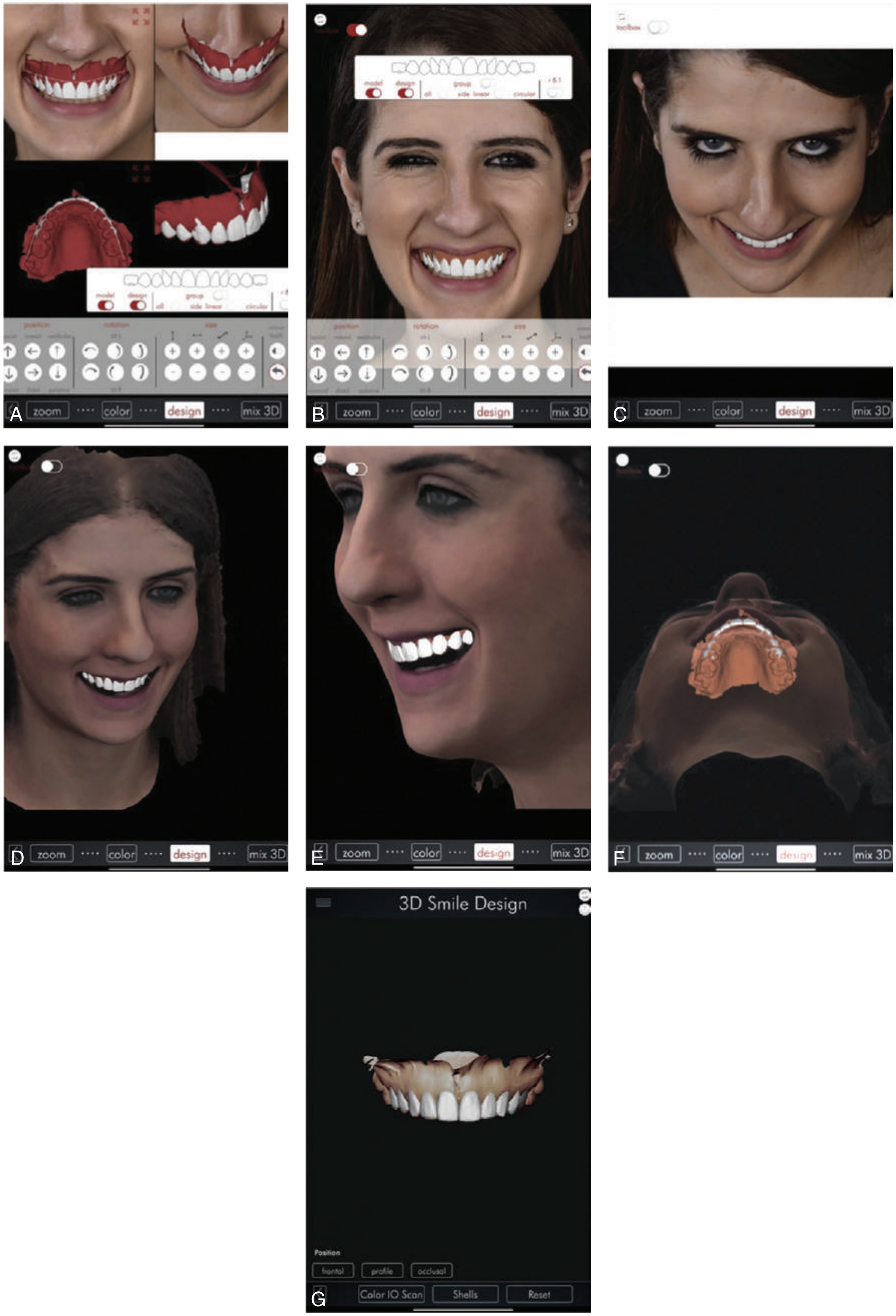

Fig. 23.40 Computerized 3-dimensional waxing. (A) 3D waxing cast presented at different angles to evaluate smile. (B) Proposed design from frontal view. (C) 12 o'clock view. (D) 3D waxing incorporated into facial scan in anterior view. (E) Smile design and facial scan in profile view. (F) 3D waxing in inferior view. (G) Definitive 3-dimensional smile design cast. (From Jreige CS, Kimura RN, Segundo ARTC, et al. Esthetic treatment planning with digital animation of the smile dynamics: a technique to create a 4-dimensional virtual patient. *J Prosthetic Dent.* 2021, in press.)

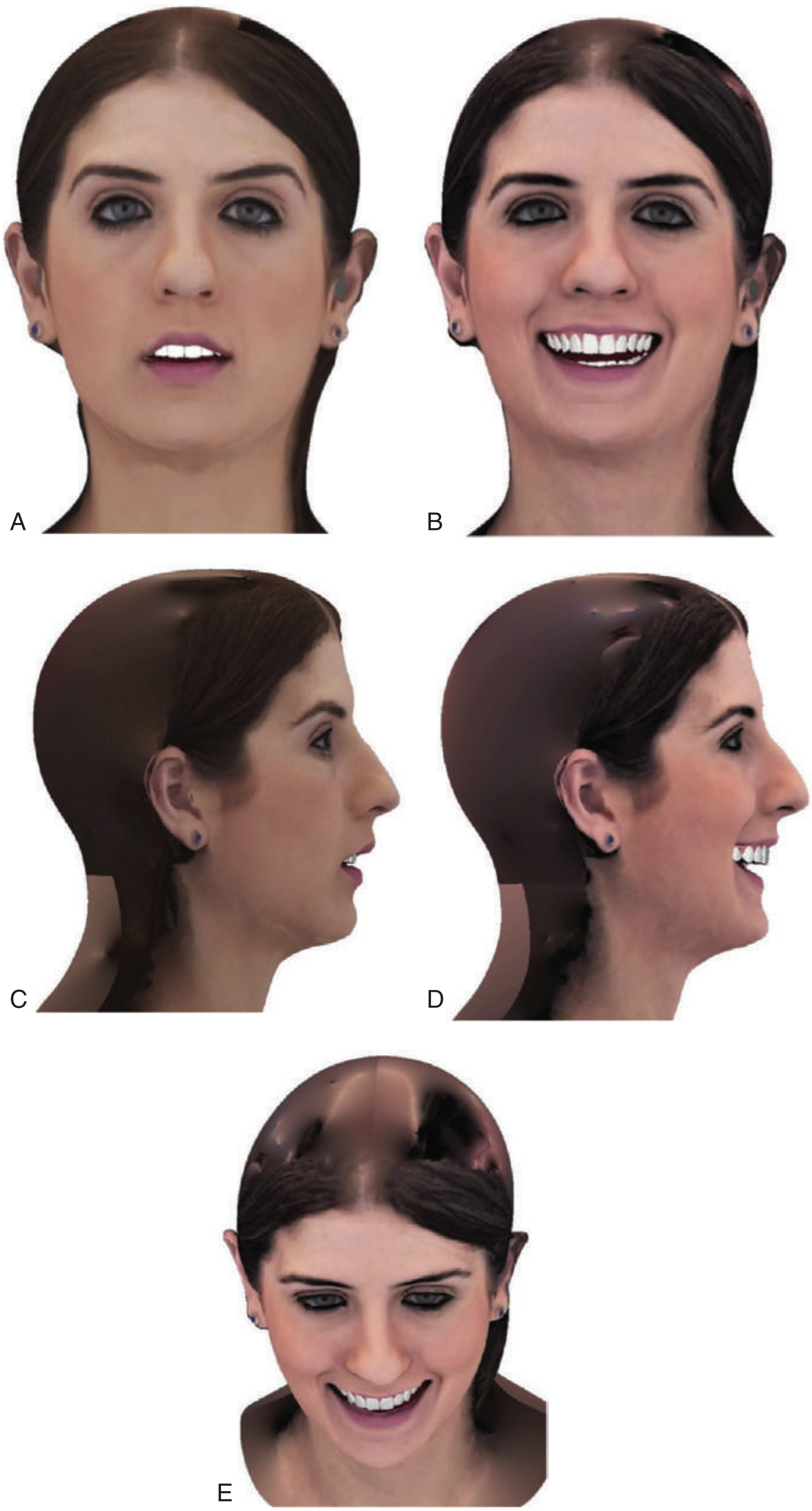

Fig. 23.41 Video frames representing 4D virtual patient. 3D smile project incorporated into facial scan. (A) Smile at rest. (B) Animated smile. (C) Lateral view of lips at rest. (D) Profile appearance of animated smile. (E) 12 o'clock view. (From Jreige CS, Kimura RN, Segundo ARTC, et al. Esthetic treatment planning with digital animation of the smile dynamics: a technique to create a 4-dimensional virtual patient. *J Prosthetic Dent.* 2021, in press.)

Fig. 23.42 Result of technique. 3D printed cast and trial restorations. (A) Maxillary cast. (B) Smile at rest position. (C) Animated smile. (D) Profile aspect of lips at rest. (E) Lateral assessment of animated smile. (F) 12 o'clock view. (G) Comparison between initial status, 4D virtual plan, and trial restorations. (From Jreige CS, Kimura RN, Segundo ARTC, et al. Esthetic treatment planning with digital animation of the smile dynamics: a technique to create a 4-dimensional virtual patient. *J Prosthetic Dent*. 2021, in press.)

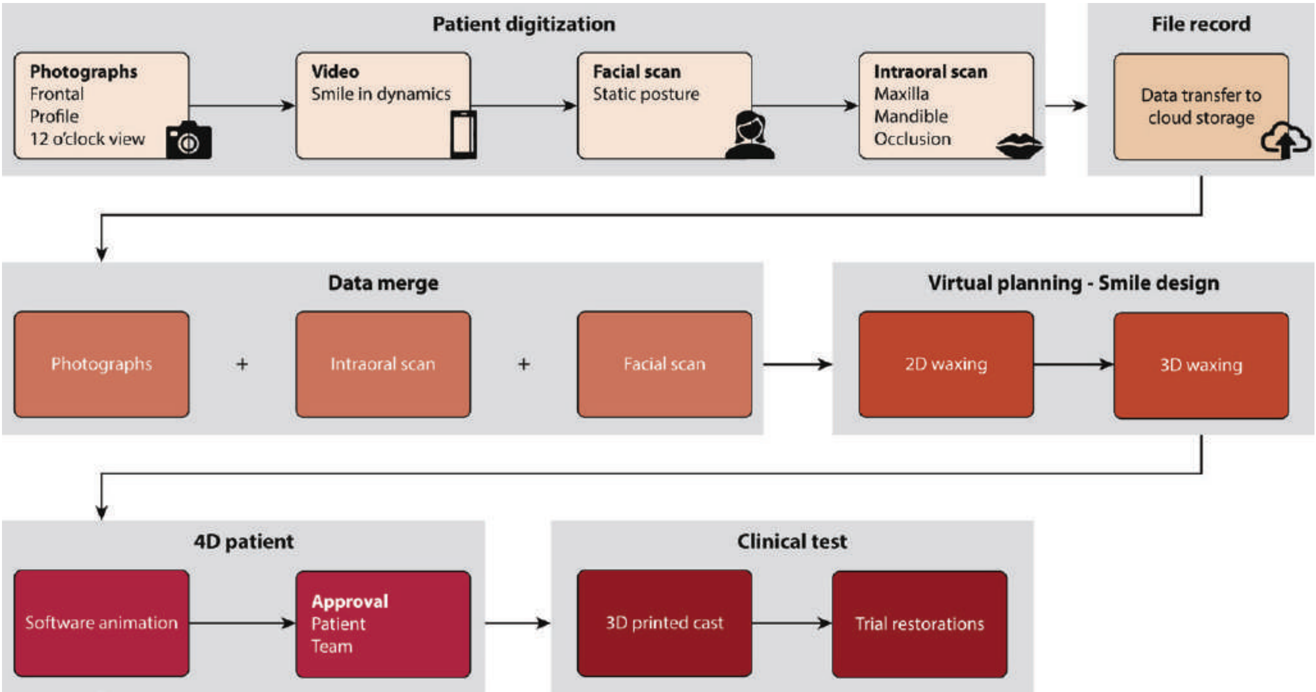

Fig. 23.43 Four-dimensional patient workflow. (From Jreige CS, Kimura RN, Segundo ARTC, et al. Esthetic treatment planning with digital animation of the smile dynamics: a technique to create a 4-dimensional virtual patient. *J Prosthetic Dent.* 2021, in press.)

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24

Metal-Ceramic Restorations

HISTORICAL PERSPECTIVE

Ceramic objects have been fabricated for thousands of years. The earliest techniques consisted of shaping the item in clay or soil and then firing it to fuse the particles together. The initial attempts resulted primarily in coarse and somewhat porous products, such as goblets and other forms of pottery. Later developments led to very detailed stoneware items. The Egyptian faience was the first known effort to coat a substructure with a ceramic veneer (Fig. 24.1). Their typical blue-green hues result from metal oxides forming during the firing process.

Later in antiquity, Chinese ceramists developed porcelain, which was characterized by vitrification, translucency, hardness, and impermeability. European attempts at developing porcelain of similar quality were conducted in the seventeenth century. These efforts spread the knowledge of porcelain's basic components: kaolin and feldspar.

As early as the second half of the eighteenth century, Pierre Fauchard and others attempted to use porcelain in dentistry. These early efforts were largely unsuccessful. However, porcelain was successfully used for dental prostheses by the end of the 1800s, when the technique of firing porcelain jacket crowns on a platinum matrix was first developed.[1] It was not until the mid-1950s that dental porcelain was developed with a coefficient of thermal expansion similar to that of dental casting alloys. The metal-ceramic restoration first became available commercially during the later 1950s.[2] Today this technique is considered a routine procedure with excellent clinical performance.[3]

Fig. 24.1 Glazed Egyptian faience tile from the Western Doorway or Gate of the Mortuary Temple of Ramses III, with a "Rekhyet" bird worshipping the cartouche of Ramses III, "Lord of the Two Lands" (ca. 1182–1151 BCE), Dynasty XX, excavated at Medinet Habu by the Oriental Institute. This is an early example of a substructure coated with a ceramic veneer. (Courtesy the Oriental Institute, The University of Chicago.)

OVERVIEW

The metal-ceramic restoration (Fig. 24.2) consists of a metal substructure (see Chapter 19) supporting a ceramic veneer that is mechanically and chemically bonded to it. The chemical component of the bond is achieved through firing.

Porcelain powders of varying composition and color, mixed with distilled water or an aqueous liquid, are applied as a slurry to the metal and fired to produce the desired appearance. The first ceramic layer, which is opaque, masks the dark metal oxide and is the primary source of color for the completed restoration. The opaque layer is covered with slightly translucent body porcelain, which is then veneered with an even more translucent enamel overlay that contains relatively little pigmentation. Achieving an accurate appearance match may warrant incorporating either translucent or highly pigmented powders into selected areas of the buildup. The shiny, lifelike appearance of the completed metal-ceramic restoration results from a surface glaze formed during an additional firing after the restoration has been shaped.

Historically, the metal-ceramic restoration was fabricated with metal margins, and the veneer was limited to visible areas. With technological advances, the use of porcelain on occlusal and lingual surfaces has become common.[4] Several techniques[5,6] have been developed to obtain porcelain margins on the facial aspect of the restoration. The latter technique is common for teeth in the esthetic zone, whereas a metal collar may be used in posterior areas in which esthetic appearance is a lesser issue.

METAL PREPARATION

Shape

Sharp angles or pits on the veneering surface of a metal-ceramic restoration should be avoided because they can contribute to internal stress in the fired porcelain.[7] Convex surfaces and rounded contours should be created so that the porcelain is

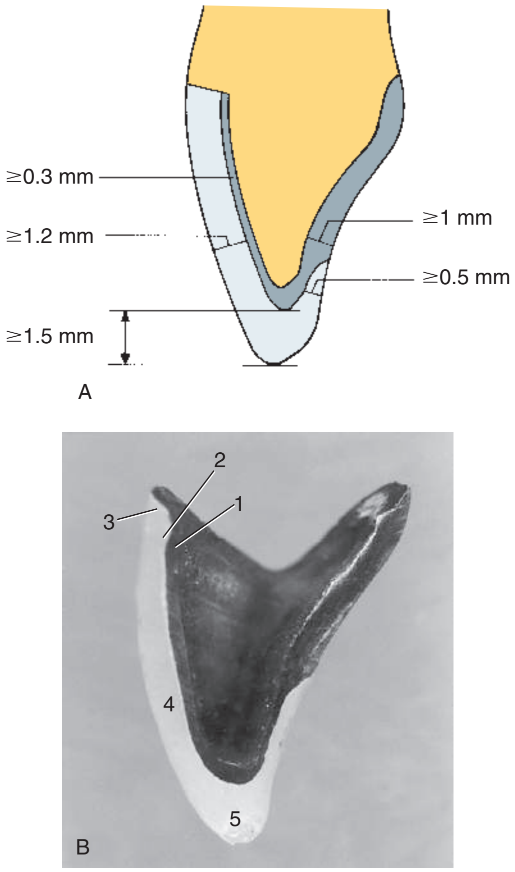

Fig. 24.2 (A) Longitudinal section through a metal-ceramic crown. Note the minimum dimensions. (B) Sectioned metal-ceramic restoration. *1*, Metal substructure; *2*, opaque porcelain; *3*, gingival porcelain; *4*, body porcelain; *5*, incisal porcelain.

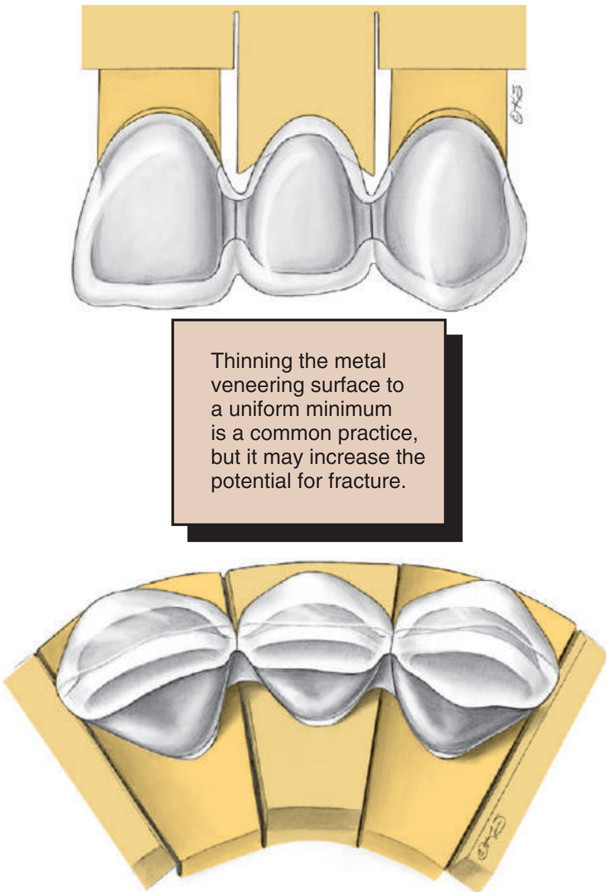

Fig. 24.3 Substructure design for an anterior partial fixed dental prosthesis. The metal should be shaped to support an even thickness of porcelain.

supported without the development of stress concentrations (Fig. 24.3). In addition, a smooth surface facilitates wetting of the framework by the porcelain slurry.

The intended metal-ceramic junction should be as definite (90-degree angle) and as smooth as possible to make finishing easier during all fabrication stages (Fig. 24.4). The metal framework must be thick enough to prevent distortion during firing. A minimum thickness of 0.3 mm is advocated for noble metal alloys; 0.2 mm is sufficient for base metal alloys, which can be finished thinner and still withstand distortion because of their higher fusing ranges, moduli of elasticity, and yield strengths (see Chapter 19).

The mechanical properties of a metal-ceramic restoration depend largely on the design of the substructure that supports the ceramic veneer. The metal-ceramic interface must be far away (ideally, at least 1.5 mm) from all centric occlusal contacts and must be distinct to facilitate the removal of excess porcelain. The veneering surface must be finished to a smooth texture with rounded internal angles to allow proper wetting by the opaque porcelain.

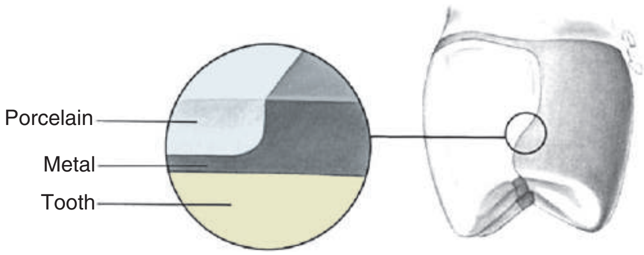

Fig. 24.4 The metal substructure should have a distinct margin for finishing the veneer.

Investment Removal

After the framework has been cast, all investment material must be removed ultrasonically, with airborne-particle abrasion, or with steam (according to the alloy manufacturer's directions). The phosphate-bonded investment material, which must be used with the high-fusing metal-ceramic alloys, is more difficult to remove from the metal surface than is conventional gypsum-bonded investment material. Hydrofluoric acid dissolves the refractory silica component of the investment material. However, this highly corrosive acid is extremely dangerous and must be handled very cautiously.[8] A small spill on the skin results in painful acid burns, and slight exposure to the fumes may produce severe corneal damage. An acid burn on the skin is treated by injection of calcium gluconate in the area, providing a means for the free fluoride from the acid to precipitate. Less dangerous substitute solutions (e.g., Stripit, Keystone Industries) are available.

Careful examination of the internal aspect of the framework under magnification may reveal residual small investment particles. Several cycles of ultrasonic cleaning may be necessary to eliminate all investment material. If airborne-particle abrasion is used for investment removal, the margins of the framework must be protected to prevent damage by the abrasive particles.[9]

Oxide Removal

The oxide layer that has been formed on the metal surface during casting must be partially removed with either acid or airborne-particle abrasion. For optimal metal-porcelain bonding, the alloy manufacturer's directions should be followed precisely, because achieving a successful bond depends on a controlled thickness of the metal-oxide layer.

Metal Finishing

When the veneering surfaces are ground, care is needed to avoid dragging the metal over itself, which may entrap air and grinding debris (which later can cause bubbling or contamination of the porcelain). Finishing the surface in one direction with light pressure helps avoid trapping debris between folds of the metal, which is a potential problem when alloys with high gold content and high elongation values are used (Fig. 24.5).

The surface should be finished with ceramic-bound stones because some of the binders used in conventional rotary instruments may be a source of contamination. Tungsten carbide burs also may be used safely. After the surface has been smoothed, it should be airborne-particle abraded with aluminum oxide according to the manufacturer's instructions. This creates a satin finish on the veneering surface that is easily wettable by the porcelain slurry (Fig. 24.6).

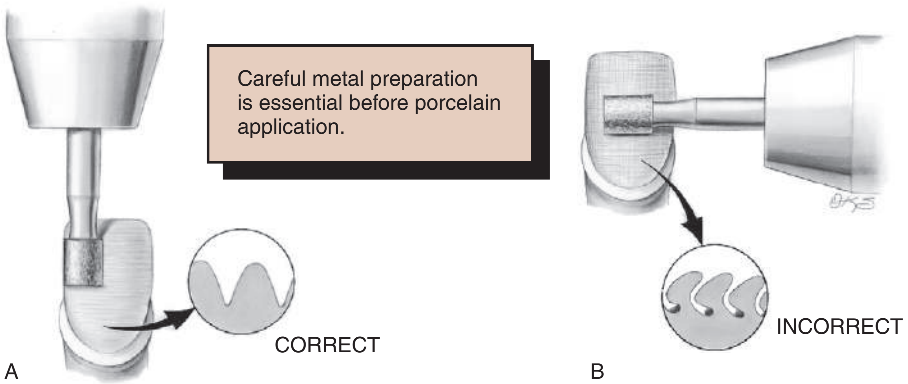

Fig. 24.5 (A) Correct way to prepare the veneer area. The metal should be ground in the same direction. (B) Incorrect multidirectional grinding can cause trapping of debris in the high-noble alloys.

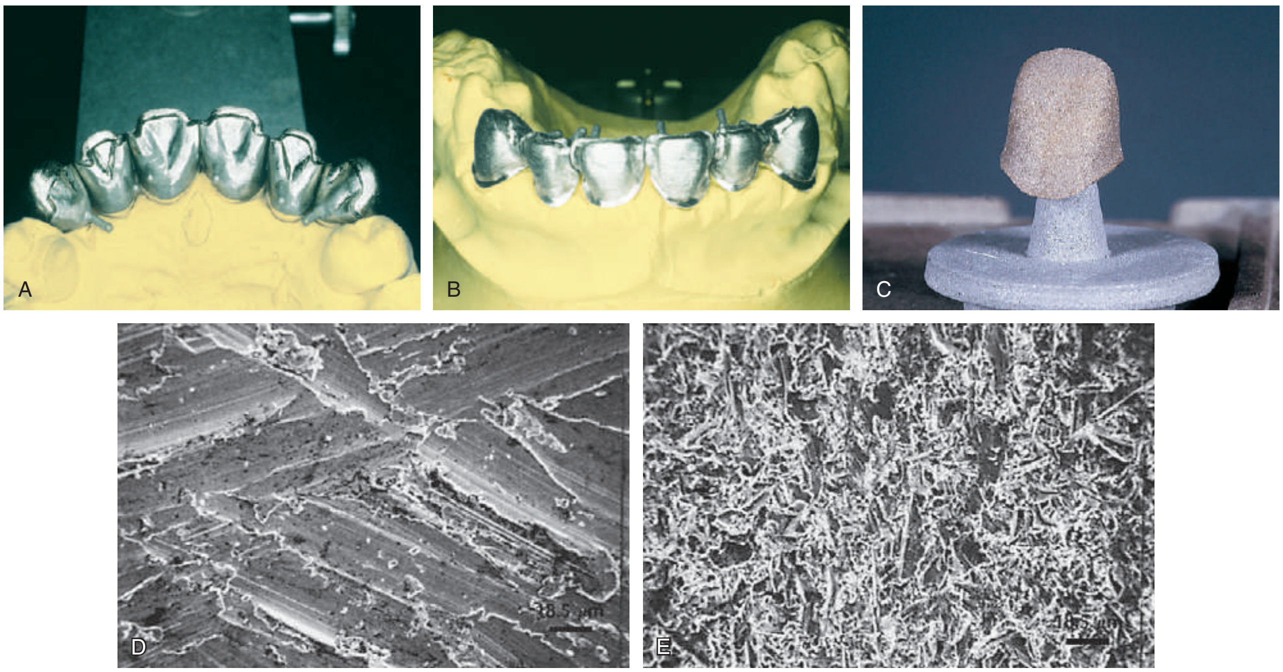

Fig. 24.6 Metal preparation. (A and B) Castings prepared by grinding. (C) Satin finish obtained by airborne-particle abrasion. (D and E) Scanning electron micrographs of metal after grinding with a stone (D) and with airborne-particle abrasion (E). (D and E, Courtesy Dr. J.L. Sandrik.)

Thickness

A dial (or metric) caliper is necessary to verify that the metal substructure conforms to all specified minimum dimensions (Fig. 24.7). Metal thickness of less than 0.3 mm may lead to distortion during firing. Typically, the margin is thinned to a knife-edge so that a metal line is not visible. There is no evidence that thinning the margin will adversely affect the fit of restorations cast in contemporary alloys.[10,11] The porcelain labial margin design can provide a better appearance, particularly when anterior or premolar teeth necessitate good esthetics at the labial margin.

Finishing

Finishing the metal-ceramic interface is a challenging laboratory procedure that requires attention to detail. The axial surfaces and visible portion of the metal collar should be contoured and finished to a rubber wheel stage before preparation of the veneering surface is attempted (Fig. 24.8A and B). At this time, the margin itself is left untouched. Round stones and tungsten carbides can be used to finish the veneering surface at the metal-ceramic interface (see Fig. 24.8C), and the desired right-angle configuration is then easily obtained. Any remaining irregularities can be blended easily with barrel-shaped stones (see Fig. 24.8D).

Fig. 24.7 Dimensions should be verified with calipers.

When the grinding phase is completed, a satin finish is obtained by airborne-particle abrasion of the veneering surface with a fine-grit alumina (see Fig. 24.8E).

Cleaning

Although a properly prepared framework appears smooth to the naked eye, its appearance is still quite rough when viewed with a microscope. Small particles, grinding debris, oil, and finger grease must be removed because they interfere with the wetting process, which is crucial for a good metal-to-ceramic bond.

The substructure can be cleaned by immersion in a general-purpose cleaning solution in an ultrasonic unit. The duration of the cleaning cycle depends on the unit, but 5 minutes is adequate in most cases. Residual soap can be removed by rinsing the substructure in distilled water. Some manufacturers recommend following this with a rinse in 92% alcohol (conventional 70% isopropyl alcohol should not be used because it contains aromatic and mineral oils, which may cause contamination). Steam cleaning is an excellent and time-saving alternative to ultrasonic cleaning. The veneering surface should not be touched once the cleaning procedures have been completed to prevent further contamination.

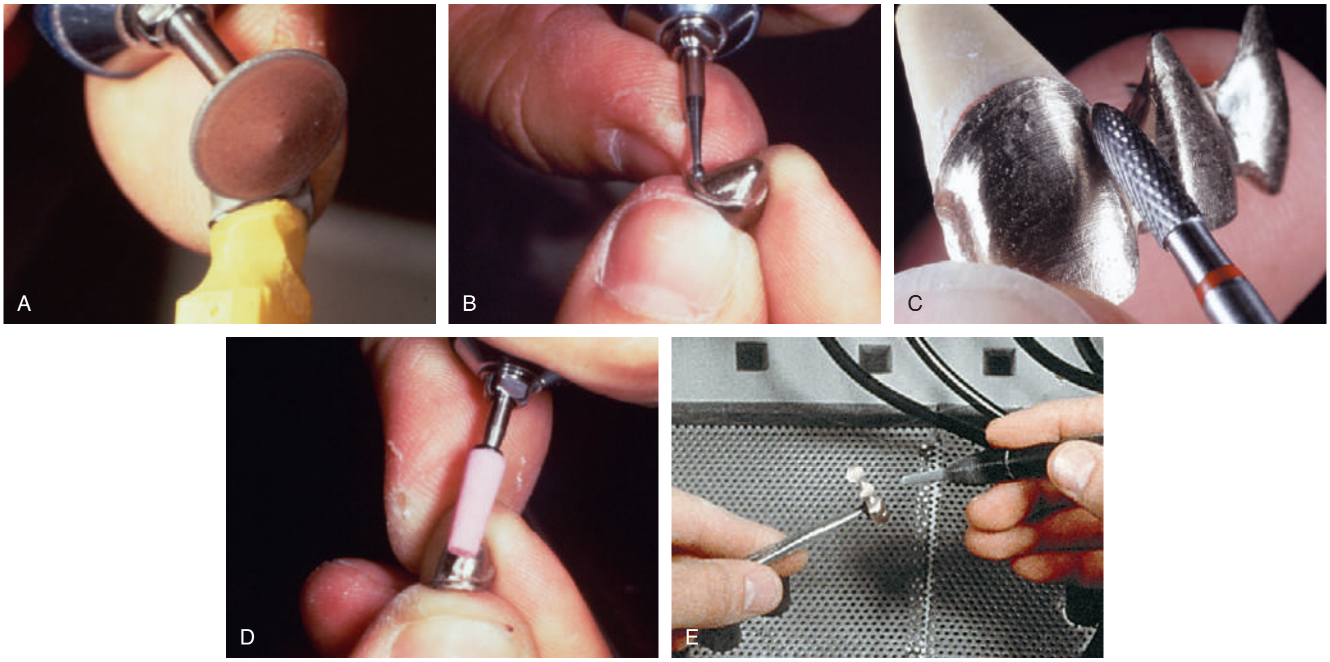

Fig. 24.8 Preparing the substructure. (A) Nonveneering surface finished to the rubber wheel stage. (B and C) Metal-ceramic junction delineated with a tungsten carbide bur. (D) Veneering surface dressed with a ceramic-bound stone. (To avoid perforation, the metal thickness should be checked regularly with calipers.) (E) Airborne-particle abrasion of the veneering area. The margins have been protected by soft wax.

Oxidizing

A controlled oxide layer must be created on the metal surface to establish the chemical bond between metal and porcelain (Fig. 24.9). In noble-metal alloys, iron, tin, indium, and gallium are the base elements used for oxide formation (see Fig. 24.15).

To obtain the oxide layer, the substructure is typically placed on a firing tray and inserted into the muffle of a porcelain furnace, and the temperature is raised to a specified level that sufficiently exceeds the firing temperature of the porcelain. A vacuum is created in the firing chamber, which, although insufficient to remove adherent gases, reduces the thickness of the oxide layer. The incorrect term *degassing* is often used interchangeably with *oxidizing* (see Factors Affecting the Bond later in this chapter).

Specific procedures may vary slightly, depending on the alloy used. Ceramic alloys with high gold content are usually held at the oxidizing temperature for several minutes. The first porcelain application can be performed as soon as the casting has cooled to room temperature after it is removed from the furnace.

Many of the alloys with lower gold content contain more base elements, which can result in a thicker oxide layer. With some of these alloys, it is therefore not necessary for the casting to be held at the oxidizing temperature for any length of time. To reduce excessive surface oxides, some manufacturers recommend brief airborne-particle abrasion of the casting with alumina or placing it in hydrofluoric acid after firing.

Because of lower costs, the use of non-noble or base metal alloys for metal-ceramic restorations is now widespread. These alloy systems undergo continuous oxide formation. Although the techniques for different systems vary, most manufacturers recommend against oxidizing substructures made of base metal alloys. Instead, they recommend performing the first porcelain application immediately after cleaning. Because the extent of oxide formation cannot be easily controlled, there is a potential for failure through the thick and brittle oxide layer with these alloy systems. However, it may be of no significance with other alloy systems.

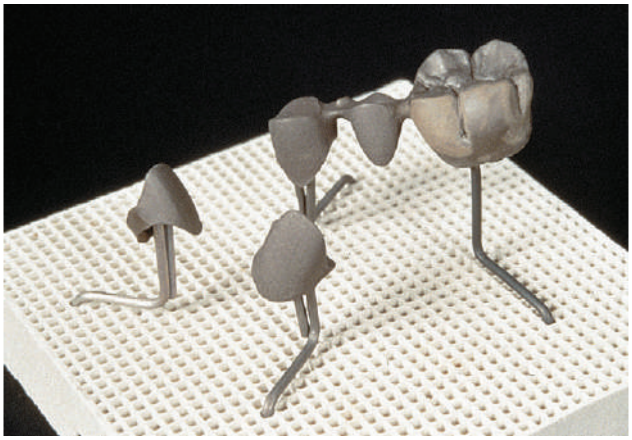

Fig. 24.9 Metal-ceramic substructure after cleaning and before oxidizing in the porcelain furnace.

MATERIALS SCIENCE

Leon W. Laub

Dental ceramics are generally classified into three groups according to their maturation or fusion range: high-fusing (1290°C to 1370°C [≈2350°F to ≈2500°F]), medium-fusing (1090°C to 1260°C [≈2000°F to 2300°F]), and low-fusing (870°C to 1070°C [≈1600°F to ≈1960°F]). In contrast to denture teeth and the original porcelain jacket crowns, which are fired in the medium- and high-fusing ranges, metal-ceramic veneer restorations are fired in the range of 950°C to 1020°C (≈1750°F to ≈1870°F). This discussion is limited to these low-fusing porcelains.

Porcelain Manufacture

Dental porcelain is produced from a blend of quartz (SiO_2), feldspar (potassium aluminum silicate orthoclase, sodium aluminum silicate albite), and other oxides. During manufacturing, the materials are heated to a high temperature to form a glassy mass and then are cooled rapidly by quenching in water, which causes the glassy mass to fracture into many small fragments. The resulting product is called a *frit*. This process may be repeated several times, after which the frit is ball-milled until the desired particle size distribution is obtained. Because fritting takes place at temperatures much higher than those used in the fabrication of dental restorations, most of the chemical reactions between raw materials occur before they are used in the dental laboratory. Typical compositions are listed in Table 24.1, although the actual compositions vary according to the proposed use of the end product. Most formulations designed for metal-ceramic use are similar to that described by Weinstein et al.[12,13] They consist of a mixture of two frits: a low-fusing glass frit and a high-expansion frit consisting of crystalline leucite ($KAlSi_2O_6$; Fig. 24.10) with tetragonal symmetry (Fig. 24.11). This mixture overcomes the two principal difficulties in veneering metal with ceramic: having a porcelain firing temperature well below the melting range of the metal and having a sufficiently high thermal expansion compatible with the metal.

TABLE 24.1 Composition of High-, Medium-, and Low-Fusing Body Porcelains (Weight Percentage)

	High-Fusing	Medium-Fusing	Low-Fusing (Vacuum Fired)	Metal-Ceramic
SiO_2	72.9	63.1	66.5	59.2
Al_2O_3	15.9	19.8	13.5	18.5
Na_2O	1.68	2.0	4.2	4.8
K_2O	9.8	7.9	7.1	11.8
B_2O_3	—	6.8	6.6	4.6
ZnO	—	0.25	—	0.58
ZrO_2	—	—	—	0.39

Modified from Yamada HN, Grenoble PB. *Dental Porcelain: the State of the Art—1977*. Los Angeles, University of Southern California School of Dentistry, 1977.

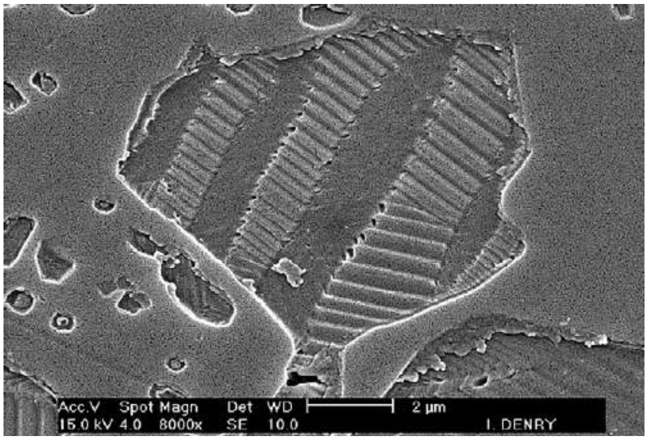

Fig. 24.10 Scanning electron micrograph of polished and etched leucite-containing dental ceramic, showing a tetragonal leucite crystal.

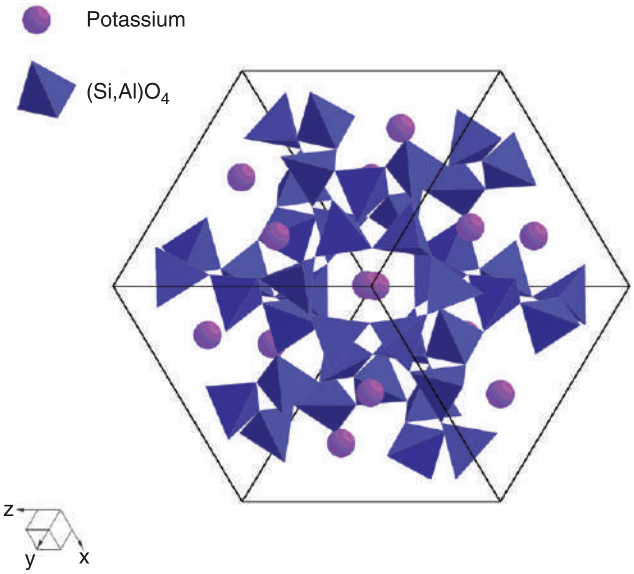

Fig. 24.11 Crystalline structure of low-temperature (tetragonal) leucite.

After firing in the laboratory, dental ceramics consist of about 20% volume tetragonal leucite crystals dispersed in a glassy matrix.[14] The structure of this glassy matrix is a random silicon-oxygen network. The silicon atom combines with four oxygen atoms in a tetrahedral configuration (Fig. 24.12). These tetrahedra may be linked into a chain with both covalent and ionic bonds, which leads to a metastable structure. However, such a silicon-oxygen network would have a very high melting point. Usually, potassium and sodium are added to the glass composition to help break down the silicon-oxygen network and are therefore known as *glass modifiers*. In dental ceramics, potassium and sodium are initially provided by the feldspars. Two desirable consequences result: (1) The softening temperature of the glass is reduced, and (2) the coefficient of thermal expansion is increased. The manufacturer adjusts the oxide content so that the dental ceramic's coefficient of thermal expansion is close to the corresponding value for the alloys used to

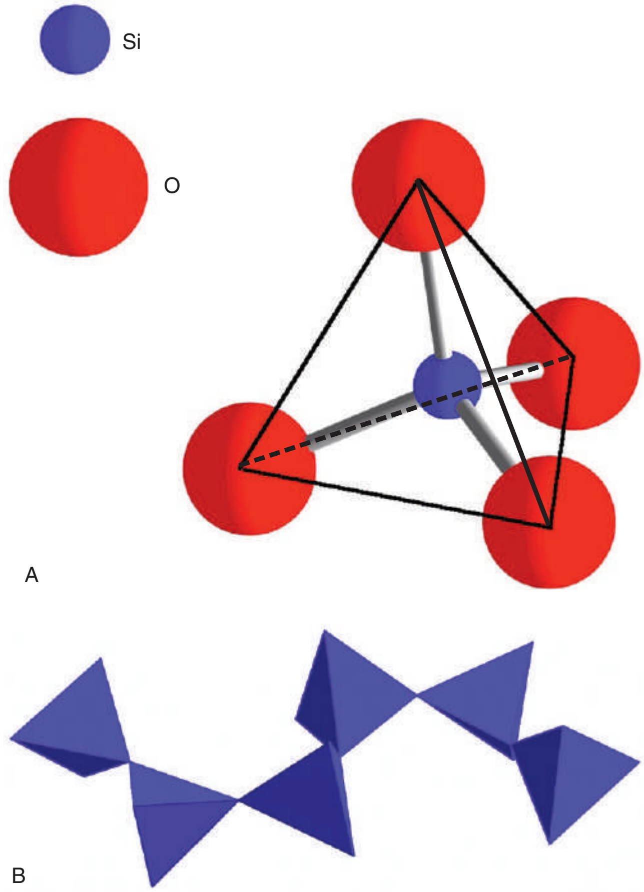

Fig. 24.12 (A and B) The silicon-oxygen tetrahedral configuration.

make the substructure. If the composition of the glass is not properly adjusted, extensive breakdown and reorganization of the silicon-oxygen network may occur, leading to a crystallization of the glass (also called *devitrification*). The change in lattice structure from a vitreous to a crystalline form (devitrification) is shown schematically in Fig. 24.13. Some devitrification may occur in dental ceramics if a ceramic restoration is fired too often, and it is typically associated with an increase in the coefficient of thermal expansion and opacity.

Feldspar also contains alumina (Al_2O_3), which acts as an intermediate oxide to increase the viscosity and hardness of the glass. As a result, dental porcelain has good resistance to slump or pyroplastic flow; this resistance is necessary for obtaining the desired configuration of the restoration.

Porcelain Technique

Dental porcelain is usually received from the manufacturer in powder form, which is mixed with either water or a water-based glycerin-containing liquid to form a paste of workable consistency. This mixture is then used to make a restoration with the required configuration. Several condensation techniques (e.g., vibration and blotting) are used to remove as much excess water as possible. The porcelain particles are drawn together during condensation by capillary action. Proper condensation minimizes steam generation during the drying phase of firing.

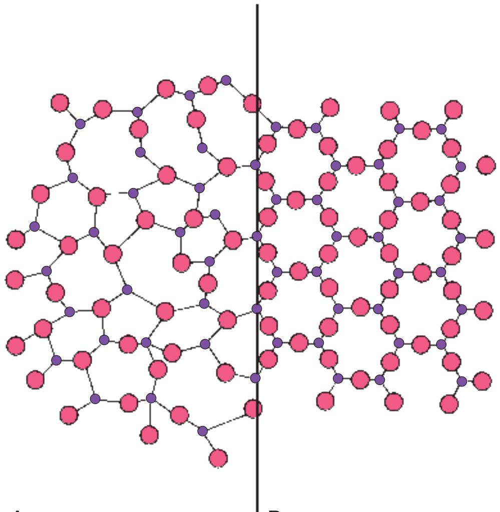

Fig. 24.13 Change in the silicon-oxygen network structure from a glassy (A) to a crystalline (B) form. (Modified from Kingery WD, et al. *Introduction to Ceramics*. 2nd ed. New York, NY: Wiley & Sons; 1976.)

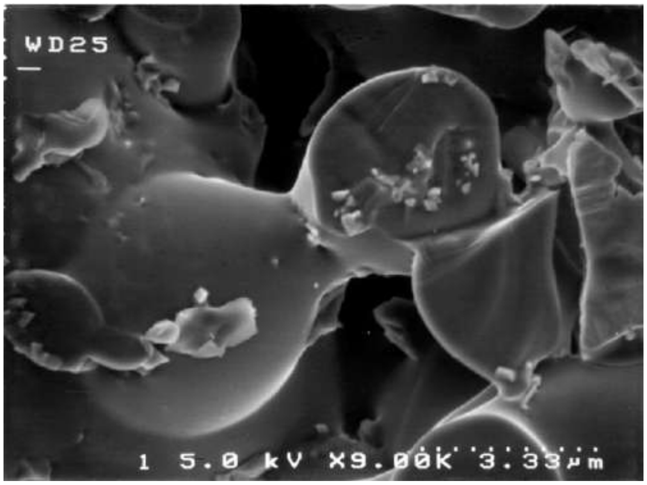

Fig. 24.14 Vitreous sintering. Partial melting of the unfused particles leads to their bonding. Observe the necking caused by the glass flow. (Modified from Van Vlack LH. *Elements of Materials Science*. 2nd ed. Reading, MA: Addison-Wesley; 1964.)

Once the mass is heated, individual porcelain particles conglomerate by sintering. The viscous flow of unfused particles results in wetting and bridging between such particles (Fig. 24.14). Consequently, interstitial space is lost, with as much as 27% to 45% volumetric shrinkage after firing.[15]

Types of Porcelain

The following porcelain blends are produced for the different roles they play in the fabrication of metal-ceramic restorations: opaque, body, and incisal porcelains.

Opaque Porcelain

This is applied as a first ceramic coat and performs two major functions: It masks the color of the alloy, and it is responsible for the metal-ceramic bond.

Opacifying oxides are added to the original porcelain blend. The density of these oxides is greater than that of the glass matrix. Consequently, the oxides of tin, titanium, and zirconium have a higher refractive index than do the components of the glass matrix (feldspar 2.01 to 2.61 and quartz 1.52 to 1.54). When a specific range of oxide particle sizes is used, most of the incident light is scattered and reflected rather than transmitted through the porcelain, effectively masking the color of the alloy substrate.

A scanning electron microscope (SEM) view of the alloy-porcelain interface[16] for an alloy with high noble metal content is shown in Fig. 24.15. When the region around the interface is examined for specific elements (a technique known as *elemental mapping*), the concentrations of aluminum and titanium can be identified. These appear as dense regions in the figure, which indicates that discrete oxide particles of aluminum and titanium are in the opaque porcelain, probably just beneath the surface. When the elemental map is compared with the photomicrograph of the interface, it is possible to identify the distribution and size of the subsurface opacifying oxide particles. Silicon also demonstrates a uniform porcelain distribution, which is to be expected.

Body Porcelain

Body porcelain is fired onto the opaque layer, usually in conjunction with the incisal porcelain. It provides some translucency and contains metallic oxides that aid in shade matching. Body porcelains are available in a wide selection of shades to match adjacent natural teeth. Most porcelain manufacturers provide an opaque shade for each body shade. Although porcelains of different manufacturers are given the same nominal shade (e.g., the popular VITA classical shade guide [VITA North America]), there is significant color variation among manufacturers,[17,18] and a dentist should know which system the technician uses.

Incisal Porcelain

Incisal porcelain is usually translucent. As a result, the perceived color of the restoration is significantly influenced by the color of the underlying body and opaque porcelain.

▪ ▪ ▪

Porcelain-Alloy Bonding

William A. Brantley • Leon W. Laub • Carl J. Drago

The formation of a strong bond between the opaque porcelain layer and the cast alloy is essential for the longevity of the metal-ceramic restoration. Extensive research since the 1970s has provided insight into the important factors for achieving metal-ceramic bonding. Early work[19] established the importance of wetting the alloy surface with the porcelain at the firing temperature. Although similar measurements of contact angles have not been reported for current dental porcelains and casting alloys, good wetting is essential for minimizing porosity at the metal-ceramic interface. A detailed relationship between the elevated-temperature contact angle and metal-ceramic bonding has not been established, but the research by O'Brien and Ryge[19] indicated that perfect wetting (a contact angle of 0 degrees) does not occur.

In the model by Borom and Pask,[20] an idealized continuous lattice structure is considered across the metal-ceramic interface for chemical bonding. This would be achieved in principle

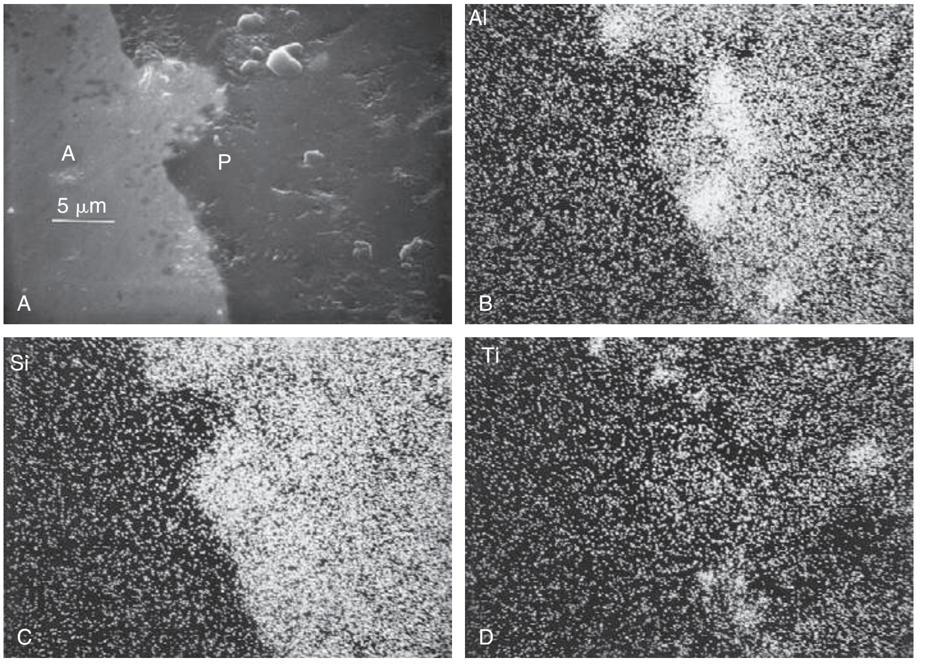

Fig. 24.15 Alloy-porcelain interface for an alloy with high noble metal content: Degudent U (DENTSPLY International Inc.) and VITA normal (VITA North America). (A) Scanning electron microscopic view of the interface. Elemental maps of aluminum (B), silicon (C), and titanium (D). (From Laub LW, et al. The metal-porcelain interface of gold crowns [Abstract no. 874]. *J Dent Res*. 1978;57:A293.)

by incorporating certain oxidizable elements in the porcelain composition that (1) can diffuse into the casting alloy at the elevated temperatures of the porcelain firing cycles and (2) have the same equilibrium chemical potentials in both the metal and ceramic. In reality, however, the situation at the dental metal-ceramic interface does not fit this idealized model. Research on gold[21] and high-palladium[22,23] alloys used for ceramic veneering has shown that the structure of oxidized regions is highly complex; similar results would be anticipated for detailed studies of other types of oxidized dental casting alloys. The existence of multiple phases in the oxidized region of the alloy indicates that the proposed continuity[20] of atomic bonds cannot generally be achieved across the metal-ceramic interface, except possibly at sites where the glass matrix of the porcelain is in contact with the solid solution matrix of the alloy.

In casting alloy compositions, manufacturers incorporate small amounts of certain base metals that form oxides[24,25] and contribute chemical bonding to the metal-ceramic adherence. Investigators using the electron microprobe and SEM[16,26–31] have shown that these elements accumulate at the metal-ceramic interface and form an interfacial oxide layer. For noble-metal alloys, elements that have a major role in porcelain adherence are iron (alloys with high gold content), tin and indium (alloys with lower gold content, palladium-silver alloys, silver-palladium alloys, and alloys with high palladium content), and gallium (alloys with high palladium content). For base metal alloys in which the principal elements are nickel and cobalt, chromium oxidation provides chemical bonding for porcelain adherence; titanium oxidation fulfills this role for titanium casting alloys.

Fig. 24.16A is an SEM photomicrograph of the interface for a high-palladium alloy bonded to dental porcelain. This alloy undergoes complex external and internal oxidation during porcelain firing cycles. The internal oxide particles in the palladium solid solution grains are too small (less than 1 to 2 µm in diameter) for accurate compositional determinations by x-ray energy-dispersive spectroscopic analysis with the SEM. X-ray diffraction[22] has shown that $CuGa_2O_3$ and SnO_2 are present in the oxidation region when the alloy surface receives standard airborne-particle abrasion with 50 µm of aluminum oxide before oxidation. Fig. 24.16B shows line scans obtained with the SEM for major elements in the metal and ceramic near the interface. Variations in the x-ray counts occurred when the line scan crossed a region of internal oxidation.

Factors Affecting the Bond

Most metal-ceramic systems require that the cast alloy be subjected to an initial oxidation step before the several layers of dental porcelain are fired. (A notable exception is the palladium-copper-gallium [Pd-Cu-Ga] high-palladium alloy Freedom Plus [Jelenko Dental Alloys], in which the oxidation step does not need to be performed before firing the opaque porcelain layer.) This step has also been called a *conditioning bake* or *degassing*. The latter term, which is frequently used in the dental laboratory industry, is inaccurate because this procedure's purpose is to oxidize the metal surface for subsequent adherence to the fired porcelain. Historically, some clinicians thought that the heating cycle might result in the loss of gases incorporated in the alloy during melting. However, this occurs during solidification because of the much greater solubility of atmospheric gases in the molten alloy than in the solidified alloy; it results in the formation of microscopic porosity[32] in the casting.

The oxide layer between the metal and ceramic should have an optimum thickness for a strong metal-ceramic interfacial bond. This was demonstrated in the 1970s for selected noble

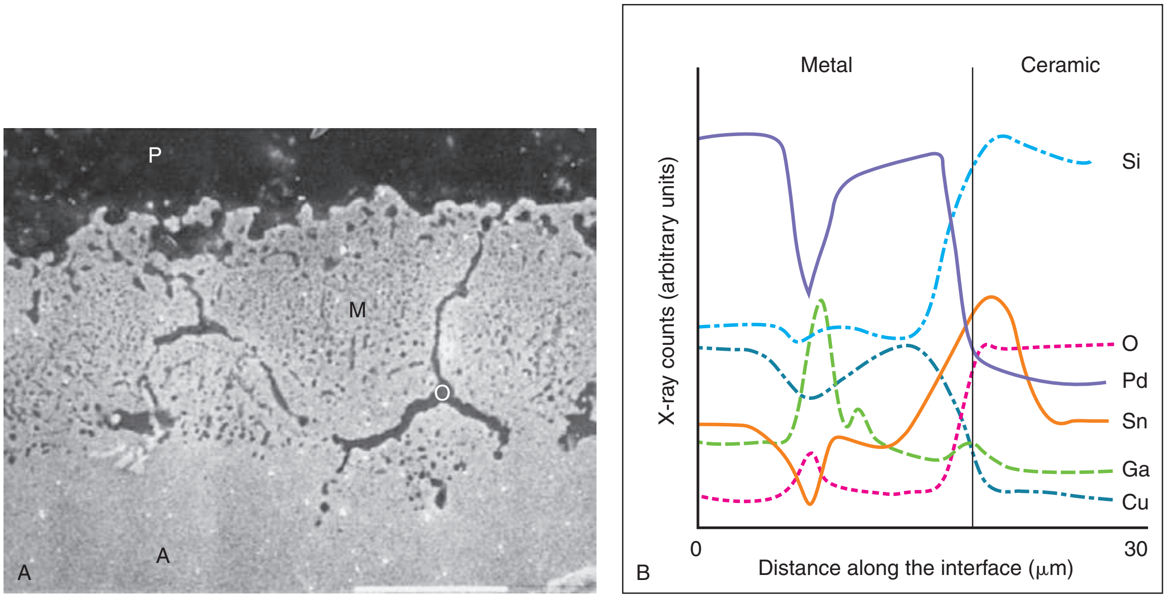

Fig. 24.16 (A) Secondary electron (scanning electron microscope [SEM]) photomicrograph of the metal-ceramic interface for Liberty (Jelenko Dental Alloys) palladium-copper-gallium (Pd-Cu-Ga) high-palladium alloy *(A)* bonded to VITA VMK 68 (VITA North America) dental porcelain *(P)*. The grain boundaries of the alloy *(M)* have been widened by the formation of oxide *(O)* deposits, and there are numerous very small oxide particles within the grains. Scale bar = 10 μm. (B) Elemental line scans perpendicular to the metal-ceramic interface obtained by x-ray energy-dispersive spectroscopic analyses for the Liberty alloy. Because the raw SEM data have not undergone matrix corrections, the relative elemental concentrations (x-ray counts) are qualitative, but the indicated trends are appropriate. *O*, Oxygen; *Si*, silica; *Sn*, tin. (From Papazoglou E, et al. New high-palladium casting alloys. Studies of the interface with porcelain. *Int J Prosthodont*. 1996;9:315.)

and base metal alloys.[33] Research has shown that with base metal casting alloys, particular care is needed to avoid excessively thick oxide layers.[34] Beryllium is added to some nickel-chromium (Ni-Cr) alloy compositions to lower the melting range; beryllium also has an effect on the thickness of the oxide layer.[35] Some systems require the application of a bonding agent before the opaque porcelain is fired. Certain formulations consist of colloidal gold suspensions that are fired on silver-colored, gold-based ceramic alloys for esthetic purposes. SEM examination of the interfaces has shown that in Ni-Cr alloys, bonding agents may increase or decrease the width of the interaction zone between the metal and ceramic.[30] An analysis of bonding agents for several Ni-Cr alloys indicates that they contain elements found in porcelain (e.g., aluminum, tin, and silicon).[35] For certain specific brands of Ni-Cr alloys, the bonding agent appears to increase the adherence between the alloy and the opaque porcelain. The manufacturer indicates whether a bonding agent is necessary or beneficial.

Airborne-particle abrasion with aluminum oxide (alumina) is routinely performed on alloy castings to create surface irregularities and to provide mechanical interlocking with the opaque dental porcelain. The viscosity of opaque dental porcelain is low enough in the firing temperature range that the material can flow into these microscopic openings. Early studies found no effect of such surface roughening in the interfacial resistance of gold-platinum-palladium (Au-Pt-Pd),[36] gold-palladium-silver (Au-Pd-Ag), and Ni-Cr[37] systems to shear loading. In more recent research with a Pd-Cu-Ga high-palladium alloy, the metal-ceramic bond strength was increased by controlled amounts of mechanical surface roughening that yielded greater notch depth for the irregularities; greater improvements were noted with coarse roughening.[38]

The linear coefficients of thermal expansion for the metal (α_M) and ceramic (α_C) must closely match to achieve a strong interfacial bond. Typically, α_M values range from 13.5×10^{-6}/°C to 14.5×10^{-6}/°C; α_C values range from 13.0×10^{-6}/°C to 14.0×10^{-6}/°C.[39] The slightly higher coefficient for the metal causes the ceramic to be in a beneficial state of residual compressive stress at room temperature (Fig. 24.17). (Thermal contraction and expansion coefficients are assumed to be equal, and residual stress is developed in the ceramic only below its glass transition temperature, at which time viscous flow is no longer possible.) Porcelain is much stronger in compression than in tension, and residual tensile stress in the porcelain must be avoided to prevent fracture of the restoration.

Adherence between the alloy casting and porcelain is very important in fixed prosthodontics; investigators have used a variety of test configurations with shear, tensile, flexural, and torsional loading to determine metal-ceramic bond strength. Ideally, the interfacial bond is strong enough that fracture of the test specimen occurs entirely within the porcelain (cohesive failure). In one early study,[40] no significant difference was found in the diametral tensile strength of commercial dental porcelains for air firing and vacuum firing. Lower tensile strength values of 28 MPa (4061 psi) for opaque porcelain, in comparison with 42 MPa (6092 psi) for gingival porcelain, were attributed to compositional differences for the two types of porcelain.[40] In addition, vacuum firing appeared to have little

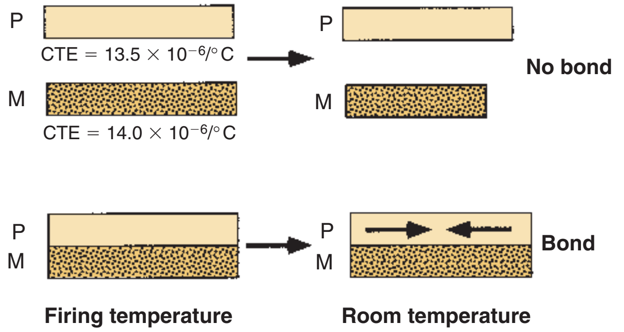

Fig. 24.17 The ceramic-metal bond at the firing temperature and at room temperature when the coefficient of thermal expansion of the metal is 0.5×10^{-6}/°C greater than that of the ceramic, which thus places the ceramic in compression at room temperature. (Adapted from Craig RG, et al. *Dental Materials: Properties and Manipulation*. 7th ed. St. Louis: Mosby; 2000.)

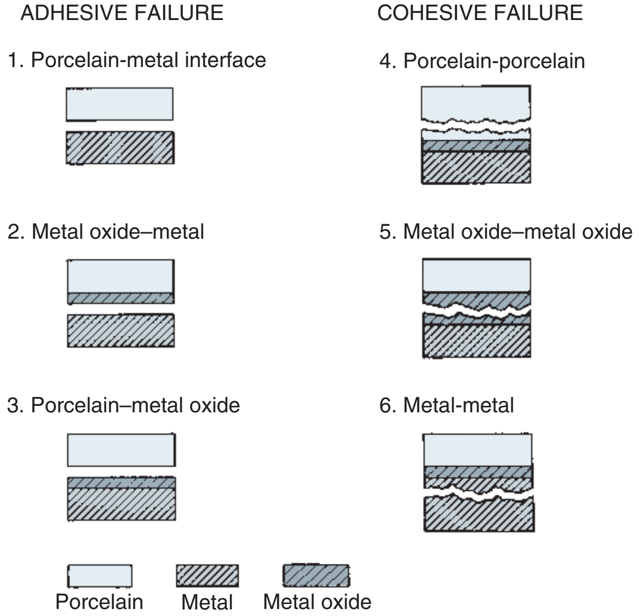

Fig. 24.18 Possible modes of failure of alloy-porcelain restorations. (Modified from O'Brien WJ. Evolution of dental casting. In: Valega TM Sr, ed. *Alternatives to Gold Alloys in Dentistry*. DHEW Publication No. (NIH) 77-1227. Washington, DC: U.S. Government Printing Office; 1977:5.)

effect on the porosity of opaque porcelain. On the basis of these findings, the tensile strength of the metal-ceramic bond should exceed 28 MPa to have cohesive failure through the porcelain rather than failure at the interface. Measurement of the shear strength of dental porcelain[41] allows a similar prediction of the minimum interfacial shear strength required for cohesive shear failure through the ceramic. Results from several studies[35,42,43] in which researchers measured the tensile bond strength of metal-ceramic systems were consistent with these concepts. Cohesive failure within the porcelain occurred at 15 to 39 MPa (2176 to 5656 psi), whereas shear bond strengths ranged from 55 to 103 MPa (7977 to 14,938 psi). For many of the shear bond strength determinations, a mixed mode of failure was observed, in which adhesive failure at the metal-ceramic interface extended into the porcelain, which fractured cohesively.

Subsequently, the focus for evaluating the metal-ceramic interfacial bond was on the measurement of porcelain adherence rather than the determination of bond strength. Anusavice et al.[44] reported a finite element analysis of the tests that had been used to measure metal-ceramic bond strength (i.e., pull-shear, three-point bending, and four-point bending). Two major problems were revealed for all bond strength tests: The stress varied with the position along the metal-ceramic interface (particularly near porcelain termination sites), and there was a lack of pure shear stress conditions that were considered necessary to simulate the loading generally expected to cause clinical failure. Furthermore, the small mismatch between the thermal contraction coefficients of the metal (α_M) and ceramic (α_C) results in an unknown amount of residual stress at the interface, and an idealized value of metal-ceramic bond strength is based on an assumed presence of a residual stress-free interface.

To avoid these problems, O'Brien[45,46] proposed a completely different approach, focusing on the mode of failure of metal-ceramic specimens or restorations rather than the measurement of bond strength. Adhesive or cohesive failure can occur at six possible sites or combinations of those sites (Fig. 24.18). Adhesive failure can occur (1) at the porcelain-metal interface if no oxide layer is present; (2) at the metal oxide–metal interface; and (3) at the porcelain-metal oxide interface. Cohesive failure can occur (4) through the porcelain, which is the desirable mode; (5) through the metal oxide layer; and (6) through the metal. (Metal fracture is highly unlikely but is described in this model for completeness.) This approach for evaluating metal-ceramic bonds by determining the area fraction of adherent porcelain on fractured test specimens was adopted in the American National Standards Institute/American Dental Association (ANSI/ADA) Specification No. 38 for metal-ceramic systems.[47] The method of microscopic measurement was not specified.

A quantitative x-ray spectrometric method was developed by Ringle et al.[48] to measure porcelain adherence. The fracture surfaces of metal-ceramic specimens loaded to failure in biaxial flexure are examined with the SEM, with x-ray energy-dispersive spectroscopic analysis. This method is based on the principle that silicon is a major element in dental porcelain but is largely absent in dental alloys (except as contaminants from investments or polishing abrasives used to prepare specimens). The amount of dental porcelain remaining on the metal surface of the fractured specimen is readily determined by measuring the silicon Kα signal, with necessary calibration measurements on the oxidized alloy surface before porcelain application, and on the porcelain surface before testing the specimen. This technique has been used to measure oxide adherence to a variety of ceramic alloys,[49] porcelain adherence to high-palladium alloys,[50,51] titanium, and an alloy of titanium-aluminum-vanadium (Ti-6Al-4V).[52–55]

Another philosophic change in the recommended method for evaluating the metal-ceramic bond occurred with the introduction of International Organization for Standardization (ISO) Standard No. 9693 for dental porcelain-fused-to-metal restorations,[56] which contains a three-point bending test.

Lenz et al.[57,58] performed a finite element analysis for this test and considered the effects of thermal stresses in the metal-ceramic specimens arising from the mismatch between α_M and α_C. Investigators using several Pd-Ga high-palladium alloys with identical values of elastic modulus found no correlation[59] between porcelain adherence measured by the x-ray spectrometric method[50,51] and the force to failure by the three-point bending test in ISO Standard No. 9693.[56] These experimental results cast doubt on the effectiveness of the x-ray spectrometric technique[48,50] in measuring porcelain adherence. A possible explanation is that the metal is forced to undergo a small amount of permanent flexural deformation with the porcelain adherence test[50] that does not occur with the measurement of force to failure (shear bond strength) of the metal-ceramic bond in the ISO standard.[56]

Other important factors that affect the metal-ceramic bond are the surface treatment of the alloy before the porcelain is fired and the atmosphere of the porcelain furnace during firing. As previously mentioned, airborne-particle abrasion of the cast alloy is typically performed before the oxidation step to help remove surface contaminants that remain from devesting and to help clean the casting and provide microscopic surface irregularities for mechanical retention of the ceramic. The oxidation step for the alloy can be performed in air or with the use of the reduced atmospheric pressure (approximately 0.1 atm) available in dental porcelain furnaces. A much thinner oxide layer is formed if the alloy is oxidized at this reduced atmospheric pressure, in comparison with the thickness for oxidation in air. Manufacturers' recommendations for oxidation of the alloy and porcelain firing cycles must be followed. An early study[60] showed that the shear bond strength of porcelain-gold alloy specimens was 60% greater when air firing was employed; another study at that time[61] revealed that the tensile bond strength varied according to the furnace atmosphere used. The shear bond strength of porcelain-nickel alloy specimens was greater when firing was performed in oxidizing atmospheres than in nonoxidizing or reducing atmospheres.[62] More recently, Wagner et al.[38] found that the use of a reducing atmosphere severely reduced the bond strength of a Pd-Cu-Ga high-palladium alloy, which confirmed the role of alloy oxidation during the standard porcelain firing cycles.

Since 2005, there has been considerable research on bonding between titanium/titanium alloy and dental porcelain. Zinelis et al.[63] reported substantial differences in bond strength for eight different porcelains bonded to commercially pure titanium and a lack of correlation between measurements of porcelain adherence[53,59] and metal-ceramic bond strength with the ISO three-point bending test.[56] An excellent review article critically summarized the results from numerous studies of bonding between titanium and dental porcelain.[64] Excessive oxidation during porcelain firing and the very hard α case surface layer (see Chapter 19) cause difficulty with porcelain bonding to cast titanium/titanium alloys. Another factor is the need for low-fusing porcelains to minimize elevated-temperature reaction with titanium; these porcelains have lower bond strengths than do traditional medium-fusing porcelains.[65,66]

Strategies for titanium surface modification before porcelain firing include roughening,[65–68] use of acidic and caustic solutions,[53,69,70] and deposition of special layers or coatings.[54,55,71–75] Clinical investigation has revealed that the prevalence of cohesive fracture within porcelain is greater than adhesive failure at the titanium-porcelain interface; it is suggested that an important concern is inadequate furnace control at the low temperatures employed with veneering porcelains for titanium.[64] Although values of bond strength for dental porcelain bonded to cast titanium in current studies meet the minimum value of 25 MPa in ISO Standard No. 9693,[56] higher bond strengths are observed for conventional nickel-chromium alloys than for titanium.[64,65,69] For noncast titanium, in which surfaces were prepared by electrical discharge machining, porcelain bond strengths were not significantly different from those of bonds to cast surfaces when α case was removed.[65,76]

A concluding area of research that has attracted interest is the effect on metal-ceramic bond strength from the use of recycled metals. This is of practical interest in dental laboratories for expensive gold and palladium alloys. High-gold, gold-palladium, and palladium-silver alloys were melted up to three times without reduction in bond strength to porcelain.[77] In contrast, melting of used metal with fresh metal for a conventional nickel-chromium alloy yielded a significant reduction in bond strength in comparison with that for entirely new metal.[78]

■ ■ ■

SELECTION CRITERIA

Most manufacturers of modern dental porcelains specify the alloy systems with which a material is compatible. Usually, *compatibility* refers to the relative coefficients of thermal expansion. The clinically selected shade determines which powders to combine. Depending on the characteristics of the color to be matched, several powders can be combined for the desired esthetic result. Commercially available porcelains can be divided into fine-grain and coarse-grain types. The typical particle size of fine-grain porcelain ranges from 5 to 110 μm; the particle size for coarse-grain porcelain can be as large as 200 μm.

Opaque Porcelain

For a proper mechanical bond and chemical interaction at the interface, opaque porcelain must wet the surface easily. It becomes the primary source of color of the restoration and must mask the color of the metal, even in thin layers. Opaque thickness generally should not exceed 0.1 mm; otherwise, achieving an esthetic result without overcontouring the restoration becomes impossible, although a greater opaque thickness may be necessary to mask the darker oxide of some alloys.[79] Small amounts of zirconium oxide and titanium oxide, in conjunction with alumina, act as the opacifying agents to block the darker color of the oxidized metal. Some of these oxides are also present in the body porcelain. Manufacturers supply opaque porcelains in paste and powder form (Fig. 24.19).

Body and Incisal Porcelains

As with opaque porcelain, the selection of body and incisal porcelains is based largely on their esthetic properties. However, the amount of shrinkage that occurs when these powders are fired

Fig. 24.19 (A to C) Types of metal-ceramic porcelain. Porcelains are available as powders or pastes. (Courtesy Ivoclar AG, Amherst, NY.)

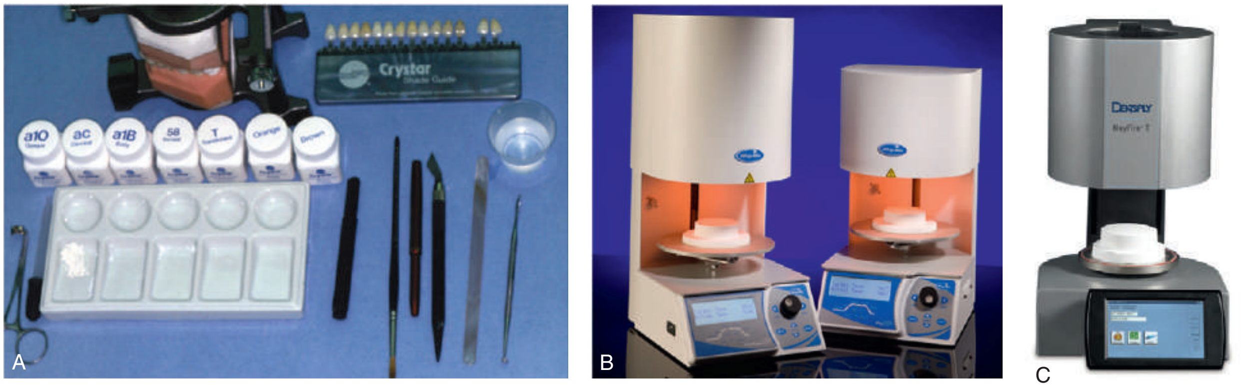

Fig. 24.20 (A) Armamentarium for porcelain application. (B) Whip Mix Pro Press 200 *(left)* and Pro 200 *(right)* porcelain furnaces. (C) Dentsply NeyFire T porcelain furnace. (B, Courtesy Whip Mix Corporation, Louisville, KY. C, Courtesy Dentsply Sirona, York, PA.)

must also be considered. The volume of body and incisal porcelains usually shrinks as much as 27% to 45% during a first firing[15]; opaque porcelain, on the other hand, may exhibit some cracking during an initial bake, but it remains relatively stable dimensionally. Low-fusing metal-ceramic porcelains (Finesse, Dentsply Prosthetics; Omega 900, VITA North America) have become popular.[80] When opposing enamel wear is likely to be a problem, these materials should be considered because, in vitro, they tend to exhibit lower abrasiveness than do conventional formulations.[81]

FABRICATION

For optimum esthetics, custom-mixing body and enamel powders to achieve desired color variations is recommended.

Porcelain Application

Armamentarium

The following equipment is needed (Fig. 24.20):

- Porcelain modeling liquid
- Paper napkin
- Glass slab or palette
- Tissues or gauze squares
- Two cups of distilled water
- Glass spatula
- Serrated instrument
- Porcelain tweezers or hemostat
- Ceramist's sable brushes (Nos. 2, 4, and 6) and whipping brush
- Razor blade or modeling knife
- Cyanoacrylate resin
- Colored pencil or felt-tip marker
- Articulating tape
- Ceramic-bound stones
- Flexible thin diamond disk (about 20 mm in diameter)

Step-by-Step Procedure

After the metal substructure has been oxidized, it must be inspected carefully. An uninterrupted oxide layer should cover the entire surface to be veneered.

Opaque porcelain. This technique is illustrated in Fig. 24.21.

1. After selecting the opaque bottle, shake it to mix the powder thoroughly. Then place it on the bench to allow the smaller pigment particles to settle. Over time, the porcelain powders segregate into layers of different particle sizes if left undisturbed.
2. Dispense a small amount of powder on a glass slab or palette. Add some modeling liquid and mix it with the spatula. Metal instruments should not be used in mixing because metal particles could rub off and act as contaminants. The proper opaque consistency should "hold an edge" for a few seconds.
3. Moisten the substructure with some of the liquid, and pick up a small bead of opaque porcelain with the tip of the brush or spatula. Apply it to the coping, which should be held with the porcelain tweezers.
4. Use light vibration to spread the material thinly and evenly. Moving the serrated instrument back and forth over the

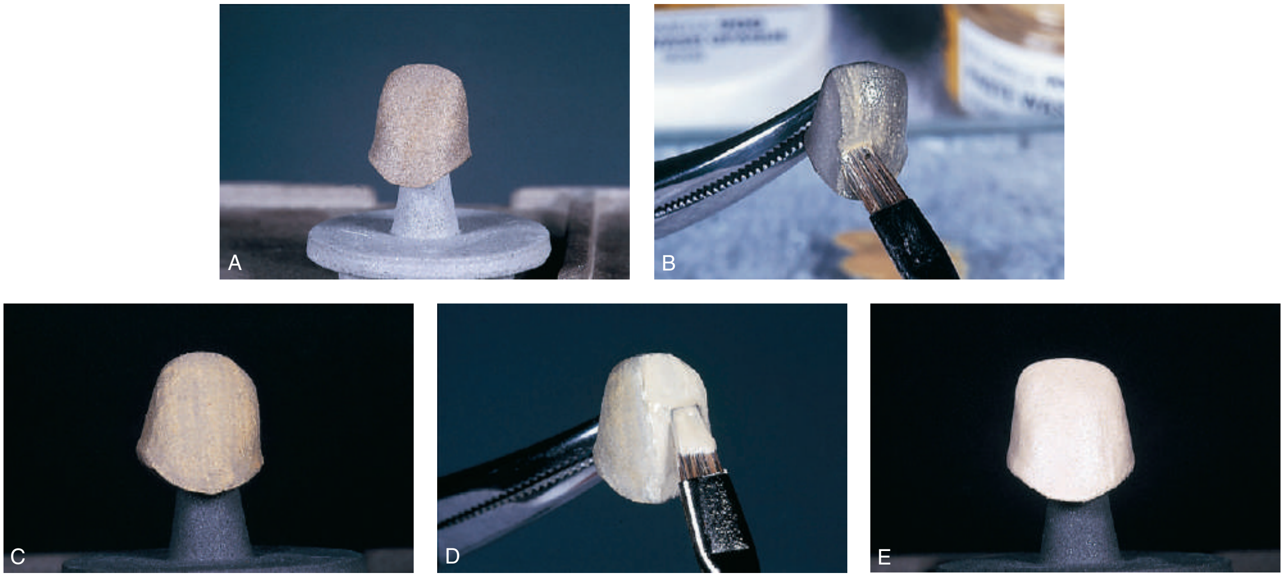

Fig. 24.21 Opaque porcelain application. (A) Substructure is oxidized. (B) Porcelain is applied. Vibration can be used to help spread the opaque porcelain into an even, thin film (C). (D) Application of additional opaque porcelain. (E) After drying in front of the furnace, the opaque layer should have a uniform matte-white appearance. Excess powder must be removed before firing.

handle of the tweezers creates the necessary disturbance. Excess moisture that comes to the surface can be blotted off with a clean tissue. Vibration may not be as necessary with the so-called paint opaque materials.

5. Apply a second bead on top of the first, and spread it in a similar manner. To minimize the entrapment of air when the two masses meet, do not apply opaque porcelain adjacent to the initial mass. If the moisture content is properly controlled, condensing poses little difficulty. A mix that is too wet will slump and produce too thick a layer on the substructure, especially in the concave areas near the porcelain-metal junction.
6. Once the veneering surface is covered, add more material to a dry base. Wetting the initial application before adding more porcelain may be necessary. If not, the moisture will be absorbed immediately by the dry base layer before a new material can be properly condensed and distributed, which results in a porous and weakened application (similar to constructing a sandcastle with wet sand on a dry beach). The addition of more liquid and further vibration will resolve the problem.
7. When the entire veneering surface has been covered, remove any excess material from other surfaces with the side of a slightly moistened brush. If the metal immediately adjacent to the veneer has been properly prepared and smoothed, it is not difficult to remove the excess porcelain. However, this crucial task is often overlooked, and its omission can make metal polishing much more difficult.
8. After removing any excess porcelain, carefully inspect the inside of the restoration for porcelain particles. A stiff, dry, short-bristle brush can be used to remove the particles.
9. Before firing, inspect the opaque application to see that it satisfies the following criteria:
   - The entire veneering surface is evenly covered with a smooth layer that masks the color of the metal.
   - There is no excess anywhere on the veneering surface.
   - There is no opaque material on any external surface adjacent to the veneer.
   - There is no opaque material on the internal aspect of the substructure.

   If these criteria have been met, the coping is transferred to a firing tray and placed near the open muffle of the porcelain furnace for several minutes. This allows moisture to evaporate. When drying is completed (this varies according to specific manufacturer's recommendations), reinspect the work for any residual excess opaque powder. Material that was previously overlooked is now clearly visible because the chalky white porcelain contrasts with the darker oxidized metal. A stiff, short-bristle brush can again be used to remove any excess porcelain powder. The opaque layer is then fired according to the manufacturer's recommendations.
10. After the first firing, remove the work from the muffle and set it aside to cool to room temperature.
11. At this time, inspect the opaque veneer for cracks, thin spots, and general adequacy of coverage. When the veneer is removed from the furnace, it appears yellow; however, when it has cooled, the color is the more representative matte white. Fired opaque material should have an eggshell appearance. A slightly glossy appearance is an indication of overfiring. If necessary, a second application of opaque material can be made. Small cracks and fissures are common after the first firing. This problem can be resolved by the application of moisture, followed by a thin mix of opaque material carefully condensed into the fissures. When correcting a thin area where the color of the metal has not been masked completely, moisten the surface before applying a second coat (to facilitate wetting).

12. After firing, check that the opaque application (Fig. 24.22) meets the following criteria:
    - Relatively smooth, even layer masking the dark color of the framework
    - Eggshell appearance
    - No excess on any external or internal surface of the restoration (which would prevent it from seating fully on the die)

Body and incisal porcelains. When an opaque layer has been fired satisfactorily, the body and incisal porcelains (Fig. 24.23) can be applied. The use of several porcelains in one restoration is common. Body porcelains with increased opacity (often called *opacious dentin*) may be used in areas where less translucency is required (e.g., the gingival area of the pontic, incisal mamelons) to mimic existing anatomic features of adjacent natural teeth. Special neck powders can be applied on the cervical third, and incisal powders on the incisal edge, to simulate natural enamel. In general, the restoration is built to anatomic contour; when it is acceptable, a cutback similar to that made during the waxing stage allows for a veneer of the more translucent incisal porcelain.


Fig. 24.22 Appearance of the opaque porcelain.

1. Dispense the neck, body, incisal, and other powders on a glass slab or palette. If the same slab was used for the opaque porcelain, any opaque residue must be removed.
2. Mix the powders with the recommended liquid or distilled water. The moisture content for these powders should be the same as for opaque porcelain. Specially formulated liquids that allow longer manipulation than is possible with conventional glycerin-containing liquids are available.
3. Wet the previously fired opaque layer with a small amount of the liquid, and place a bead of neck powder on the cervical portion of the veneering surface. Gentle patting with a brush and light tapping on the cast produces adequate vibration during the preliminary stage of condensation. Hold a tissue close for the removal of excess surface moisture. During the entire buildup procedure, the facial surface should not be blotted with tissue because the smaller pigment particles might be removed. Blotting consistently from the lingual aspect is recommended and results in superior esthetics.
4. After placing the neck powder and sculpting it, build the veneer to anatomic contour with body porcelain. Use the adjacent and opposing teeth as a guide. Where contact is anticipated between the wet buildup and stone cast, the cast can be coated with a small amount of cyanoacrylate resin, immediately blown into a thin layer. This seals the surface and prevents the absorption of moisture from the buildup.
5. To compensate for the firing shrinkage that results when the particles fuse, slightly overbuild the porcelain. A typical metal-ceramic anterior crown shrinks 0.6 mm at the incisal edge and 0.5 mm midfacially (Fig. 24.24).[82]

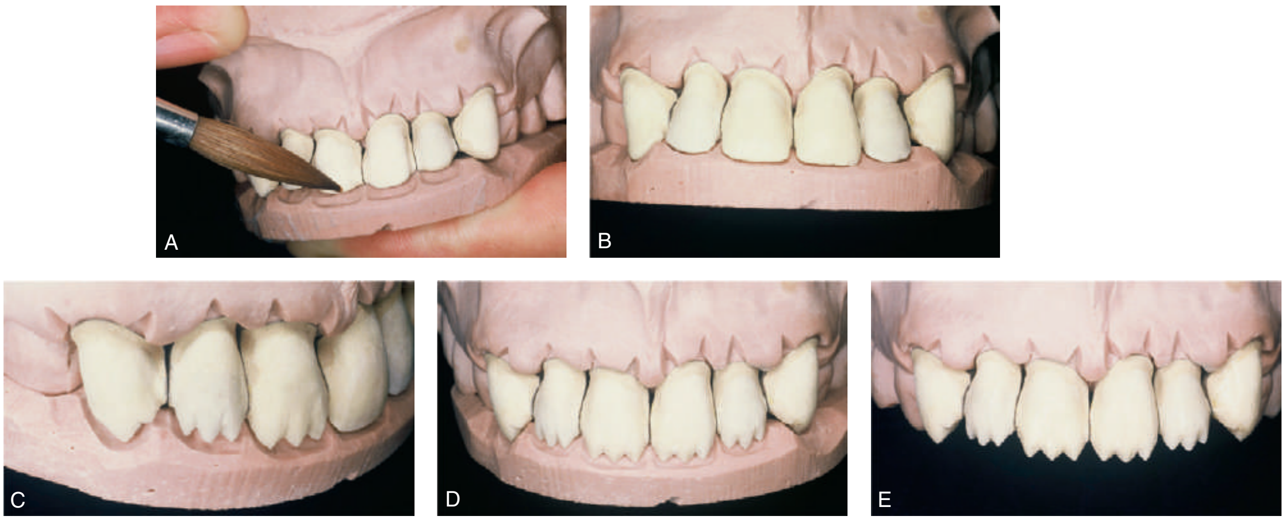

Fig. 24.23 Body and incisal porcelain application. (A to E) Development of incisal mamelons with opacious dentin. The incisal plaster or silicone putty index is made from the anatomic contour wax patterns (see Chapter 18) and serves as a guide to developing proper incisal edge position.

Continued

Fig. 24.23 Cont'd (F and G) Cervical and body powders are added to the contour. (H) Alternatively, the incisal index can be used to establish incisal edge position. This is especially helpful for extensive restorations. (I) Restorations are slightly overbuilt. (J) The buildup is smoothed with a whipping brush. (K) Restorations are separated with a razor blade before firing. Additional porcelain is added to the proximal contacts. (L and M) Restorations after firing of the first body bake. (N) Porcelain is added in areas of deficient contour. (O) After firing, the proximal contacts are carefully adjusted, and the restorations are seated on the cast. (P to S) Restorations are contoured by grinding. Careful attention is paid to the shape and position of line angles and incisal edges. When completed, the restorations are ready for clinical evaluation and final contouring intraorally (see Chapter 29).

6. When the body buildup is completed, assess it for proper mesiodistal, faciolingual, and incisogingival contour.
7. Depending on the desired appearance, make a cutback for the more translucent incisal powder. Some manufacturers recommend carrying the incisal veneer all the way to the cervical portion of the restoration; others suggest limiting it to the incisal third. The possibilities are almost infinite, and only with experience can the dentist predict the finished product's appearance. Whether the cutback is made with a razor blade, scalpel, or modeling instrument, condensing the body buildup well before cutting back is necessary. This minimizes the risk of fracture during the process. Furthermore, to minimize the chance of damaging the unsupported incisal portion of the buildup, the cutback should be made from incisal to cervical aspects. Space for the incisal veneer must be adequate in the interproximal area.
8. Apply the incisal powder in the same manner, and overbuild the restoration as described for body porcelain. The remaining body powder must be wet before application

of the incisal powder, and, again, intermittent light vibration helps achieve an acceptable level of condensation. Prolonged condensation should be avoided; it does not reduce porosity[83] or increase fracture toughness[84] and may lead to unwanted redistribution of the pigmented particles.

9. Mark the opposing teeth on the stone cast with a red or green felt-tip marker. These markings are not absorbed if the cast first has been coated with cyanoacrylate resin. The articulator can then be closed to allow the antagonists to contact the wet porcelain. If this is done carefully, the markings are transferred onto the buildup without fracturing, and the buildup can be modified to the necessary occlusal scheme. Only red or green dyes, which burn off without leaving a residue, should be used for these markings. Blue or black pigments usually contain metal oxides or carbon, which, after firing, can discolor the porcelain.

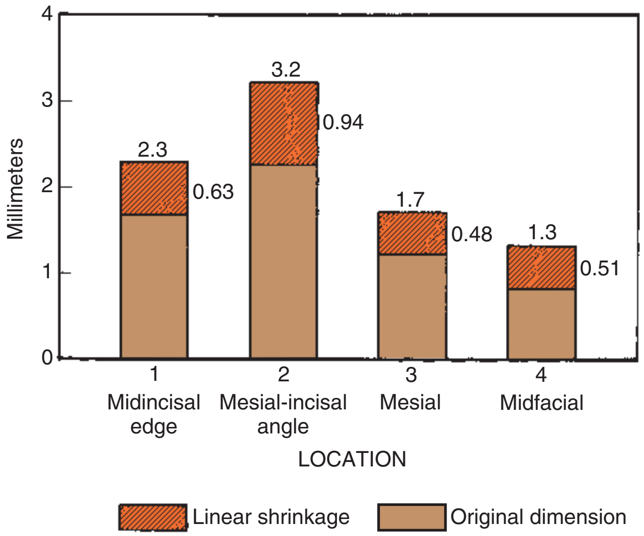

Fig. 24.24 Mean shrinkage values from firing of a typical maxillary central incisor metal-ceramic crown. (From Rosenstiel SF. Linear firing shrinkage of metal-ceramic restorations. *Br Dent J*. 1987;162:390.)

10. Moisten the proximal contact areas immediately before removing the completed buildup from the cast. This reduces the risk of fracturing that portion of the buildup.
11. After the restoration has been removed from the cast, fill in the proximal contact areas. At this time, the work should be reinspected for any excess material beyond the veneering area (which, as before, must be removed before firing). The internal aspect of the coping should be reinspected even more carefully because enamel powders are quite transparent in thin layers and are not easily detected after firing.
12. Place the restoration on a firing tray close to the open muffle at the drying temperature recommended by the manufacturer. A drying time of 6 to 10 minutes is usually sufficient. If a restoration is fired prematurely, the residual moisture in the buildup may generate steam, and the accompanying vapor pressure causes the buildup to explode. After the drying process, once it has been determined that no undesired excess material remains, proceed with firing. When the firing is completed, allow the work to cool to room temperature before further handling. Follow the manufacturer's recommendations concerning the cooling rate after firing. Incorrect cooling rates may lead to residual stresses that eventually result in porcelain fracture during function. Thermal expansion increases after slow cooling because additional high-expansion leucite crystallizes.[85] In general, alloys with high thermal expansion coefficients require more rapid cooling than do alloys with low coefficients.[86]
13. Be especially critical when evaluating the first (or low-bisque) bake. If the surface is fissured, grind the porcelain before adding any more (Fig. 24.25). The shape of the restoration should conform to the standards set by dental anatomy and the predetermined occlusal arrangement for the patient.
14. Remove all excess material with ceramic-bound stones. A flexible diamond disk is imperative for proper shaping of the embrasure spaces. To extend its usefulness, the disk should be kept moist.

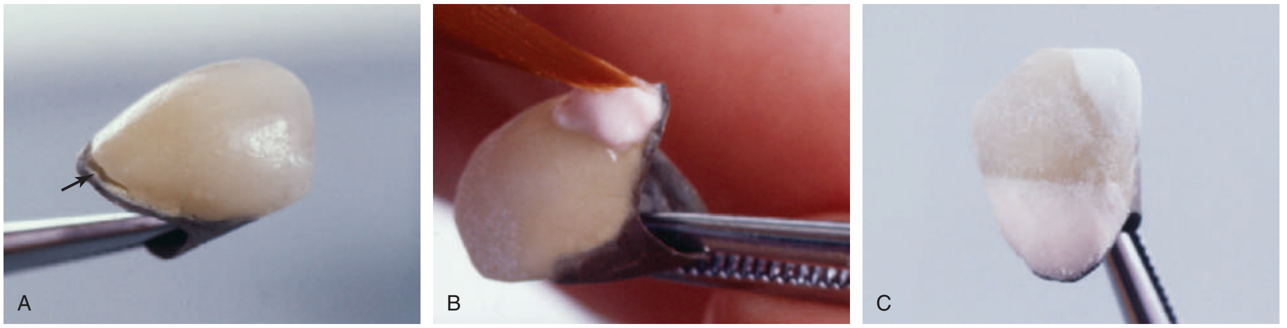

Fig. 24.25 (A) This restoration had a defect *(arrow)* at the gingival margin after the first firing. Access for repair is made by grinding out such cracks. (B) Additional porcelain is applied after the area is moistened. (C) The porcelain has been added, and the restoration is ready for a second firing.

15. When the restoration has been contoured and all the necessary areas reduced, certain portions probably require a second application of porcelain.
16. Before a second corrective bake (also referred to as a *patch bake*), clean the restoration ultrasonically to remove any grinding debris.
17. Place the second body and incisal layers directly on the slightly moistened low-bisque bake. Evaluate the color at this time, keeping the restoration moist. Sometimes another bake is needed, particularly for an extensive prosthesis. However, an excessive number of firings leads to devitrification of the porcelain, with a loss of translucency and a decrease in the restoration's fracture resistance.[87]

Internal Characterization

Internal or intrinsic characterization or staining may be accomplished by incorporating colored pigments in the opaque, body, or incisal powder. These pigments are ceramic in nature, and their physical properties are similar to those of porcelain powders.

Most commercially available porcelains have colored opaque modifiers that can be selectively mixed with the opaque to increase the saturation of the desired pigment. A variation of this approach is to use opacified dentin powders that produce a finished restoration with a slightly higher chroma than one prepared with the more translucent dentin powders. Similarly, a translucent powder can be used to enhance incisal translucency (Fig. 24.26). Highly colored glazes, commonly used as surface stains, may be layered within the buildup powders to create special effects (Fig. 24.27).

The use of internal stains presents little technical difficulty for operators familiar with metal-ceramic procedures. Because the pigment is built into the material, however, if the desired effect is not obtained through internal staining, the porcelain must be stripped from the substructure in order to achieve the desired shade match.

Another technique for internal characterization is to fire the body powders initially, carve them into the desired mamelon shape, and then apply the subsequent enamel powders. A disadvantage of this approach is that an additional firing is needed.

Contouring

The appearance of the finished restoration depends on its color, shape, and surface texture, which can be altered by shaping and characterizing dental porcelain to mimic the appearance of natural teeth (see Fig. 24.23P–S).

The appearance of restorations can be influenced considerably through the selected use of optical illusion (see Chapter 20). The human eye is capable of discerning differences in height and width, but its depth perception is far less developed. Even trained observers experience difficulty when attempting to recognize subtle differences in the third dimension.

Through selective contouring, the apparent shape of a restoration can be made to look quite different from its actual configuration. The perceived size of a tooth depends on the reflection of its line angles and the relative position and spacing of these reflections. Even though an edentulous area on one side may be slightly larger than a space occupied by the corresponding tooth on the contralateral side, a restoration can be made to appear similar (or even identical) through careful mimicking of the line angle distribution and contours immediately adjacent to the line angles. The clinician can create an illusion that the restoration is narrower than it really is (Fig. 24.28). In addition, by simulating the normal distance between line angles superimposed on a pontic in an edentulous area that is otherwise too narrow, it is possible to create the illusion that teeth are of normal size but merely crowded. Careful application of these principles may trick the casual observer into concluding that the teeth overlap and that a portion of the tooth (or restoration) is

Fig. 24.27 Porcelain stain was applied intrinsically to create the effect of discolored dentin in these mandibular incisors, seen before firing.

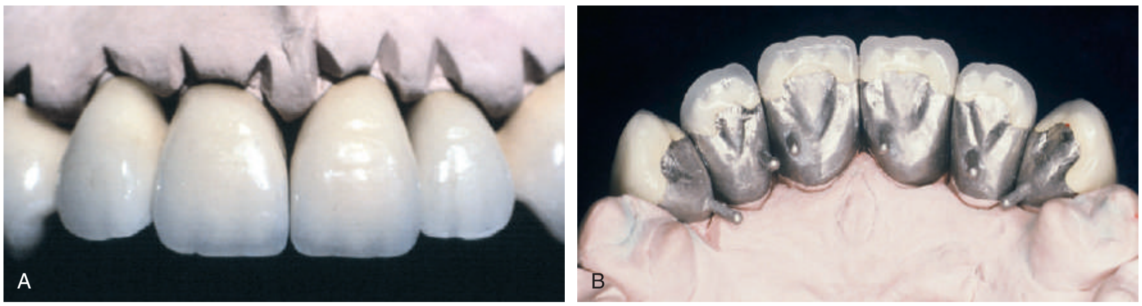

Fig. 24.26 (A and B) Natural incisal appearance has been achieved through subtle layering of porcelains of different translucencies.

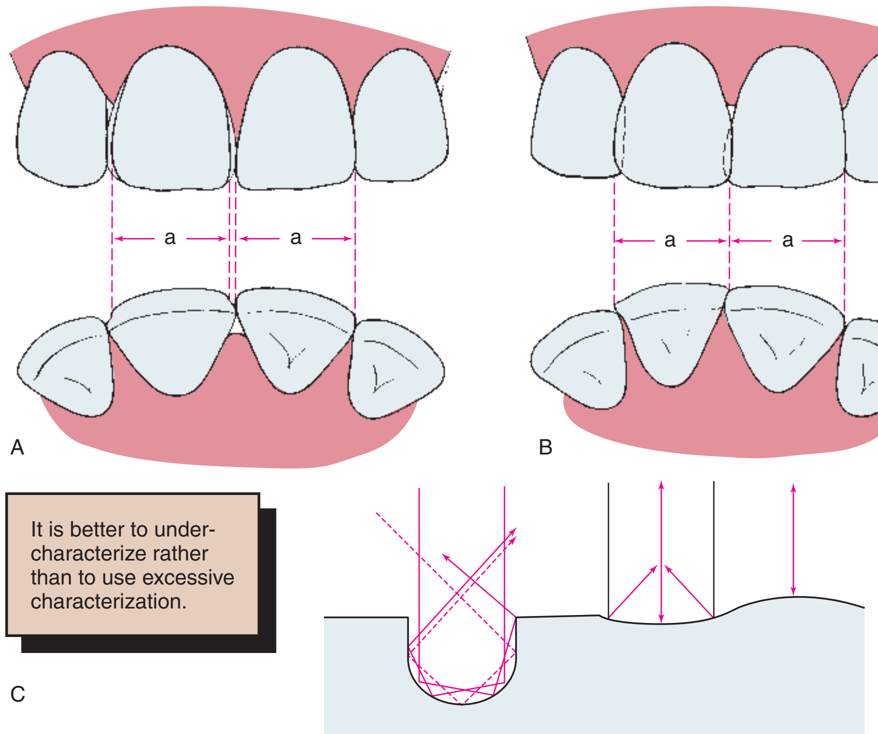

Fig. 24.28 (A and B) The esthetics of an abnormally sized restoration can be improved by matching the location of the line angles and adjusting the interproximal areas. (C) The pattern of light reflection depends on the surface texture of the restoration. (A and B, Redrawn from Blancheri RL. Optical illusions and cosmetic grindings. *Rev Assoc Dent Mex*. 1950;8:103.)

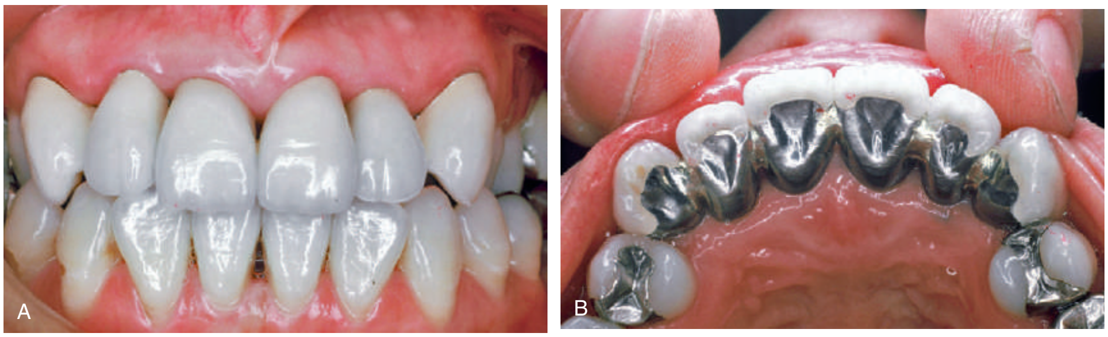

Fig. 24.29 (A and B) Glazed and polished restorations.

behind an adjacent tooth, although, in reality, the overlap does not exist.

The surface texture of a metal-ceramic restoration should resemble that of the adjacent teeth, including selected characterizing irregularities that exist on those teeth. Several rules of light reflection must be remembered when the clinician attempts to accomplish this:

- A flat surface reflects primarily parallel light bundles.
- A convex surface results in divergence of reflected light, whereas a concave surface creates a convergent light bundle.
- Sharp transitions (e.g., geometric line angles) result in line reflections, but smooth, gently flowing curved surfaces create a reflection pattern with greater surface area.

Thus a smooth restoration can appear larger than one of identical size that has been characterized or textured. Careful study of adjacent teeth and an understanding of how their reflective patterns should be simulated before characterization are essential. Care must also be taken not to "overcharacterize," which would draw attention to the restoration and reveal that it is artificial.

Glazing and Surface Characterization

Metal-ceramic restorations are glazed to create a shiny surface similar to that of natural teeth (Fig. 24.29). (An acceptable alternative is to polish the ceramic [see Chapter 29].) The glazing cycle can be performed concurrently with any necessary surface characterization (see Chapter 29).

In *autoglazing*, the contoured bisque bake is raised to its fusion temperature, which is maintained for a time before cooling. A pyroplastic surface flow occurs, and a vitreous layer or surface glaze is formed. Sharp angles and edges are rounded slightly during this process. Consequently, occlusal contact in porcelain is altered slightly during glazing.

In contrast, in *overglazing*, a separate mix of powder and liquid is applied to the surface of a shaped restoration, and the restoration is subsequently fired. The firing procedure is similar to that for autoglazing, although there are variations among brands. Because most metal-ceramic restorations include low-fusing porcelain, overglazing is not currently in widespread use.

External Characterization

Surface stains are highly pigmented glazes, which can be mixed with glycerin and water (supplied with most commercially available staining kits).

By moistening the bisque firing, the dentist can cause the restoration to appear as if it is glazed. After the desired effect has been obtained by placing selected stains on the surface, the restoration is held outside the open muffle of the glazing furnace, and the stain is allowed to dry.

When it turns white and chalky, any excess that may have been accidentally applied to the metal surface is removed, and the restoration is fired. During this staining and glazing bake, a pyroplastic surface flow occurs, and a glassy layer (or autoglaze) forms on the surface in which the stains are incorporated.

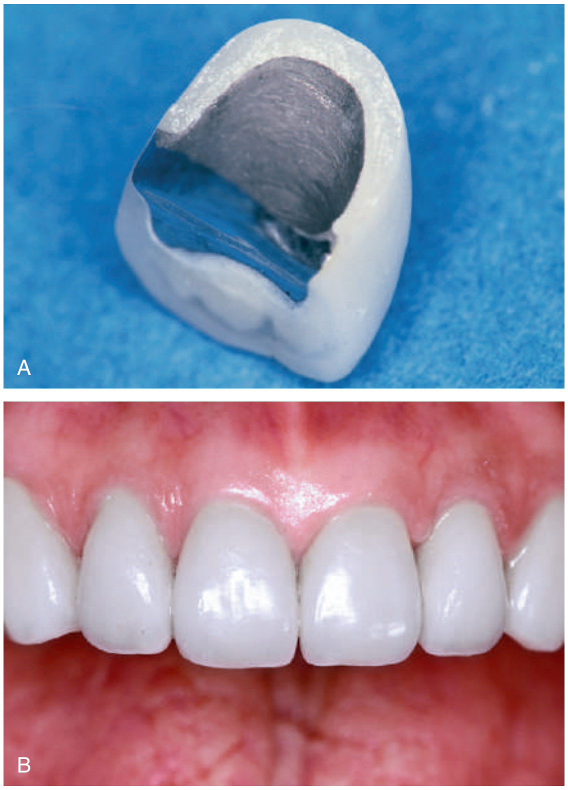

Fig. 24.30 (A and B) Metal-ceramic restorations with porcelain labial margins combine the excellent esthetics of ceramic restorations with the strength of the metal-ceramic technique.

PORCELAIN LABIAL MARGINS

Many patients object to the grayness at the margin associated with metal-ceramic restorations. However, hiding the margin subgingivally may not be possible. If esthetics is of prime importance, a collarless metal-ceramic crown (Fig. 24.30) or a ceramic crown (see Chapter 25) should be considered. On collarless crowns, the facial margin is porcelain, and the lingual and proximal margins are metal (Fig. 24.31).

Some technicians fabricate a 360-degree porcelain margin to optimize light transmission in the gingival area and provide optimal esthetics. That technique is quite demanding. Preparation for these restorations is similar to that for a ceramic crown (see Chapter 10) with a circumferential shoulder margin with rounded internal line angles.

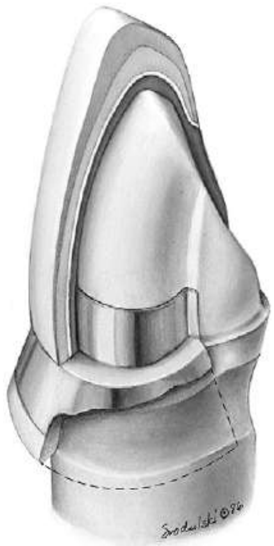

Fig. 24.31 Schematic of a collarless restoration fabricated with the platinum foil technique. To support the foil during burnishing, a "skirt" of a suitable blockout material has been added to the facial aspect of the die adjacent to the proposed porcelain labial margin. This prevents distortion of the foil upon removal from the die. Alternatively, a blocked-out die can be duplicated in epoxy resin or electroplated.

Advantages and Disadvantages

The collarless crown's most obvious advantage is the esthetic superiority over the conventional metal-ceramic restoration. Plaque removal also is easier when gingival tissues are in contact with vacuum-fired glazed porcelain than when they are contacting highly polished gold. Therefore, porcelain appears to be the material of choice for restorations that will be in contact with gingival tissues.

The difficulties encountered during fabrication, however, limit its application. Although a technically comparable result is feasible,[88,89] the marginal adaptation of these restorations (as currently produced by most commercial laboratories) is slightly inferior to that of cast metal. Because of careless handling, fracture of the unsupported margin is sometimes a problem during evaluation or cementation. Fracture during function is rarely a problem because the labial margin is not subjected to high tensile stresses.[90] In addition, the collarless metal-ceramic restoration is more time-consuming and therefore more costly to make.

Indications and Contraindications

A porcelain labial margin is indicated when a conventional metal-ceramic restoration will not create the desired esthetic result. It is contraindicated when an extremely smooth, 1-mm-wide shoulder margin cannot be prepared in the area of the ceramic veneer. (In this regard, the conventional metal-ceramic restoration is somewhat more forgiving.) Although multiple porcelain margins may be used in one fixed dental prosthesis without a sacrifice of marginal adaptation, the limitations of the operator and the auxiliary technical staff should be carefully and objectively assessed before the dentist and patient commit themselves to a fixed prosthesis consisting of multiple collarless retainers.

Framework Design for Labial Margin

Various framework designs have been proposed with different facial framework reductions (Fig. 24.32).[91] In general, the more metal reduction, the better the esthetic result; however, the technical procedures become more demanding. Removal of up to 2 mm of the labial framework has been shown not to decrease the fracture resistance of the restoration.[92,93]

Step-by-Step Procedure

This procedure is illustrated in Fig. 24.33.

1. Apply cyanoacrylate resin to the labial margin area of the die. This acts as a sealant of the porous stone. Compressed air should be used to minimize the thickness of the film.
2. Apply a porcelain release agent to the shoulder margin of the prepared die.
3. Seat the opaque porcelain-coated casting on the die.
4. Mix porcelain for the shoulder margin, and apply it directly to the die and the opaque porcelain. Light tapping assists in condensation and should be done before the dry buildup is separated from the die.
5. After the first firing of the shoulder margin porcelain, reseat the crown on the die. At this time, the restoration should be examined for margin discrepancies. A second firing of the shoulder margin porcelain is usually necessary.
6. Relubricate the die, reseat the crown, and apply a thinner mix of porcelain powder to the shoulder margin. Vibration helps the porcelain fill the defect completely. After blotting, the restoration can be separated from the die.
7. When the firing is completed, use a water-soluble marking agent to detect premature contacts. The marking agent is applied to the shoulder margin, and the restoration is then gently tried on the die. The markings will be visible on the porcelain and the inner aspect of the casting.
8. Adjust any areas of contact of the restoration, and proceed with the conventional buildup of body and incisal porcelains, followed by glazing of the final restoration.

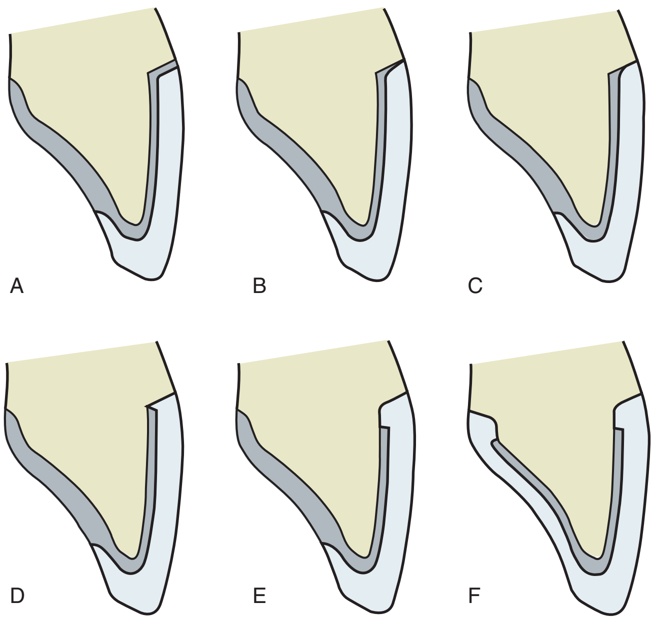

Fig. 24.32 Labial margin designs for metal-ceramic restorations. (A) A thin metal band provides excellent adaptation but is very unesthetic unless it can be hidden subgingivally. For esthetic reasons, this design is rarely used for anterior teeth. (B) A "disappearing" margin, sometimes called a *conventional margin*, is commonly used and is esthetically acceptable to some patients. However, the metal often causes unacceptable grayness of the gingival tooth surface. (C to E) Various cutback designs for labial porcelain margin restorations. Reducing the metal provides better esthetics but makes the laboratory phase more demanding and may result in margin chipping. (F) A 360-degree porcelain margin provides excellent light transmission in the gingival area and optimal esthetics; however, laboratory fabrication is very demanding. This design requires a preparation design that is similar to that for a ceramic crown (see Chapter 11) with a circumferential rounded shoulder margin. Close cooperation between dentist and technician is essential in determining the best labial margin design.

Fig. 24.33 The direct lift (cyanoacrylate resin) technique for a porcelain labial margin. (A) Armamentarium. (B) Cyanoacrylate resin (e.g., Krazy Glue) serves as a sealant of the porous stone die. (C) The resin is applied to the area of the die where it will be in direct contact with the porcelain. Compressed air is used to minimize film thickness. (D) Recommended separating medium. (E) The separating liquid is applied to the shoulder margin of the prepared die. (F) The opaque porcelain–covered casting is seated on the prepared die. (G) Mixing the porcelain for the shoulder margin. (H) Shoulder margin porcelain is applied in direct contact with the die and opaque porcelain. (I) Light tapping is used to assist in condensation. (J) The dry buildup is separated from the die. (K) The buildup before firing. (L) First firing of the shoulder margin porcelain is completed. (M) The fixed restoration is reseated on the die. Note the minor marginal discrepancy. (N) Before additional porcelain application, the die is relubricated. (O) Second application of shoulder margin porcelain. (P) Vibration. (Q) Separating from the die after the second application of shoulder margin porcelain.

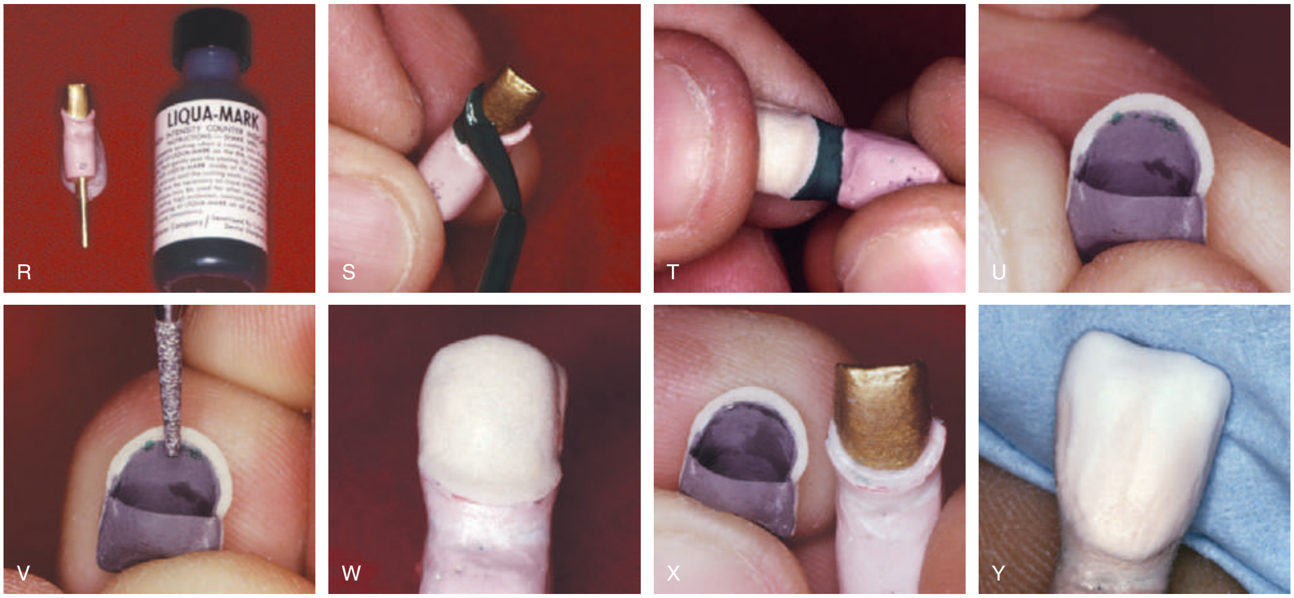

Fig. 24.33 Cont'd (R) Water-soluble marking agent for detecting premature contact. (S) The marking agent is applied to the shoulder margin. (T) The fired restoration is gently tried on the die. (U) Markings are visible on the porcelain and on the internal aspect of the casting. (V) Excess porcelain is removed. (W) The seated restoration. (X) Internal view of the completed shoulder margin. (Y) Conventional buildup with body and incisal powders.

TROUBLESHOOTING

Technical failures can occur in the complex metal-ceramic system and are difficult to detect. Different errors may lead to problems that appear similar. Table 24.2 summarizes some of these.

Cracks

Surface cracks and fractures in the opaque porcelain are usually of little concern. They can be patched before the body firing begins. Fractures during the bisque bake, however, are often the result of improper condensation, overly rapid drying, or haphazard moisture control. Poor substructure design, resulting in areas of unsupported porcelain, also can lead to porcelain failure (see Chapter 19). After cementation, pinpointing the cause of failure may be difficult. If the substructure is properly designed and the porcelain-metal interface is kept away from direct occlusal contact, cracks and fractures should not develop during normal function.

Bubbles

Even the most experienced ceramist sometimes traps air between the metal and the opaque porcelain. Usually, this is of little concern. However, if a restoration is fired too many times, the trapped air may appear as blisters that rise to the surface. If this occurs, the porcelain must be stripped, and the procedure must start over.

If bubbles appear after only a few firings, improper casting technique, insufficient metal preparation, or haphazard moisture control can usually be isolated as the cause (Fig. 24.34).

TABLE 24.2 Common Reasons for Failure of Metal-Ceramic Restorations

Failure	Reason
Fracture during bisque bake	Improper condensation
	Improper moisture control
	Poor framework design
	Incompatible metal-porcelain combination
Bubbles	Too many firings
	Air entrapment during buildup of restoration
	Improper moisture control
	Poor metal preparation
	Poor casting technique
Unsatisfactory appearance	Poor communication with technician
	Inadequate tooth reduction
	Excessive thickness of opaque porcelain
	Excessive firing
Clinical fracture	Poor framework design
	Centric stops too close to metal-ceramic interface
	Improper metal preparation

Unsatisfactory Appearance

Poor esthetic results often result from poor communication between the operator and the dental technician (see Chapter 16). An opaque application that is too thick can result in opacity of the veneer. Inadequate tooth reduction, especially in the cervical

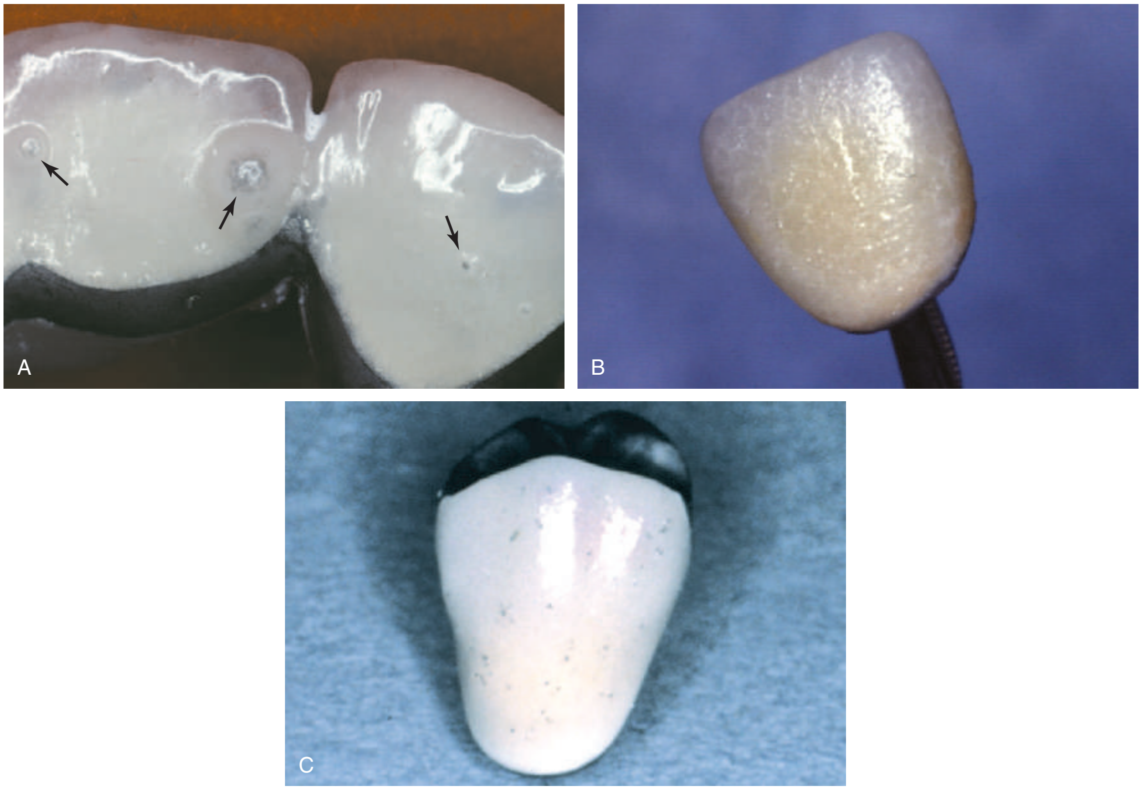

Fig. 24.34 (A) Bubbles *(arrows)* have made this metal-ceramic restoration unacceptable. (B) Devitrified porcelain on a metal-ceramic restoration is the result of an excessive number of firings. (C) Contamination of the porcelain surface has made this prosthesis unacceptable.

third and the interproximal areas, is one of the more common causes of a poor esthetic result. Careful communication, based on a thorough understanding and knowledge of relevant laboratory procedures and color science, is essential.

PRESS-ON-METAL TECHNIQUE (FIG. 24.35)

Geoffrey A. Thompson

Metal-ceramic restorations became commercially available in the 1950s, and, for generations, they have served as the standard for esthetic restorations despite labor-intensive manufacturing procedures. More recently, a novel technique for applying porcelain to a metal substructure called Press-on-Metal (POM) has received increased interest. Some of the benefits of the POM technique are its capability to be used with a noble or base metal alloy, reduced porcelain firing shrinkage, better fitting margins, and a porcelain-metal bond strength that meets or exceeds ISO standards.[94–101] Because of the versatility of the POM technique, entering into a digital workflow at different access points is possible. If desired, most conventional fabrication steps may be eliminated, such as making a definitive cast, waxing and cutback, and investing and casting.[94,95] One of the few drawbacks is that there is a limited selection of POM ceramic ingot shades; however, restorations can be individualized and made more esthetically pleasing by using available stain and glaze materials or by using a cutback and custom characterization technique.[94,95]

The pressing ingots are available in six basic shades and one bleach shade and allow for matching all the classic Vita A–D shades. Two pressing ingot sizes are available and, depending upon the number of units to be pressed, can be mixed to press from one to six restorations while reducing material waste. The coefficient of thermal expansion is compatible with many dental casting alloys, and its flexural strength is approximately two times greater than feldspathic porcelains (Table 24.3).

Entering a digital workflow can begin chairside with an intraoral scanner for production of a 3D image of a prepared tooth, or it can begin in the laboratory by using a conventional definitive impression or a stone cast produced from a definitive impression and a laboratory scanner. From this point, CAD-CAM design and manufacture of the substructure can begin. The restoration can be planned by using digital design software program and then milled or printed from

TABLE 24.3 Physical Properties of Pressing Ingot

CTE (100-500 °C) [10^{-6}/K]	13.4
Biaxial flexural strength [MPa]	130
Chemical durability [µg/cm²]	<100
Pressing temperature [°C]	940-950

Fig. 24.35 Press-to-metal technique. (A) Press-on-metal porcelain system. (B) Metal-framework before oxidation. (C) Special opaque porcelain is applied and fired. (D to F) The opaque framework is waxed to the contour of the body porcelain. (G) Investing the waxed framework. (H) After wax elimination, the porcelain is pressed. (I) Pressed body porcelain. (J) The incisal mamelons have been created by grinding the pressed porcelain. (K) The incisal porcelain is added with special powders in the conventional manner. (L) The completed restoration. (Courtesy Kuraray Noritake Dental Inc., Tokyo, Japan.)

a noble or base metal alloy. Alternatively, a wax pattern can be printed from a castable wax and then invested and cast in metal. Substructures should be between 0.3 and 0.5 mm thick (Fig. 24.36). To adequately support the press-on ceramic, recommended ceramic support and substructure design features should be adhered to.

The incorporation of a holding pin is a useful design feature and common to each method of substructure fabrication (Fig. 24.37A). If the holding pins on a fixed dental prosthesis are straight, they should also diverge (see Fig. 24.37B). After the casting is invested, in preparation for pressing, the pin serves as a substructure stabilizer during pressing. The pin also serves as a useful device while the restoration is being handled in the laboratory.

After the substructure is manufactured, finished, oxide fired, and opaque applied, it is weighed after opaque firing and will be used to determine the wax weight after the complete waxing. A fully anatomical wax unit that restores contacts, occlusion, and esthetics is created on the substructure and will become the pressed ceramic in the completed restoration. The wax unit may be produced by hand, or it can be manufactured. If the wax unit is manufactured, it should

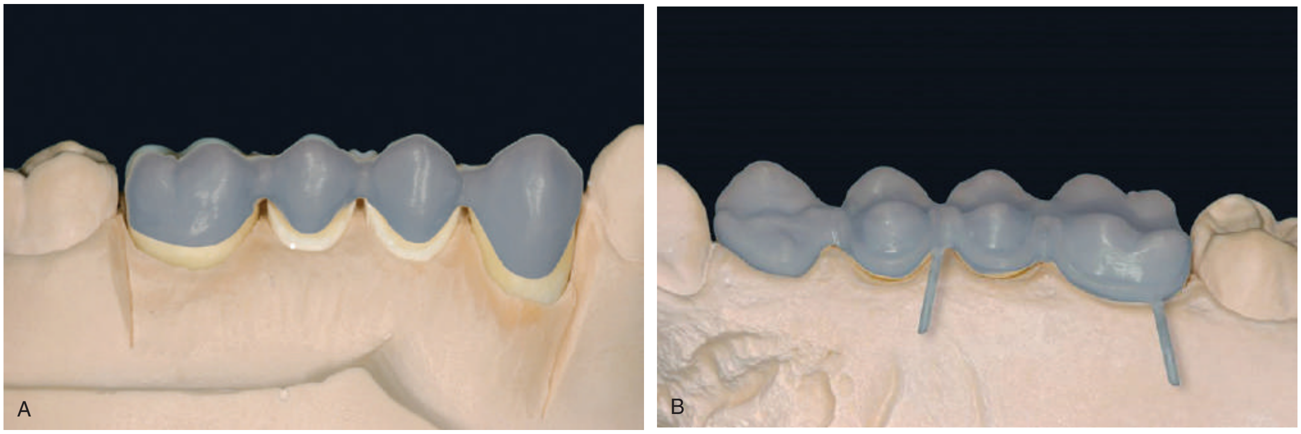

Fig. 24.36 Framework is waxed to anatomic contour and then reduced while maintaining an anatomical tooth form. (A) Buccal. (B) Lingual.

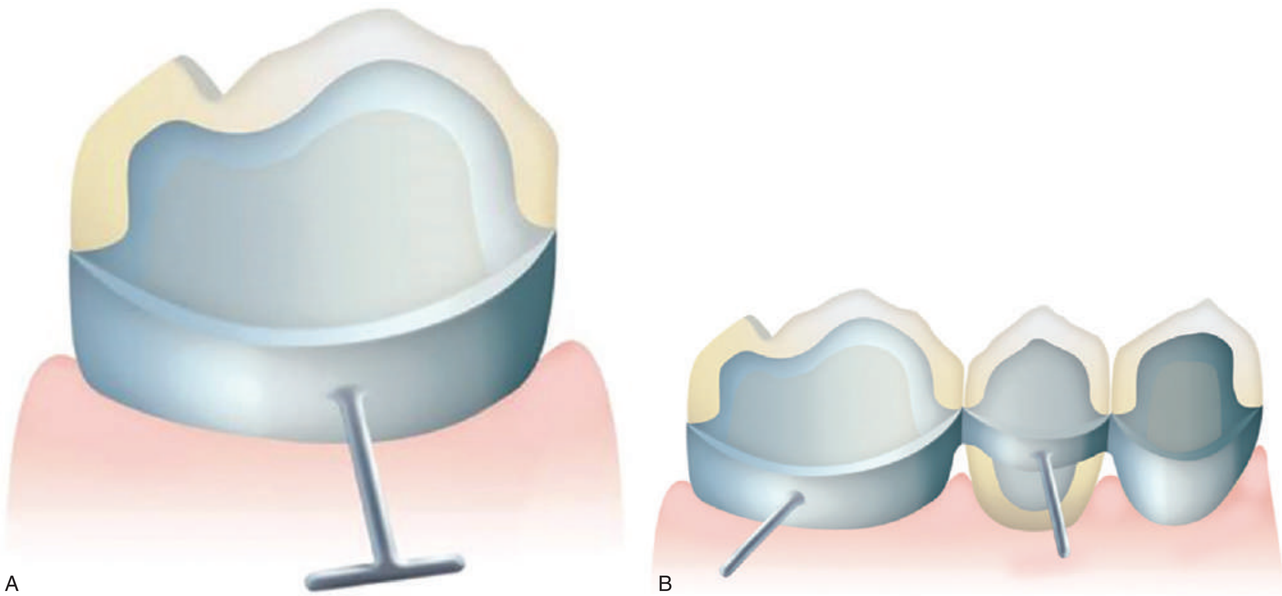

Fig. 24.37 Retention made from wax wire. (A) Wax wire with diameter of 1.0 to 1.5 mm. (B) Diverging wax wires.

be replaced on the substructure to refine its fit and marginal adaptation to the substructure. Each wax unit on the substructure is sprued (Fig. 24.38) at an appropriate angle with reference to the ring base to ensure a good flow of the press ceramic (Fig. 24.39). Wax sprues should be 3 mm in diameter and 3 to 10 mm in length. The sprue and wax pattern should not exceed 16 mm in total length. Weigh the sprued substructure and its ring base. The size of the press ceramic ingot may be chosen depending on the weight of the wax. The weight of the wax is determined by subtracting the weight of the substructure plus opaque and the weight of the ring base from the total weight; the remainder equals the wax weight. The manufacturer will recommend the number and size of ingots based on the wax weight.

Select an appropriately sized investment ring system and place the ring onto the ring base assembly (Fig. 24.40).

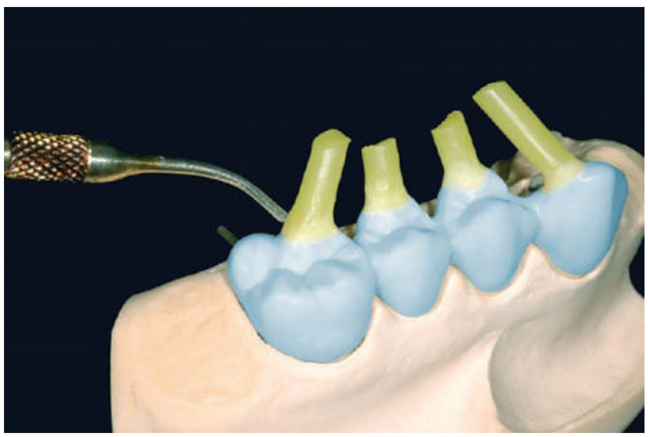

Fig. 24.38 Each unit is provided with a 3-mm diameter sprue.

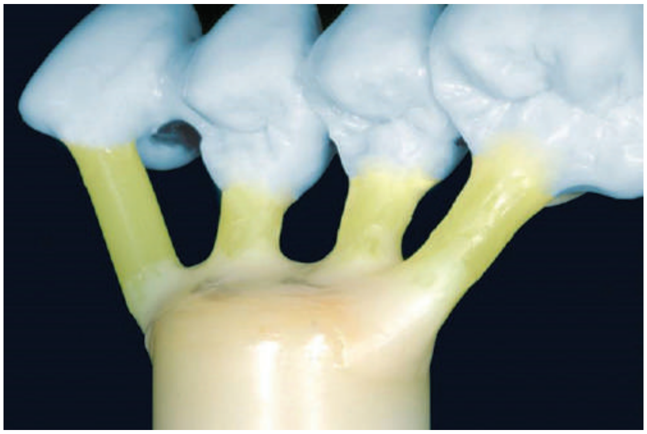

Fig. 24.39 Place the sprues in the same direction as the direction of flow and in the thickest part of the wax pattern.

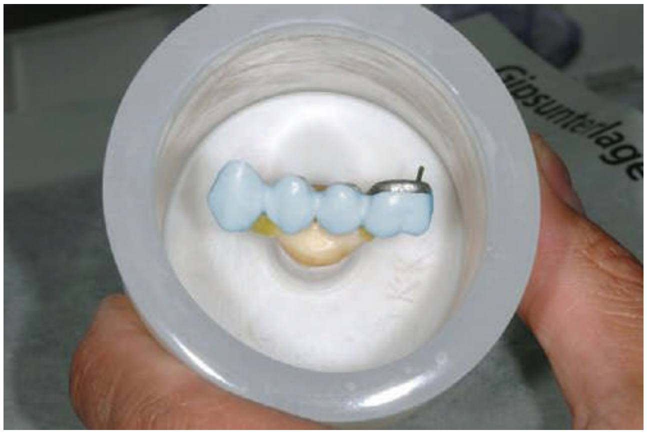

Fig. 24.40 Carefully position the ring on the ring base while taking care not to touch the wax pattern.

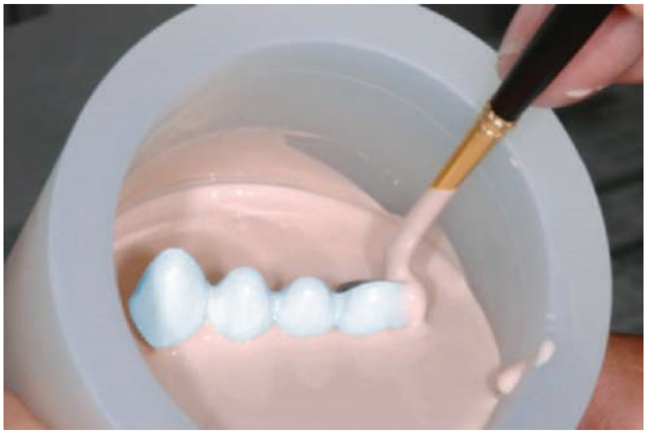

Fig. 24.41 Carefully fill the investment ring and allow the material to set.

Fig. 24.42 Place the completed press on metal ingots, plunger, and ring assembly at the center of the hot press furnace.

Carefully invest the assembly using appropriate hand instruments (Fig. 24.41). Following setting, remove the ring base and slide the investment ring out of the ring. Place the ring near the back wall of the furnace, tipped, and with the open side down.

Following wax elimination, select the appropriate color, size, and number of press ceramic ingots and coat the Alox plunger with separating powder. Place room temperature press ceramic ingots into the hot investment ring, followed by the plunger, and place the entire assembly into the pressing furnace (Fig. 24.42).

After pressing is completed, recover the hot ring from the oven and let it cool to room temperature. Remove the investment and Alox plunger using a large separating disk (Fig. 24.43) and recover the pressed ceramic-metal restoration from the remaining investment using glass beads. Separate the sprues and finish the restoration (Fig. 24.44) on the definitive cast using rotary cutting instruments suitable for glass-ceramics.

Restorations may be stained or characterized as esthetics require (Fig. 24.45).

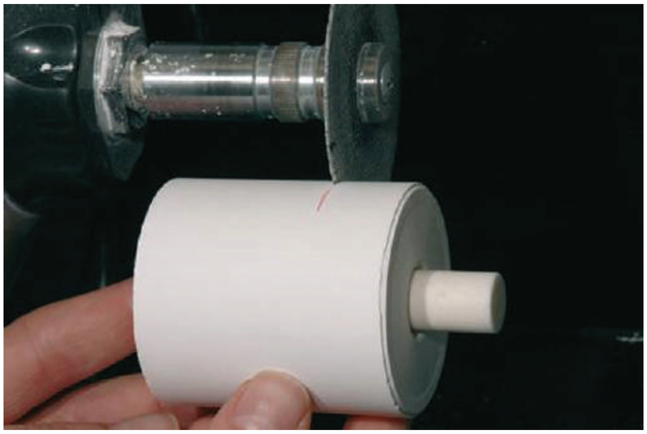

Fig. 24.43 Following cooling of the assembly, remove the investment at the height of the plunger using a separating disk.

A conventional workflow has been previously described, and POM departs from that method only at the step of applying porcelain and is not different from a digital workflow.

■ ■ ■

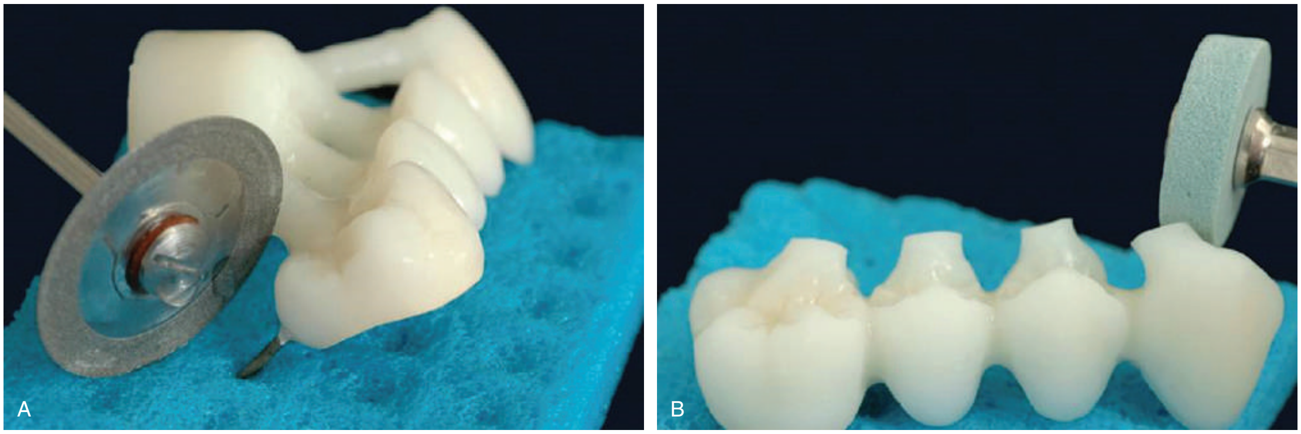

Fig. 24.44 (A) Separate the sprues, and (B) smooth the sprue attachment sites.

Fig. 24.45 Shade adjustments and individual characterization may be made using stains.

REVIEW OF TECHNIQUE

Fabricating a metal-ceramic restoration involves the following steps:

1. Patterns are waxed to anatomic contour.
2. The cutback is completed and verified with an index made from the anatomic waxing.
3. The patterns are cast (see Chapter 22) and seated on the die.
4. After finishing (and clinical evaluation if desired; see Chapter 29), the substructures are coated with opaque porcelain to mask the metal color.
5. Body powders are added to build to contour and cut back to standardize the amount of enamel powder that is added.
6. Enamel powder is added, and the buildup is slightly overcontoured to compensate for firing shrinkage.
7. After preliminary contouring, the bisque bake can be evaluated clinically. The incisal edge position is adjusted for function, esthetics, and phonetics.
8. After contouring, the restorations are glazed, and the metal is polished before cementation.

SUMMARY

Substructure design for metal-ceramic restorations must be based on an understanding of fundamental material properties. Restorations should be waxed to anatomic contour and then cut back in the area that is to be veneered. This allows porcelain thickness to be even, which not only is a means of obtaining superior mechanical properties in the completed restoration but also simultaneously helps standardize shade matching.

Metal-ceramic restorations with excellent appearance and good mechanical properties are obtainable if the techniques of metal preparation, framework design, porcelain manipulation, drying, and firing are carefully followed. Lifelike effects can be achieved by layering cervical, body, and incisal porcelains and by the judicious use of internal characterization and special dentin powders with relatively higher concentrations of opacifiers. Although it may create esthetic problems in many patients, the simplest way to obtain a good marginal fit is to use a narrow, 0.2- to 0.3-mm facial collar.

Whenever optimum appearance is desired, the procedures described in this chapter for fabricating a labial porcelain margin should be considered. However, the level of expertise needed to produce excellent marginal adaptations with these techniques is higher than that needed to use a cast margin; this should be considered in treatment planning. When failure occurs, all technical steps and materials should be reevaluated.

STUDY QUESTIONS

1. Discuss the types of dental porcelains used in the fabrication of a metal-ceramic restoration. What are the composition differences among the various powders? How does the handling differ?
2. What are the prerequisites for casting preparation before the initial firing?
3. What is the role of a vacuum in firing a metal-ceramic restoration? Which procedures require a vacuum, and which are performed without it?

4. How do firing schedules vary as a function of the alloy used?
5. What is vitrification? What is devitrification?
6. Discuss the porcelain-metal bond. Which components of the alloy are involved? Which components of the dental porcelain are involved?
7. Discuss two different techniques for fabricating a porcelain labial margin.
8. Describe the causes of fractures and air bubbles during the bisque bake.
9. Discuss the advantages of the press-on metal technique.

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Ceramic Restorations

Ceramic inlays, onlays, veneers, and crowns can be some of the most esthetically pleasing restorations currently available. They can be made to match natural tooth structure accurately in terms of color, surface texture, and translucency. Well-made ceramic restorations can be virtually indistinguishable from unrestored natural teeth (Fig. 25.1).

The first ceramic crowns were made on a platinum matrix and were referred to as *porcelain jacket crowns*. Over the years, improved materials and techniques have been introduced in an attempt to overcome disadvantages associated with porcelain jacket crowns. These improvements, particularly the use of higher strength, more translucent, and easier to process ceramics, as well as adhesives for bonding the ceramic restoration to tooth structure, have led to a resurgence of interest in ceramic restorations, including the more conservative inlays and veneers (Fig. 25.2). With increasing demand for esthetics, ceramic restorations are now an important part of contemporary dental practice.

In this chapter, the historical background of ceramic restorations and more recent developments are reviewed. The laboratory procedures necessary for the fabrication of ceramic inlays, veneers, and crowns are reviewed, and the alternatives are compared.

The importance of the design of the tooth preparation to the success of ceramic restorations cannot be overemphasized (see Chapters 7 and 8).

HISTORICAL BACKGROUND

The first attempt to use ceramics for making ceramic dentures was made by Alexis Duchâteau, a French pharmacist, and Nicolas Dubois de Chémant, a French dentist, in 1774. De Chémant worked at the Sèvres porcelain factory and refined the formula until he obtained "clinically" acceptable ceramic dentures. He was later granted a patent for the fabrication of "mineral teeth." More than a hundred years later, C. H. Land made the first ceramic crowns and inlays with a platinum foil matrix technique in a gas-powered furnace and was granted a patent in 1887.[1] As this method was fraught with a number of risks, it did not become popular until electric furnaces were introduced

Fig. 25.1 Ceramic crown restoring the right maxillary central incisor. (B and C) Maxillary anterior teeth restored with facial veneers and a ceramic fixed dental prosthesis. (B and C, Courtesy Dr. D.H. Ward.)

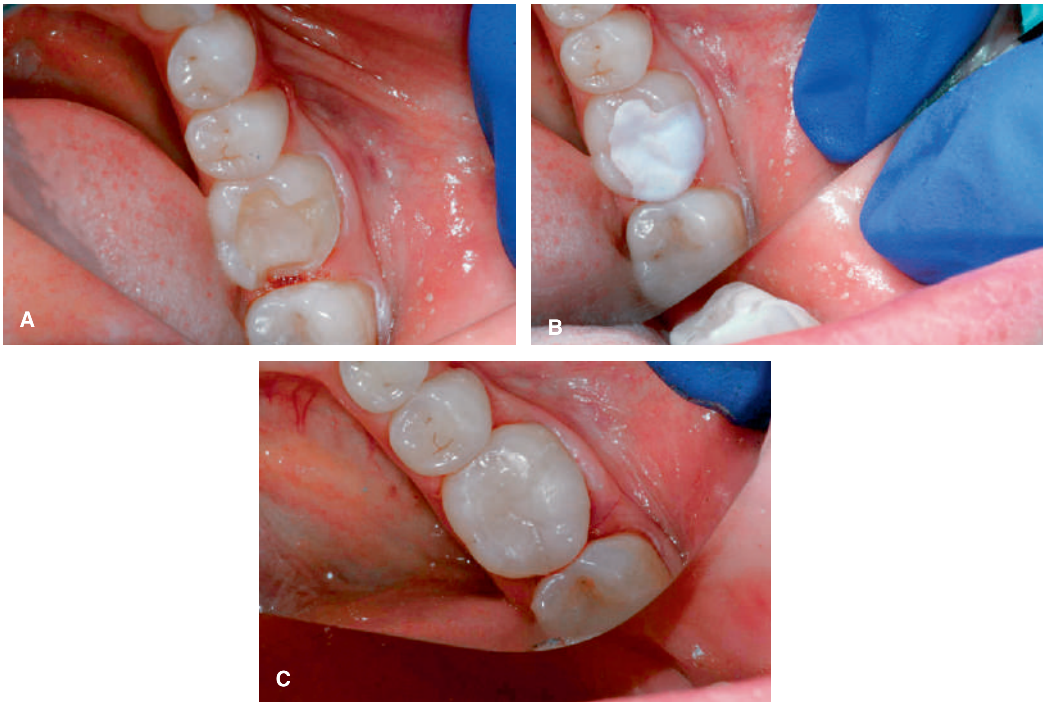


Fig. 25.2 (A) Mandibular molar prepared for conservative ceramic onlay after cuspal fracture. (B) Lithium disilicate evaluated intraorally before crystallization. (C) Completed restoration.

a number of years later.[2] The popularity of ceramic restorations declined with the introduction of acrylic resin in the 1940s and continued to be low until the disadvantages of resin veneering materials (increased wear, high permeability leading to discoloration and leakage) were realized.[3–5] In 1962, Weinstein and Weinstein[6] patented a leucite-containing porcelain frit for use in metal-ceramic restorations. The presence of leucite, an aluminosilicate with high thermal expansion, allowed a match between the thermal expansion of the ceramic and that of the metal (see Chapter 24). The appearance of ceramic restorations was improved by the introduction of vacuum firing, which considerably reduced the amount of porosity and therefore resulted in restorations that were denser, stronger, and more translucent than could be achieved with air firing.[7]

HIGH-STRENGTH CERAMICS

The chief disadvantage of the early restorations was their low strength, which limited their use to low-stress situations, such as those encountered by anterior teeth. Yet, fracture was a fairly common occurrence, which prompted the development of higher strength materials.[8,9] These developments have followed two paths. One approach is to use two ceramic materials to fabricate the restoration. A high-strength but nonesthetic ceramic core material is veneered with a lower strength, esthetic porcelain. Conceptually, this is similar to the metal-ceramic technique (see Chapter 24), although the color of the ceramic core is more easily masked than that of a metal substructure. The other approach is the development of a monolithic ceramic that combines good esthetics with high strength. This has the obvious attraction of not needing the additional thickness of material to mask a high-strength core.

Monolithic zirconia restorations[10,11] provide a good compromise of outstanding strength and esthetics that are acceptable for posterior restorations. Restorations are milled from a presintered blank. This is called soft machining because presintered zirconia is much easier to mill than the fully sintered material. The restorations can be colored by dipping of the presintered material in special colorants,[12] although the process has drawbacks, including nonuniformity of the coloring[13] and color change after adjustment.[14] Because of their high strength, less tooth reduction is needed than for other ceramic or metal-ceramic systems.[15] Preshaded zirconia blanks that are layered with various levels of translucency are also available, offering adequate shade and translucency control. Alternatively, zirconia cores or frameworks can be machined from presintered blanks and further veneered with porcelains of matching expansion. Wear of opposing enamel appears to be less with monolithic zirconia than other dental ceramics,[16] although the restoration must be carefully polished because a rough surface will lead to increased wear of the opposing tooth.[17]

STRENGTHENING MECHANISMS OF DENTAL CERAMICS

In spite of their excellent esthetic qualities and outstanding biocompatibility, dental ceramics, like all ceramic materials, are brittle. They are susceptible to fracture at the time of placement and during function. Brittle materials such as ceramics always contain at least two types of flaws from which fracture can initiate: fabrication defects and surface cracks. Methods used to improve the strength and clinical performance of dental ceramics include control of fabrication defects,[18] crystalline reinforcement, and stress-induced transformation.

Control of Fabrication Defects

Fabrication defects are created during processing. In sintered ceramics, they consist of voids or inclusions generated during sintering. Condensation of a ceramic slurry by hand before sintering may introduce residual porosity.[19] Porosity on the intaglio surface of clinically failed glass-ceramic restorations has been shown to be a fracture initiation site.[20] Sintering under vacuum is an efficient means of reducing the porosity in feldspathic dental ceramics by a factor of 10, from 5.6 to 0.56 volume percent.[7]

Besides porosity, surface cracks represent another type of fabrication defects, induced by machining or grinding. Fig. 25.3 shows a crack present on the proximal surface of an as- machined lithium disilicate restoration, together with machining grooves. The average natural flaw size varies from 20 to 50 μm.[21] Usually, fracture of the ceramic material originates from the most severe flaw, which effectively determines the fracture resistance of the restoration.[18] Microscopic examination of machined restorations with or without crack detection with a fluorescent dye prior to cementation would therefore constitute good practice.[18] Ceramic engineers analyze failure with a statistical approach, assessing flaw size and spatial distribution to predict reliability.[22]

Crystalline Reinforcement

Strengthening by crystalline reinforcement involves the introduction of a high proportion of crystalline phase into the ceramic material to improve the resistance to crack propagation. The crystals can deflect the advancing crack front to increase the fracture resistance of two-phase materials. Microstructural features that typically lead to crack deflection include (1) anisotropic crystal structure, such as in lithium disilicate or mica glass-ceramics and (2) residual strains such as in leucite-reinforced ceramics.[23] Lithium disilicate and mica crystals are characterized by a layered structure.[24] Crack propagation along the crystal layers is much easier than across. In addition, lithium disilicate and mica glass-ceramics exhibit a house of cards microstructure with interlocking crystals oriented in all directions. This leads to multiple deflections of the crack front, which constitutes an efficient mechanism for increasing the resistance to crack propagation.[25]

Fig. 25.3 Scanning electron micrograph of a machined lithium disilicate crown showing machining grooves and a macrocrack on the proximal surface.

Crystalline reinforcement can also be achieved by using a crystalline phase whose thermal expansion coefficient is *greater* than that of the matrix. A good example is leucite-reinforced ceramics. Upon cooling, the leucite crystals contract more than the surrounding glassy matrix, and this produces tangential *compressive* stress around the crystals. Such tangential stresses tend to divert the crack around the particle and provide a modest but definite increase in the resistance to crack propagation.[26]

Stress-Induced Transformation

In some highly crystalline ceramic materials, such as partially stabilized tetragonal zirconia, strengthening can be obtained through a martensitic stress-induced transformation. Zirconia is monoclinic at room temperature and tetragonal between about 1170°C (≈2140°F) and 2370°C (≈4300°F). The transformation from tetragonal to monoclinic zirconia is accompanied by an increase in volume. The tetragonal form can be retained at room temperature by addition of various stabilizing oxides such as yttrium oxide. In tetragonal zirconia stabilized with 3 mol% yttria (3Y-TZP; where TZP stands for tetragonal zirconia polycrystal), stress can trigger the transformation from tetragonal to monoclinic; this is accompanied by an increase in grain volume, efficiently blocking further crack propagation.[26,27] The use of higher amounts of yttrium oxide stabilizer (4Y-PSZ and 5Y-PSZ, where PSZ stands for partially stabilized zirconia) leads to the retention of the cubic phase at room temperature, in addition to the tetragonal phase. The cubic phase is fully stabilized and does not exhibit a stress-induced transformation. As a result, the mechanical properties of zirconia ceramics containing cubic zirconia are not as high as those of 3Y-TZP.[28] Surface treatments such as airborne particle abrasion have been shown to trigger the stress-induced transformation in tetragonal zirconia ceramics which leads to an increase in strength.[29] Zirconia ceramics currently offer the best mechanical properties of all available dental ceramics.[10]

Glazing

With weaker feldspathic porcelains, the addition of a surface glaze can also be used for strengthening. The principle is the formation of a low-expansion surface glaze layer formed at a high temperature. Upon cooling, the low-expansion glaze places the surface of the porcelain in compression and reduces the depth and width of surface flaws.[30]

With contemporary dental ceramics, self-glazing is the standard technique. This consists of an additional firing in air after the original firing, without application of a low-expansion glaze. However, self-glazing does not significantly improve the flexural strength of feldspathic dental porcelain.[31,32]

Prevention of Stress Corrosion

Similarly to glasses, the strength of ceramics is reduced in moist environments. This weakening is caused by a chemical reaction between water and the ceramic at the tip of the strength-controlling crack, which results in an increase in the crack size—a phenomenon called *stress corrosion* or *static fatigue*.[33] According to Michalske and Freiman,[34] the reaction steps involve the following:

1. The adsorption of water to strained silicon-oxygen-silicon (Si-O-Si) bonds
2. A concerted reaction involving simultaneous proton and electron transfer
3. The formation of surface hydroxyls (OH^-) by opening of the Si-O-Si bonds

Sherrill and O'Brien[35] first reported a reduction in fracture strength of about 30% when dental porcelains were fractured in water, and other authors[36,37] have concluded that stress corrosion is detrimental to the performance of dental ceramics. Partially stabilized tetragonal zirconia (3Y-TZP) ceramics are also sensitive to aging, and low temperature degradation (LTD) of zirconia in the presence of moisture is a well-documented phenomenon.[38,39] Newer formulations involving co-doping with trivalent ions and grain boundary engineering appear to be promising approaches for minimizing LTD.[40] However, autoclaving of zirconia restorations, implant abutments, or implants should be avoided as a precaution to prevent any LTD initiation.

CERAMIC SYSTEMS

The microstructure of some ceramic systems discussed in this chapter is illustrated in Fig. 25.4, and their properties are summarized in Table 25.1.

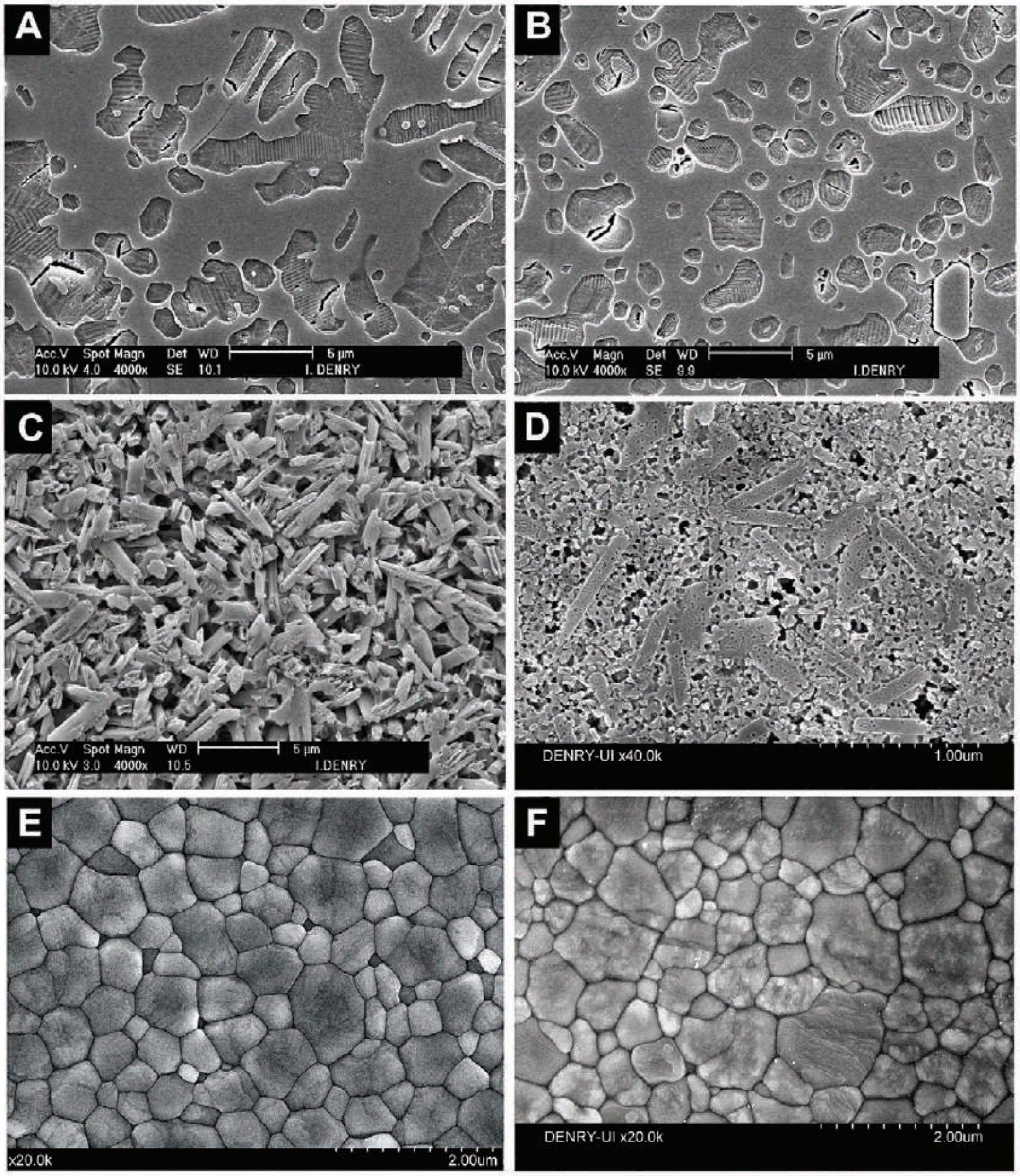


Fig. 25.4 Representative dental ceramics etched to reveal microstructure. (A) A feldspathic porcelain (IPS Classic, Ivoclar AG, Amherst, NY). (B) A leucite-reinforced pressable ceramic (OPC, Pentron Clinical, Orange, CA). (C) A lithium disilicate pressable ceramic (OPC 3G, Pentron Clinical). (D) A zirconia-reinforced lithium silicate ceramic (Suprinity, VITA North America). (E) A machined and sintered tetragonal zirconia ceramic (BruxZir Full Strength, Glidewell Laboratories). (F) A machined and sintered cubic zirconia ceramic (ZPex Smile, Tosoh Tokyo).

TABLE 25.1 Comparison of Available Ceramic Systems

Vita Ambria	IPS empress CAD	IPS e.max CAD	IPS e. max ZirCAD	Celtra Duo	Vita Suprinity	Vita Mark II	Cerec blocs C	BruxZir Anterior	BruxZir Full Strength	Lava Esthetic	Lava Plus	Metal-ceramic
VITA North America	Ivoclar AG	Ivoclar AG	Ivoclar AG	Dentsply Sirona	VITA North America	VITA North America	Dentsply Sirona	Glidewell Labs	Glidewell Labs	3M ESPE Dental	3M ESPE Dental	Various
Zirconia-lithium silicate	Leucite	Lithium disilicate	Tetragonal zirconia	Zirconia-lithium silicate	Zirconia-lithium silicate	Feldspar	Feldspar	Cubic + tetragonal zirconia	Tetragonal zirconia	Cubic + tetragonal zirconia	Tetragonal zirconia	Leucite
Anterior three-unit FDPs, crowns	Inlays, onlays, crowns, veneers	Anterior three-unit FDPs, crowns	Crowns, FDPs	Crowns, veneers	Crowns, veneers	Inlays, onlays, crowns	Inlays, onlays, crowns	Anterior three-unit FDPs, crowns	Crowns, FDPs	Anterior three-unit FDPs, crowns	Crowns, FDPs	Crowns, FDPs
Heat-pressed	CAD-CAM	CAD-CAM	CAD-CAM	CAD-CAM	CAD-CAM	CAD-CAM	CAD-CAM	CAD-CAM and sintered	CAD-CAM and sintered	CAD-CAM and sintered	CAD-CAM and sintered	Cast framework, sintered porcelain
Medium/high	Medium/low	Medium/high	Medium	Medium/high	Medium/high	Medium/low	Medium/low	High	Very high	High	Very high	Very high
Medium/high	Medium/low	Medium/high	Medium	Medium/high	Medium/high	Medium/low	Medium/low	High	Very high	High	Very high	Medium
Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Opaque	Medium	Opaque	Opaque
Medium	Medium	Low	Not tested	Medium	Medium	Medium	Not tested	Not tested	Not tested	Not tested	Not tested	Medium
Good	Fair	Fair	Not tested	Good	Good	Fair	Fair	Not tested	Not tested	Not tested	Not tested	Good

CAD-CAM, Computer-aided design/computer-aided manufacturing; *FDP*, fixed dental prosthesis.

Aluminous Core Ceramics (Historical)

A high-strength ceramic core was first introduced to dentistry by McLean and Hughes[41] in 1965. They advocated using aluminous porcelain, which is composed of aluminum oxide (alumina; Al_2O_3) crystals dispersed in a glassy matrix. Their recommendation was based on the successful use of alumina-reinforced porcelain in the electrical industry[42] and the fact that alumina has high fracture toughness and hardness.[43]

The technique devised by McLean[44] involved the use of an opaque inner core containing 50% by weight alumina for high strength. This core was veneered by a combination of esthetic body and enamel porcelains with 15% and 5% crystalline alumina, respectively[45] (Fig. 25.5) and matched thermal expansion.

Some all-ceramic systems rely on a high-strength nonesthetic core; some rely on a high-strength esthetic material.

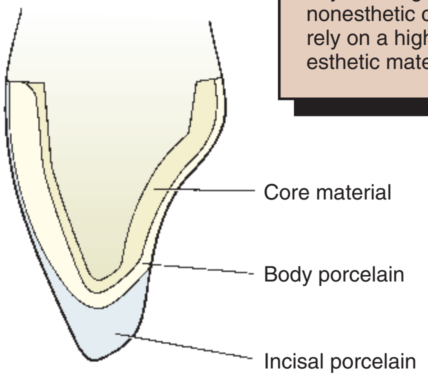


Fig. 25.5 The strength of a veneered zirconia crown is derived from its high strength zirconia core, onto which esthetic body and incisal porcelains are fired. This is analogous to the metal-ceramic crown, whose strength is derived from a metal substructure.

The resulting restorations were approximately 40% stronger than those with traditional feldspathic porcelain.[46]

High-strength core frameworks for ceramic restorations were later produced with a slip-casting procedure[47] such as the VITA In-Ceram (VITA North America, Yorba Linda, California). Slip-casting is a traditional technique in the ceramic industry and is used to make sanitary ware. The starting medium in slip-casting is a slip that is an aqueous suspension of fine ceramic particles in water with dispersing agents. The slip is applied onto a porous refractory die, which absorbs the water from the slip and leads to the condensation of the slip on the die. The piece is then fired at a high temperature (1150°C [≈2100°F]). The refractory die shrinks more than the condensed slip, which allows easy separation after firing. The fired porous core is then glass infiltrated, a unique process in which molten glass is drawn into the pores by capillary action at a high temperature.[48] Materials processed by slip-casting tend to exhibit lower porosity and fewer processing defects than do traditionally sintered ceramic materials. The strength of In-Ceram was about three to four times greater than that of earlier alumina core materials.[49,50] Marginal fit of In-Ceram restorations has been reported as very good[51] or good[52] but also as poor,[53] which emphasizes the technique sensitivity of the process, the need to select a skilled dental laboratory (Fig. 25.6), and ultimately explains the success of computer-assisted design and computer-assisted manufacturing (CAD-CAM) restorations.

Heat-Pressed Ceramics

Leucite Based

Heat-pressed ceramics for dental restorations were developed in the early 1990s. The restorations are waxed, invested, and pressed in a manner somewhat similar to that for gold casting

Fig. 25.6 (A) Defective maxillary metal-ceramic crowns. Esthetic problems included high value and opacity. (B) Crowns removed. The preparations are not discolored and thus allow a translucent ceramic crown system. (C) Maxillary ceramic crowns with a translucent slip-cast spinel core material. (Courtesy Dr. R.B. Miller.)

in the lost wax technique. Marginal adaptation seems to be better with heat pressing than with the high-strength alumina core materials,[53] although results from individual dental laboratories are technique-sensitive and may vary. Early heat-pressed ceramics contain leucite ($KAlSi_2O_6$), a potassium aluminosilicate, as a major reinforcing crystalline phase, dispersed in a glassy matrix (Fig. 25.4B), a microstructure very similar to that of sintered feldspathic ceramics (Fig. 25.4A). The crystal size varies from 3 to 10 µm, and the leucite content varies from approximately 35% to approximately 50% by volume, depending on the material. As mentioned earlier, research has shown that residual tangential stresses are developed around the leucite crystals upon cooling, providing some degree of strengthening by crack deflection.[26] Ceramic ingots are pressed at a high temperature (≈1165°C [≈2130°F]) into a refractory mold made by the lost-wax technique. The ceramic ingots are available in different shades.

Two finishing techniques can be used: a characterization technique (surface stain only) and a layering technique, involving the application of a veneering porcelain (Fig. 25.7G and H). The two techniques lead to comparable mean flexural strength values for the resulting ceramic composite.[54] The thermal expansion coefficient of the core material for the veneering technique is usually lower than that of the material for the staining technique, to be compatible with the thermal expansion coefficient of the veneering porcelain. An example of leucite-containing ceramic for heat-pressing is IPS Empress (Ivoclar AG, Amherst, New York).

Lithium Disilicate Based

The quest for stronger ceramics for dental restorations led to the development of improved heat-pressed ceramics. IPS e.max (Ivoclar AG) is an example of the later heat-pressed dental ceramics. The major crystalline phase of the core material is a lithium disilicate ($Li_2Si_2O_5$). The microstructure consists of randomly oriented interlocked crystals in a "house of cards" microstructure (Fig. 25.4C).[55] The material is pressed at 920°C (≈1690°F) and layered with a glass containing some dispersed fluorapatite crystals.[56]

The indications for these higher-strength pressable dental ceramics include crowns and anterior three-unit fixed dental prostheses (FDPs).

Zirconia-Reinforced Lithium Silicate Ceramics

Zirconia-reinforced lithium silicate-based glass-ceramics (ZLS) have been introduced as pressable (Celtra Press, Dentsply Sirona, Charlotte, NC; Vita Ambria, VITA North America) or machinable materials (Celtra Duo, Dentsply Sirona; Vita Suprinity, VITA North America) for heat-pressing or CAD-CAM techniques, with claimed mechanical properties comparable to or higher than those of lithium disilicate glass-ceramics.[57] The technology relies on the addition of 10 mass percent zirconium oxide to lithium silicate glass compositions.[10] Zirconia acts as nucleating agent but remains in solution in the glassy matrix, with two main consequences: A dual microstructure consisting of very fine lithium metasilicate (Li_2SiO_3) and lithium disilicate ($Li_2Si_2O_5$) crystals is obtained (Fig. 25.4D); meanwhile, the glassy matrix is reinforced by the presence of zirconium oxide in solution.[58] The microstructure is achieved in two stages. In the first precrystallized stage, the glass-ceramic contains only lithium metasilicate crystals and is easy to machine. The final crystallization stage, leading to the dual lithium silicate microstructure, is obtained after a short heat treatment at 840°C (1544°F) for 8 minutes. The main difference between ZLS ceramics and lithium disilicate glass-ceramics in their final stage of crystallization concerns the nature of the crystalline phases: lithium metasilicate plus lithium disilicate for ZLS ceramics, and only lithium disilicate for lithium disilicate ceramics.[10] The zirconia-containing lithium silicate glass-ceramic material illustrates the ongoing quest for ceramic materials that offer adequate translucency combined with superior mechanical properties. These stable ceramics may offer better reliability than zirconia ceramics but may not represent the endpoint for this quest.

Fluorapatite Ceramic Ingots for Heat-pressing Onto Zirconia Frameworks

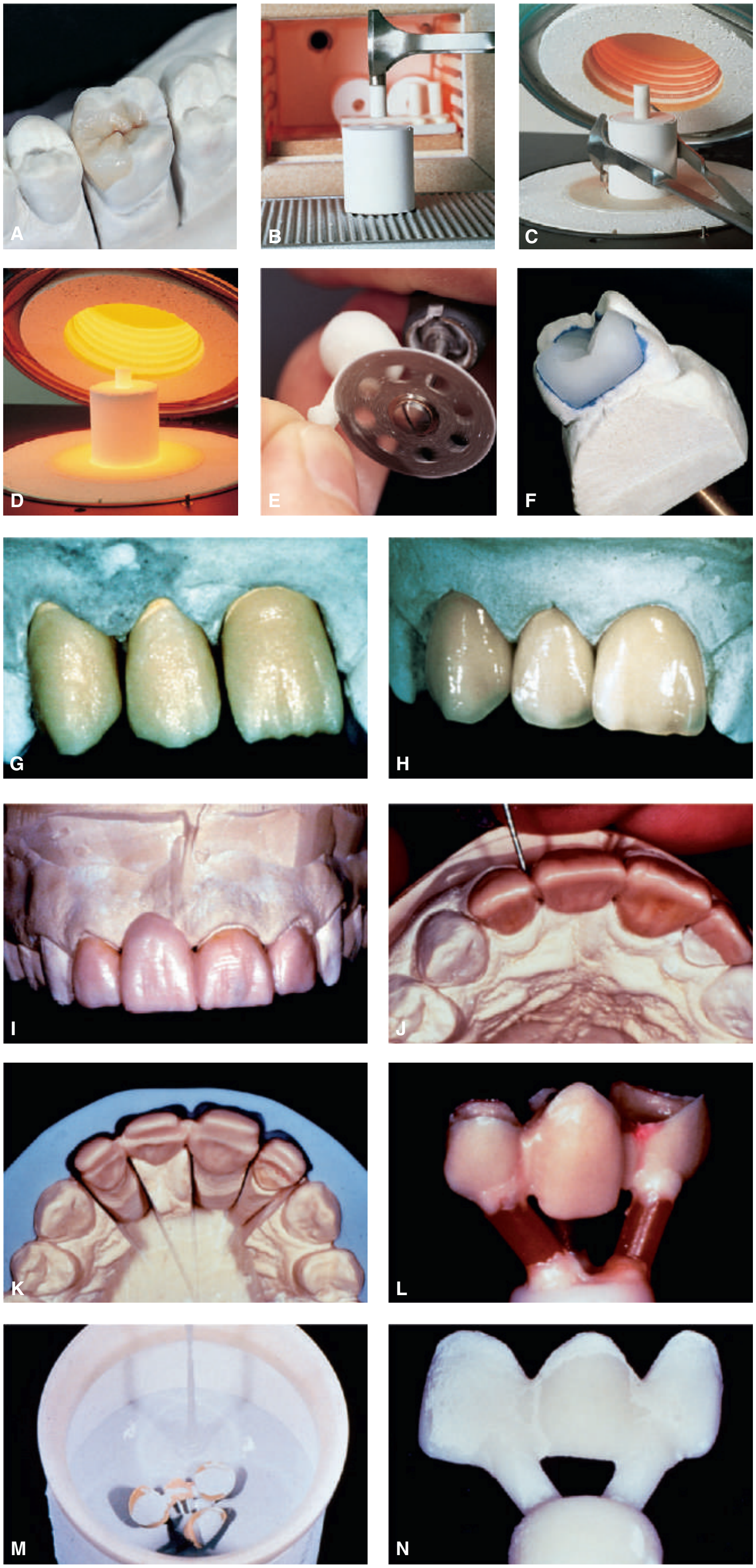
A heat-pressing technique to veneer zirconia frameworks is also available. It consists of using a highly translucent glass-ceramic containing fine fluorapatite crystals (IPS e max ZirPress, Ivoclar AG) that is heat-pressed onto an invested zirconia framework. The coefficient of thermal expansion of the fluorapatite glass-ceramic matches that of the core zirconia (between 10.5 and 11.0×10^{-6}°C^{-1}). This allows rendering of highly esthetic restorations in a controlled process designed to minimize delamination of the veneering ceramic.

Fabrication Procedure for Heat-Pressed Restorations

1. Wax the restoration to anatomic contour, attach sprue, and invest as with conventional gold castings (Fig. 25.7A). If the veneering technique is used, only the body porcelain shape is waxed.
2. Heat the investment to 800°C (or recommended temperature) to eliminate the wax pattern.
3. Insert a ceramic ingot of the appropriate shade and refractory plunger in the investment ring (Fig. 25.7B) and place the refractory cast in the special pressing furnace (Fig. 25.7C).
4. After heating to 1165°C, slowly press the softened ceramic into the mold under vacuum (Fig. 25.7D).
5. After pressing, recover the restoration from the investment by airborne-particle abrasion, section the sprue (see Fig. 25.7E), and refit the pressed restoration to the die (see Fig. 25.7F). Esthetics can be enhanced by applying an enamel layer of matching porcelain (see Fig. 25.7G and H) or by adding surface characterization and stains. The procedure for an FDP is similar (Fig. 25.7I–Q).

Machined Ceramics

The evolution of CAD-CAM systems for the production of machined inlays, onlays, veneers, and crowns led to the development of new machinable ceramics. Some of these ceramics are machined in the fully sintered stage (hard machining), while others, such as zirconia ceramics, are machined in a presintered green stage for easier machining (soft machining).



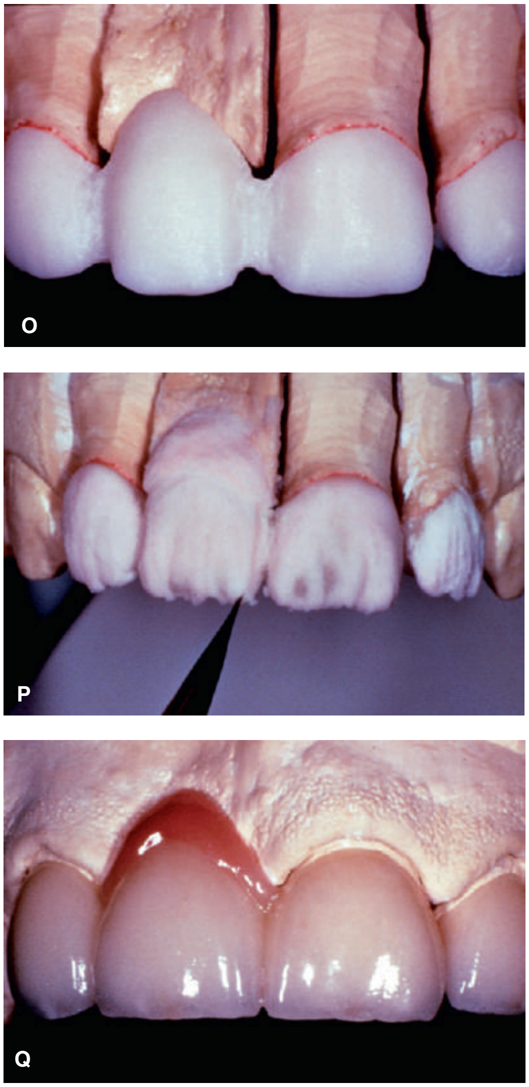


Fig. 25.7 Heat-pressed ceramic technique. (A) Ceramic inlay restoration for a maxillary molar. A wax pattern is made in a manner similar to that for conventional gold castings. (B) After the pattern is invested, it is burned out, and a ceramic ingot and an alumina plunger are placed in the heated mold. (C and D) The pressing is done under vacuum pressure at 1165°C. (E) The sprue is removed. (F) The pressed restoration is seated on the die. (G and H) For esthetic anterior restorations, only the dentin-colored ceramic is pressed. The incisal porcelain is applied by brush in the conventional manner. (I) Three-unit fixed dental prosthesis and veneer waxed to anatomic contour. (J) The technician ensures that the connector size is adequate (4 × 4 mm). (K) A silicone putty matrix is used to aid in cutback of the wax pattern. The sprue is inserted into the framework (L), the framework is invested (M), and the lithium-silicate ceramic is pressed into the mold. (N) The pressed restoration. (O) Framework on definitive cast. (P) Applying veneering porcelain. (Q) Completed restorations. (Courtesy Ivoclar AG, Amherst, New York.)

CEREC System

The CEREC system (Dentsply Sirona) is a popular CAD-CAM system that has been marketed since the 1980s; improved systems were introduced over the years as advances in scanning and milling machines were developed. The current Omnicam intraoral scanning wand with an upgraded software program is a significant improvement over earlier versions. The equipment consists of a computer-integrated imaging and milling system, with the restorations designed on the computer screen (Fig. 25.8A). Several materials can be used with this system: VITA Mark II (VITA North America), CEREC Blocs C (Dentsply Sirona), IPS Empress CAD (Ivoclar AG), IPS e.max CAD (Ivoclar AG), Suprinity (VITA North America), and Celtra Duo (Dentsply Sirona). VITA Mark II contains a feldspar (sanidine, $KAlSi_3O_8$) as a major crystalline phase within a glassy matrix. CEREC Blocs C are also described as feldspar-based ceramics with high translucency and moderate strength. IPS Empress CAD is a leucite-reinforced ceramic designed for making machined anterior restorations where esthetics are critical and strength requirements low. IPS e.max CAD contains lithium disilicate as a major crystalline phase, and various degrees of translucency are available. Vita Suprinity and Celtra Duo are ZLS ceramics. Composite resin blocks and interpenetrating phase composites (IPCs) such as Vita Enamic (VITA North America) are also available for use with this system. Weaknesses of the earlier CEREC systems included poor marginal fit of the restorations[59] and the lack of sophistication in machining of the occlusal structure. The marginal adaptation of CEREC 3 was improved,[60] and achieving improved occlusal anatomy became feasible. The most recently introduced version of the CAD-CAM software program (Cerec 5.1 SW; Dentsply Sirona) allows complete three-dimensional visualization of the designed restoration with "virtual seating" capabilities. The various surfaces of the virtual restoration can be modified in all three dimensions before machining.

Interpenetrating Phase Composites

IPCs are characterized by two phases that are each intact three dimensionally (intertwined) throughout the fully dense material. Such composites are formed by infiltration of a porous structure (first phase) with a liquid to form the second interpenetrating phase. Melt-infiltration of glasses followed by solidification and monomer infiltration followed in turn by thermoset polymerization is a common fabrication method.[61] IPCs are often tougher and stronger and display a higher damage tolerance (R-curve behavior) than either pure phase.

Because of esthetic needs, only ceramic-glass and ceramic-polymer IPCs have been developed for dentistry. The first (In-Ceram Alumina, VITA North America) was based on alumina (68%) infiltrated with a lanthanum-containing glass.[62] Fabrication of porous alumina is achieved by initial sintering characterized by surface diffusion without shrinkage. In-Ceram Alumina was the first fully dense net-shape ceramic available for dental restorations, and it performed very well (91.5% to 100% success) in at least eight clinical trials of between 5 and 7 years.[63]

The second IPC for dental restorations was introduced in 2013 (VITA Enamic, VITA North America). This IPC is based on initial sintering of porcelain powder to approximately 70% of full density, followed by infiltration with dental monomers.[64] Whereas the porous ceramic network has a strength of 135 MPa and the polymer below 30 MPa, the infiltrated IPC has a strength of 160 MPa.[65] As would be expected, many bulk and elastic properties are intermediate between those of particle-filled resins and ceramics. In fatigue testing, VITA Enamic performed as well as lithium disilicate.[66] This IPC has three additional advantages over other CAD-CAM and pressable ceramics: (1) reasonable brittleness index; (2) lower hardness; and (3) similar creep response to enamel (lower contact stress development and good stress redistribution).[64]

Fabrication Procedure

1. Tooth preparation follows typical ceramic guidelines.
2. Coat the preparation with opaque powder.
3. Use the optical scanner to obtain an image of the preparation, aligning the camera with the path of insertion of the restoration (Fig. 25.8B). When the best view is obtained, store it in the computer.
4. Identify and mark the margins and contours on the computer screen. The computer software assists with this step (Fig. 25.8C).
5. Manipulate the design software to simulate excursive movements and adjust restoration design accordingly (Fig. 25.8D).
6. Select the appropriate size block of the selected material from which the restoration is to be milled (Fig. 25.8E–G), and insert the appropriate shade of ceramic block in the milling machine. Fabrication time for a crown varies (Fig. 25.8H and I). Lithium disilicate crowns can be machined from blocks that have been fired only to achieve an intermediate level of crystallization, enabling more efficient milling with less wear on the cutting tools. Specifically, the metasilicate crystals allow for good edge stability and machinability. Subsequent firing converts the BlueBlock lithium metasilicate crystals to their final crystallized state to achieve significantly higher strength. After crystallization, IPS e.max CAD lithium disilicate reportedly consists of up to 70% lithium disilicate crystals in a glassy matrix (Fig. 25.8J and K).
7. Additional characterization can be achieved with surface stains incorporated into an overglaze (Fig. 25.8L).
8. Evaluate the restoration in the patient's mouth, etch, silanate, and lute it to place as described in Chapter 30.

Machined and Sintered Ceramics

Zirconia Ceramics

Extensive research in the field of zirconia ceramics and CAD-CAM technology has led to the development of zirconia ceramics for dental restorations.[67] Tetragonal zirconia stabilized with 3 mol% yttrium oxide (3Y-TZP) was the first material introduced and is currently still widely used, both as core and as monolithic material.[68] It is a polycrystalline ceramic with a dense microstructure (Fig. 25.4E) and a grain size that increases with sintering temperature. Grain size in turn affects mechanical properties as shown in Fig. 25.9. Recently, more translucent

Fig. 25.8 Cerec Omnicam computer-assisted design and computer-assisted manufacturing (CAD-CAM) system. (A) The Cerec Omnicam system consists of an imaging system, a computer, and a milling system. (B) Making an optical impression. (C) A number of computer-assisted designs for extracoronal restorations are available. (D) The software enables simulated mandibular movements to help evaluate that the desired occlusal structure is approximated. (E–G) Blocks are available in different ceramic systems, as is composite resin. (H) Milling of a blue, translucent-state lithium disilicate crown in progress.

zirconia ceramics were introduced. These materials are stabilized with larger amounts of yttria, typically 4 or 5 mol%, leading to a high proportion of cubic phase, which increases grain size, decreases grain birefringence and thereby increases translucency.[28,69] Characteristic microstructure of cubic zirconia ceramics is shown in Fig. 25.4F. Both high strength (tetragonal) and high translucency (cubic) zirconia copings are machined from presintered zirconia blocs. Enlarged copings are designed

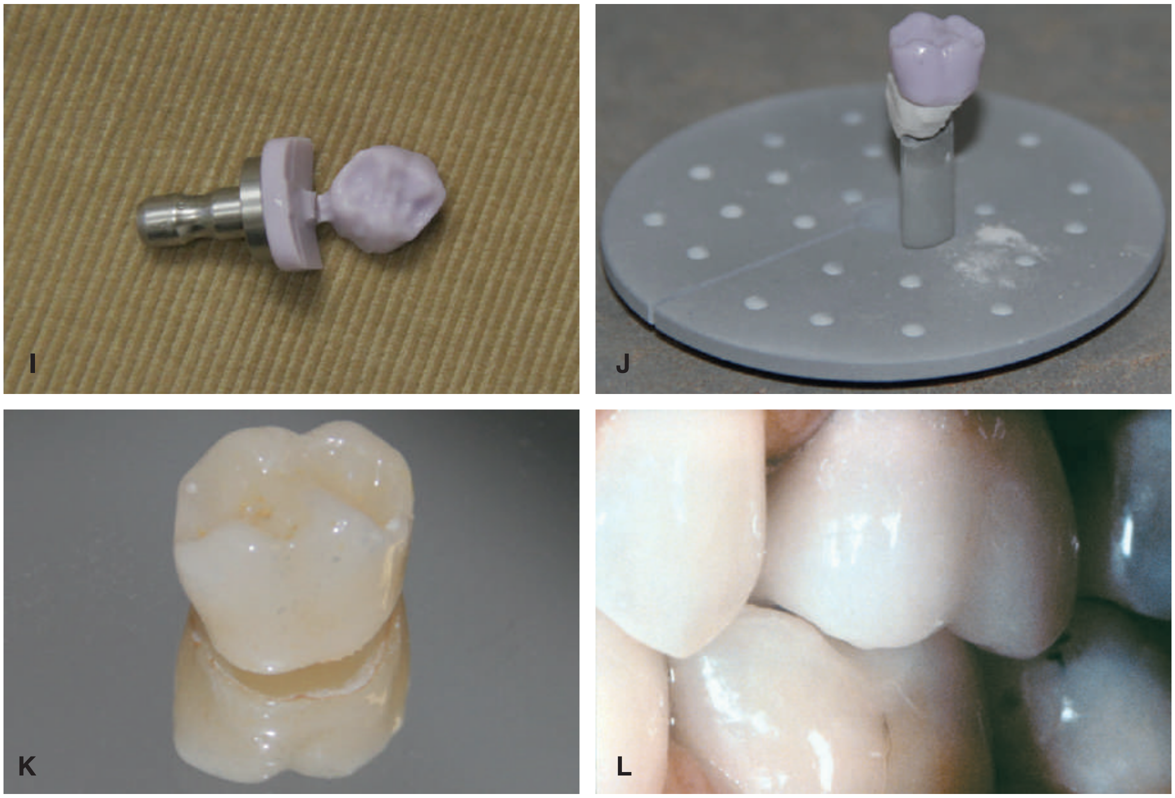


Fig. 25.8 Cont'd (I) Completely milled extracoronal restoration. (J) Restoration onfiring tray before firing to transform the lithium metasilicate into lithium disilicate. On firing, the restoration achieves its desired appearance. (K and L) Completed crown. (A–D and H–L, Courtesy Dr. R. Fox, Dentsply Sirona Charlotte, NC. E, Courtesy VITA North America,. F, Courtesy Ivoclar AG, Amherst, NY. G, Courtesy 3M ESPE Dental, St. Paul, MN.)

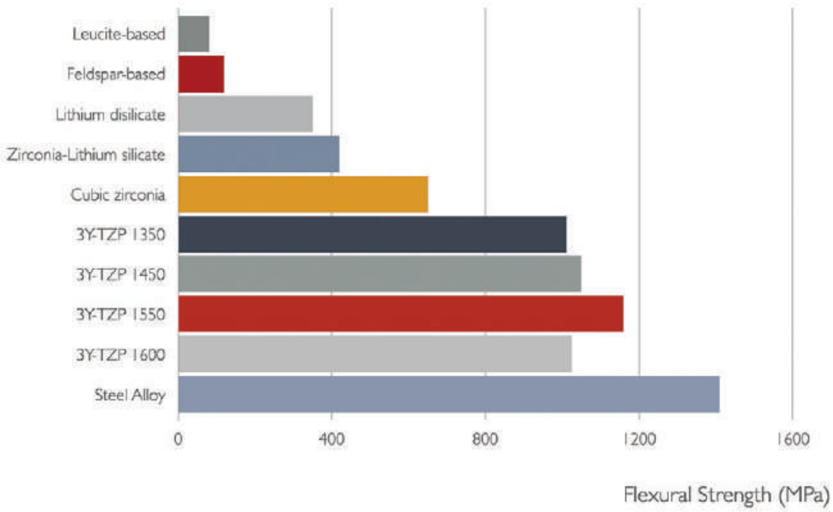


Fig. 25.9 Bar graph summarizing the mean flexural strength of ceramic materials.

to compensate for the sintering shrinkage (about 25%). The restorations are later sintered at high temperature (1350 to 1600°C [≈2460 to ≈2912°F], depending on the manufacturer) for several hours.[10] As mentioned earlier, both grain size and, consequently, strength depend on sintering temperature (see Fig. 25.9). Veneering ceramics with matching thermal expansion are available for core zirconia ceramics, to achieve an esthetic restoration for anterior teeth (Fig. 25.10). For posterior

Fig. 25.10 The Lava system. (A) Lava computer-assisted design/computer-assisted manufacturing (CAD-CAM) designing and milling machine. (B) Computer design of framework. (C and D) Framework milled from zirconia block. (E) Veneering porcelain. (F) Teeth prepared for posterior ceramic partial fixed dental prosthesis. (G) Completed restoration. (H) Framework evaluation for anterior partial fixed dental prosthesis. (I) Completed anterior partial fixed dental prosthesis. (A–E, Courtesy 3M ESPE Dental, St. Paul, Minnesota. F and G, Courtesy Dr. L. Jones and M. Roberts, CDT. H and I, Courtesy Dr. V. Bonatz.)

teeth, anatomic-contour (monolithic) restorations, in which the color is imparted with an intrinsic dye (Fig. 25.11),[12,13] or pre-shaded blocks are used. Tetragonal zirconia materials (BruxZir Full Strength, Glidewell Laboratories, Newport Beach, CA; e.max ZirCAD, Ivoclar AG; Lava Plus, 3M ESPE Dental, St. Paul, MN) exhibit very high strength and high fracture toughness. However, translucent zirconias with higher cubic phase content and larger grain size (BruxZir Anterior, Glidewell Laboratories; Lava Esthetic, 3M ESPE Dental) exhibit lower strength and fracture toughness and are indicated for crowns and short span anterior FDPs.[70] This is because of the lower fracture toughness of the cubic phase and its absence of stress-induced transformation.[28] Medium and long-term clinical performance has been excellent for both tetragonal zirconia, although early failures related to chipping of the veneering porcelain have been reported in the past.[71,72] Clinical data regarding the performance of cubic zirconia is currently being acquired.

SELECTION OF CERAMIC SYSTEMS

The primary purpose in recommending a ceramic restoration is to achieve the best possible esthetic result. Typically, this is at the risk of reduced restoration longevity because of the potential for fracture of the ceramic material, and the restoration may have a slightly inferior marginal adaptation than does a metal-ceramic crown.

Fracture Resistance

Long-term performance of ceramic restorations has long been hampered by problems with restoration fracture, and these restorations were mainly confined to lower stress anterior teeth; their greatest benefit was the improved esthetics. However, the newer materials, particularly the monolithic zirconias and ZLSs, have much higher strength (see Table 25.1), and long-term clinical performance, including for FDPs, is promising.

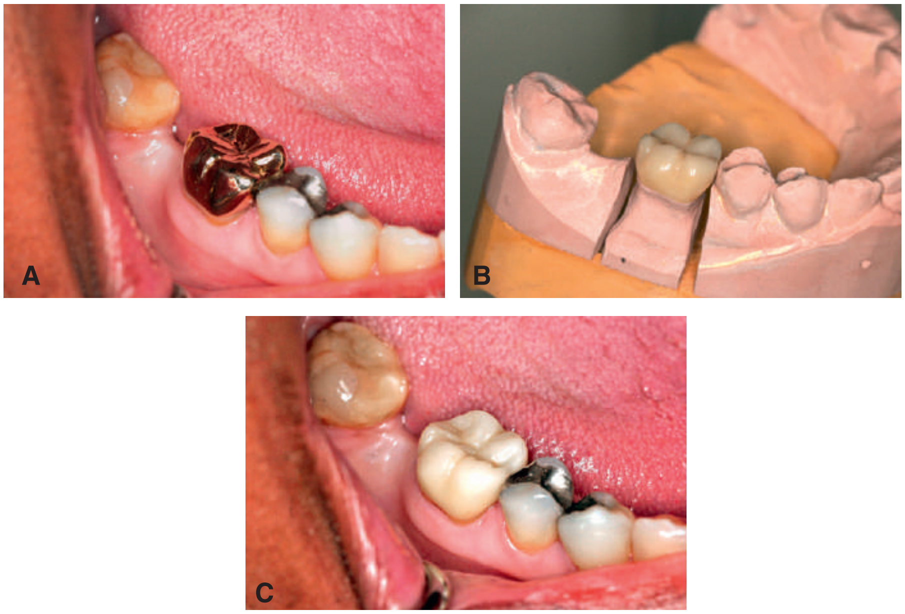


Fig. 25.11 (A) Patient was unhappy with the appearance of the gold crown on the mandibular first molar. (B) Monolithic zirconia crown. (C) The contour of the existing crown was scanned and replicated in the esthetic replacement.

Esthetics

Knowledge of the available ceramic systems is needed to select a material that will provide the best esthetics for a particular patient. This is especially important when a single maxillary incisor is matched to an adjacent tooth, undoubtedly still the most difficult challenge in fixed prosthodontics. Careful consideration should also be given to the availability of laboratory support because no dental laboratory invests in the expensive equipment needed for all of the available systems. The marginal adaptation of the resulting restorations is very important, even when resin bonding is used. When selecting a system, the dentist should carefully evaluate the internal and marginal adaptation, using an elastomeric detection paste (any residue must be thoroughly removed before the restoration is bonded). Although research studies have identified differences among the various systems (see Table 25.1),[53] it should be emphasized that these results may not represent an individual laboratory's results.

The translucency of the adjacent teeth and discoloration of the tooth being restored must also be considered when the most appropriate system is selected.[73] A more opaque, high-strength core, ceramic system (e.g., Lava, 3M ESPE) would not be a good choice for highly translucent teeth. However, such a system might be a good choice if the tooth exhibits discoloration that would not be well masked by a more translucent material. Conversely, when fracture is a concern, the higher strength materials should normally be given preference (see Table 25.1 and Fig. 25.9).

Abrasiveness

One concern with ceramic restorations is the potential for abrasion of the opposing enamel, particularly in patients with parafunctional habits. Whenever possible, a low-abrasion material should be considered and the restorations must be carefully polished. Abrasiveness has been studied in vitro and in clinical studies;[16,74–82] the results are summarized in Table 25.1. Polishing techniques for ceramic restorations are illustrated in Chapter 29.

INLAYS AND ONLAYS

Refractory Dies

Ceramic restorations can be made through the use of the CAD-CAM process or with the heat-pressed systems, but some technicians still select a refractory die technique for extremely thin veneers (Fig. 25.12). Marginal adaptation can be excellent, depending more on the technician's skill than on the ceramic material used.[83]

Step-by-Step Procedure

1. Pour an elastomeric impression of the prepared teeth in type IV or V stone; then repour it or duplicate it in ceramic refractory material, using an appropriate removable die system. The Di-Lok (see Chapter 17) or a similar system is convenient for this technique. The dies need to be separated very carefully because the refractory material is friable and breaks if mishandled.
2. Trim the refractory cast as far as possible to minimize the quantity of ammonia released during decontamination.
3. Mark the margins lightly with a special pencil (V.H.T., Whip Mix Corporation, Louisville, Kentucky).
4. Decontaminate the cast by firing according to the manufacturer's instructions. This is normally done in two stages: the first in a burnout furnace, the second under vacuum pressure in a porcelain furnace.
5. Allow the cast to cool, and then soak it in soaking liquid or distilled water for 5 minutes. This seals the die and prevents moisture from being drawn out of the porcelain buildup.
6. Apply an initial layer of porcelain to the refractory cast, and fire the cast according to the manufacturer's directions.

Fig. 25.12 Fabrication of facial veneers and ceramic onlay with the refractory die technique. (A) A surfactant "de-bubbleizer" is used to spray the impression, after which it is lightly blown dry. (B) The impression is poured with die stone. The preparation margins are marked before die spacing (C), and the cast is duplicated with an elastomeric duplicating material (D). (E) The mold is filled with the refractory investment. A die-lock system can be used (F); alternatively, a reverse dowel pin can be used with the dowel pin remaining in the cast base (G). (H) As another alternative, special high-heat dowel pins (High Temp Ceramic Dowel Pins, Dental Ventures of America, Inc., Corona, CA) can be used. (I) Margins are marked with a special pencil (V.H.T., Whip Mix). (J) The investment is decontaminated. (K) The blue margin marking turns red during this firing. (L) The dies are soaked in distilled water until bubbling disappears. (M) Adjacent proximal areas are coated with die hardener to prevent moisture from being absorbed into the cast.

With some systems, a higher strength core material is used as the initial coat.

7. Build up the restorations onto moist dies; for inlays, leave short of the margins.
8. Make a relieving cut through the central fossa, and fire the porcelain.
9. Fill in the central fossa area, and build up to the margins.
10. Contour and refine occlusion and proximal contacts. Glaze according to the manufacturer's instructions.
11. Remove the investment with a bur and 50-µm alumina in an airborne-particle abrasion unit. Transfer the restorations to the definitive dies on the mounted cast.

Fig. 25.12 Cont'd (N) The initial porcelain application. (O and P) The first application is fired. (Q) Additional firing is needed to compensate for shrinkage. (R) The veneer is built up to final contour and glazed. The investment is removed with a bur (S) and an airborne-particle abrasion unit (T). (U) Finished veneer on definitive cast. (V) Inlays and onlays are made in a similar manner. (Courtesy Whip Mix Corp, Louisville, Kentucky.)

12. If necessary, adjust the restoration margins and occlusion with fine-grit diamond stones. Polish with diamond polishing paste.

CERAMIC PARTIAL FIXED DENTAL PROSTHESES

Ceramic FDPs have a checkered history. Historically, researchers attempted to fabricate them with aluminous porcelain by connecting alumina cores with pure alumina rods. These restorations were usually unsuccessful; either they fractured, or the restorations encroached excessively into the embrasures, resulting in hygiene deficiencies. Leucite-containing heat-pressed ceramics do not appear to possess adequate strength for FDPs. Clinical trials of posterior ceramic FDPs have yielded disastrous results.[84] Anatomic-contour zirconia has much higher laboratory strength than these materials and has shown excellent clinical performance for posterior FDPs.[11] Machined lithium disilicate ceramics and veneered and monolithic zirconia systems have also been recommended as suitable for FDPs.[85] Although the newer materials are successful for FDPs, their manufacturers recommend a design with substantial connectors (typically 4 × 4 mm, as opposed to 2.5 × 3 mm recommended for metal connectors). Of the current ceramics, zirconia requires the smallest connectors. In situations with limited prosthetic space, zirconia FDP frameworks are preferred because larger embrasures promote access for cleaning and ideal esthetics.

CERAMIC FOUNDATION RESTORATIONS

Ceramic materials have been used as foundation restorations for endodontically treated teeth[86–88] to overcome esthetic problems associated with metal post and core systems (see Chapter 12). The post is made of tetragonal zirconia, (CosmoPost, Ivoclar AG; ER C-Post, Komet USA, Rock Hill, SC; TZP-post, Dentsply Maillefer, Tulsa, OK) chosen for its excellent strength,[89] and, depending on the system, the core material can be composite resin or a pressable ceramic (IPS Empress Cosmo, Ivoclar AG). Alternatively, a custom post and core can be milled from tetragonal zirconia with a CAD-CAM system.[90]

RESIN-BONDED CERAMICS

The performance of ceramic restorations has been enhanced by the use of resin bonding. This technique was first devised for the porcelain laminate veneer technique[91,92] and has been applied to other ceramic restorations. The technique entails the use of hydrofluoric acid or a less toxic substitute to etch the ceramic and a silane (silicon compounds, hydrogen compounds, and other monomeric compounds that are used as coupling agents to bond inorganic materials to organic resins) coupling agent to bond a resin luting agent to the ceramic. The luting agent is bonded to enamel after etching with phosphoric acid, as with resin-retained FDPs (see Chapter 26), and bonded to dentin with a dentin-bonding agent. Significant reduction in the fracture incidence of some types of ceramic crowns has been reported when an adhesive cement has been used.[93] Nonsilicate zirconia ceramics have traditionally represented a challenge for bonding since they cannot be etched with hydrofluoric acid. However, phosphate ester monomers such as 10-methacryloyloxydecyldihydrogen phosphate (10-MDP), have shown great promise with excellent bonding outcomes. 10-MDP is now widely used with zirconia ceramics.[94–96] For feldspathic and leucite-reinforced ceramics, resin bonding is the recommended procedure and is also used extensively for luting ceramic inlays and onlays.[97,98]

Etching and Silanating the Restoration

1. Support the restoration in soft wax with the fitting surface uppermost.
2. Apply a 1-mm coat of the etching gel (Ceram-Etch gel [9.5% hydrofluoric acid], Gresco Products, Inc. (Stafford, Texas), or the ceramic manufacturer's recommended product) to the intaglio surface only.
3. The etching time depends on the ceramic material. Feldspathic porcelain is typically etched for 5 minutes.
4. Very carefully rinse away the gel under running water. The gel is very caustic and should not be allowed to contact skin or eyes.
5. Continue to rinse until all the gel color has been removed.
6. Dry the ceramic with oil-free air. A hair dryer is recommended to ensure that the ceramic is not contaminated.
7. Apply the silane according to the manufacturer's recommendations. Some manufacturers recommend a heat-polymerized silane coupling agent for increased bond strength, rather than a chemically activated silane. Heat polymerizing is normally done by the laboratory, and care must be taken to clean the fitting surface thoroughly with alcohol before cementation.

   The cementation procedures are presented in Chapter 30.

SUMMARY

For many years, ceramic restorations have been the most esthetic of fixed prostheses. However, they are technique sensitive and if used incorrectly, they have a number of complications in comparison with the metal-ceramic crowns. Each ceramic has an esthetic and functional benefit for each clinical scenario that promotes optimal health for a tooth or implant. Selection and delivery of the appropriate cementation protocol that is specific for each ceramic is imperative to the esthetic and functional success.

Improved materials and techniques have increased interest in ceramic restorations. Porcelain laminate veneers have proved to be conservative and esthetic alternatives to complete coverage. Ceramic inlays and onlays may provide a durable alternative to posterior composite resins without the extensive tooth preparation needed for crowns. The highest-strength materials are suitable for high-stress applications, including FDPs.

STUDY QUESTIONS

1. Discuss the advantages and disadvantages, indications, and contraindications of ceramic crowns.
2. Which ceramic systems might be considered for a partial fixed dental prosthesis? What are the limitations with ceramic restorations in this application?
3. Compare the fabrication steps for a machined ceramic system with those of a heat-pressed ceramic system. What are the advantages of each?
4. Describe the fabrication steps for laminate veneers.
5. What are the main differences between tetragonal and cubic-based zirconia ceramics available for computer-assisted design/computer-assisted manufacturing (CAD-CAM) systems? What are the advantages and limitations of these restorations?

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26

Resin-Bonded Fixed Partial Dentures

Van P. Thompson, Contributing Author

OVERVIEW

Resin-bonded fixed partial dentures have had variable popularity since the technique for splinting mandibular anterior teeth with a perforated metal casting was described by Rochette in 1973.[1] However, research shows their 5-year clinical performance to be similar to that of conventional fixed partial dentures (FPDs) and even implant-supported crowns.[2] One study compared performance of single-implant crowns with two-unit cantilevered resin-bonded FPDs over a 10-year period and found that the single-tooth implant had more biological complications of supporting structures.[3]

Back in the 1970s, Rochette's work suggested an alternative to conventional metal-ceramic FPDs and the associated substantial removal of tooth structure needed to create strong, anatomically contoured, and esthetic restorations (Fig. 26.1A and B) (see Chapter 9). An FPD that requires only minimal removal of tooth structure is appealing, particularly for intact, caries-free abutment teeth (Fig. 26.2A and B). Compared with dental implants, a resin-bonded FPD has the advantage of not requiring surgical procedures. The primary goal of the resin-bonded FPD is replacement of missing teeth with maximal conservation of tooth structure.

The advent of electrolytic etching of metal surfaces to provide micromechanical retention for bonding of metal to enamel led to broad application of resin-bonded prostheses.[4] The restoration is straightforward in concept and consists of one or more pontics supported by thin metal retainers bonded lingually and proximally to the enamel of the abutment teeth (Fig. 26.3). The success of these conservative FPDs depends on bonding between etched enamel and the metal casting and requires precise and defined metal engagement of the abutments.

Early bonded retainers tested the limits of this application. In general use, compromised design of the early retainers (with some bonded only to lingual enamel) was compounded by the challenge of properly etching the metal. As a result, early failures were common, leading to reduced popularity. Since then, design parameters have been enumerated and tested clinically.[5–8] Ceramics and adhesive bonding have greatly improved, resulting in more conservative and predicable treatment. Ceramic resin-bonded FPDs are less invasive and require less chair time than other treatment choices for tooth replacement. The resin-bonded FPD offers patients an alternative to traditional FPDs or implants and complements the dentist's prosthodontic armamentarium.

DEVELOPMENT OF RESIN-BONDED FIXED PARTIAL DENTURES

Bonded Pontics

The earliest resin-bonded prostheses were extracted natural teeth or acrylic resin teeth used as pontics that were bonded to the proximal and lingual surfaces of abutment teeth with composite resin.[9,10] The composite resin connectors that retained the prosthetic tooth required supporting wires, a stainless-steel mesh framework, or polyethylene fiber mesh (Ribbon) to reduce the occurrence of brittle fracture. Use of these bonded pontics is limited to short anterior spans and have limited longevity. Since degradation of the composite resin bond to the wire or mesh leads to subsequent failure, such restorations are typically used only as interim restorations.[11–14]

Cast Perforated Resin-Bonded Fixed Partial Dentures (Mechanical Retention)

Rochette[1] introduced the concept of retaining metal to teeth by using flared perforations of the metal casting in 1973. Composite resin was allowed to extrude between the tooth and its perforated cast metal retainer. Once the resin polymerized, the metal casting was mechanically retained. The technique was primarily used for periodontal splinting, but pontics were sometimes included. Howe and Denehy[15] recognized the metal framework's improved retention compared with the previously discussed bonded pontics and suggested use of Rochette's design for FPDs with cast-perforated metal retainers and metal-ceramic pontics. They recommended to extend the framework to cover the maximum enamel surface area on the lingual surfaces with minimal or no tooth preparation. Use of these FPDs was limited to mandibular teeth or situations with minimal occlusal contact, using a heavily filled composite resin as the luting medium.

Livaditis[16] expanded this concept to replacement of posterior teeth, suggesting preparation of the abutments to establish a defined occlusogingival path of placement, which required lowering the proximal and lingual height of contour of the enamel. Once the path of placement was thus established, occlusal rests were incorporated on either side of the edentulous space, similar to those made for removable partial dentures (see Chapter 21). Wings covering the prepared proximal and lingual walls would extend interproximally into the edentulous areas and even onto occlusal surfaces. These prostheses were placed in normal occlusal contact and many have

Fig. 26.1 (A) Conventional tooth preparation for complete retainers for a fixed partial denture (FPD). (B) Definitive FPD retained on two natural tooth abutments.

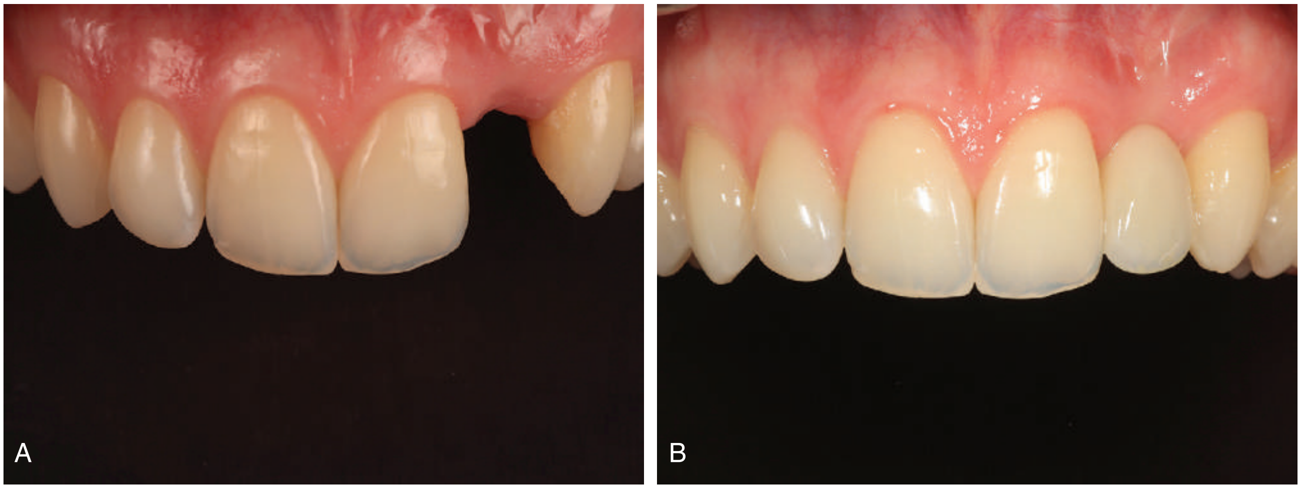

Fig. 26.2 (A) Maxillary anterior edentulous space with unrestored adjacent teeth. (B) Resin-bonded cantilevered prosthesis offered a non-surgical minimal tooth preparation solution for the patient.

Fig. 26.3 (A) Facial view of resin-bonded fixed partial denture replacing the right central incisor, which was lost as a result of trauma. (B) Lingual view of the retainers. Note the extension of the retainers over the marginal ridges of both abutment teeth, improving retention.

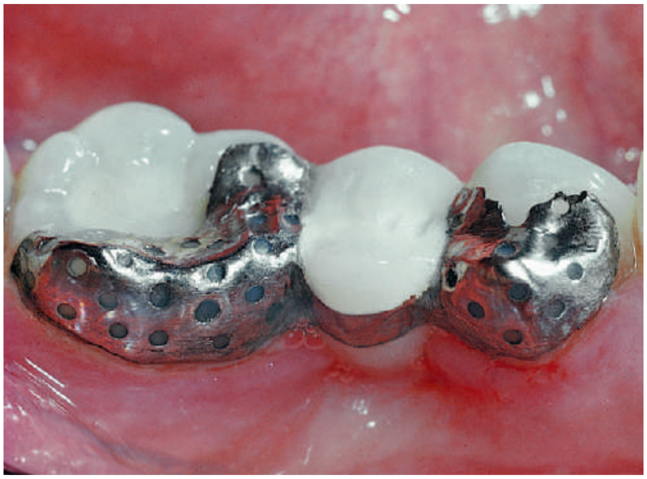

Fig. 26.4 Lingual view of an early perforated resin-bonded fixed partial denture that replaced a premolar, photographed at the 13-year recall. Note the loss of resin from the perforations, the poor gingival embrasures, and the generalized wear of the occlusal composite resin restoration on the molar abutment.

TABLE 26.1 Estimated Time to 50% Failure (Debondings) in Studies With a Two-Retainer Design Over 10-Year Mean Service Time

Study	Months to 50% Failure
Boyer et al (1993)[17]	
Perforated design	110
Etched metal[a]	250
de Rijk et al (1996)[58]	
Etched metal[b]	190

[a]At the University of Iowa; 143 anterior and 30 posterior fixed partial dentures (FPDs).
[b]At the University of Maryland; 61 anterior and 84 posterior FPDs.

survived and been reevaluated on maintenance visits for up to 13 years (Fig. 26.4). Despite such reported success rates, care must be taken in the retainer design and fabrication. Excessive numbers of perforations should be avoided lest the structural integrity of the framework be compromised.

Clinical results with the perforated technique were monitored for 15 years in a study at the University of Iowa.[17] The results from this well-controlled study suggest that for anterior FPDs, the perforated retainers have a failure rate of 50% at 110 months and 63% at about 130 months (Table 26.1). However, it is important to understand the mode of failure and how to manage failure of such retainers. The key is retrievability. These prostheses typically have two wings, one on either side of the pontic for bonding to the adjacent teeth. Failure typically occurs when only one wing debonds from its tooth. If the prosthesis is not removed, there is a high risk of caries developing under the detached retainer. Patients with such prostheses must be educated on the importance of immediately seeking care to have a partially detached prosthesis re-cemented or replaced before a carious lesion can form. Again, these restorations are not adhesively retained but are mechanically retained with the composite resin extruding through the beveled perforations in the retainers. Repair of a detached retainer is a straightforward process that is built into the design. The round low-speed dental bur that was used to bevel the perforations can also be used to remove the exposed composite resin providing retention on the other abutment. Composite resin removal can be accomplished without damaging the tooth and the FPD will be released. Once retrieved, the FPD and the abutment teeth are cleaned before re-cementation with new light-polymerizing composite resin. The advantage of straightforward retrievability with the Rochette design can be useful when an implant site requires development before an implant is placed. It can be quickly removed and re-inserted for each surgical appointment and does not place any pressure on grafts as they mature (Fig. 26.5A–C).

Etched-Cast Resin-Bonded Fixed Partial Dentures (Micromechanical Retention: "Maryland Bridge")

A technique for the electrolytic etching of cast base metal retainers was developed at the University of Maryland by Thompson and Livaditis.[4,18] Etched-cast retainers have definite advantages over cast-perforated restorations:

- Retention is improved because the resin-to-etched metal bond can be substantially stronger than the resin-to-etched enamel. The retainers can be thinner yet still resist flexing.
- The cameo surface of the cast retainers is highly polished and resists plaque accumulation.

During the course of this work, the need for a composite resin with a low film thickness for luting the casting became apparent. This led to the first generation of resin cements, which allowed micromechanical bonding into the undercuts in the metal casting created by etching and simultaneously provided adequate strength while permitting complete seating of the cast retainers. Comspan (Dentsply Caulk), the first of these cements, was moderately filled (60% by weight) with a film thickness of approximately 20 µm.[19] This generation of luting agents does not adhere chemically to the metal.

Electrolytic etching of base metal alloys proved to be critically dependent on base metal alloy composition and attention to detail in the laboratory. Initial etching methods were developed for a nickel-chromium (Ni-Cr) alloy (Biobond C & B Flux, Dentsply Sirona) and a nickel-chromium-molybdenum-aluminum-beryllium (Ni-Cr-Mo-Al-Be) alloy (Rexillium III, Pentron Clinical, San Diego, CA).[20] These methods were followed by simplified techniques,[21] chemical etching,[22] or gel etching.[23] They all yield similar results, provided that the technique is optimized for a specific alloy.[24] The degree of undercut created by this etching process is shown in Fig. 26.6. Lack of attention to detail can result in unintended electropolishing or surface contamination.[25] Over time, however, both techniques exhibit severely degraded bond strengths in a moist environment.

Highly variable results have been reported from different dental laboratories in which the same alloy is etched.[26] Etching and bonding techniques were adopted on the basis of bond strength testing of specimens subjected to only 24 hours or 7 days of water exposure. When resin-to-metal test specimens were aged for 6 months in water and then thermally stressed by 10,000 or more thermal cycles, large reductions in bond strengths were recorded.[27,28] Therefore, data from specimens

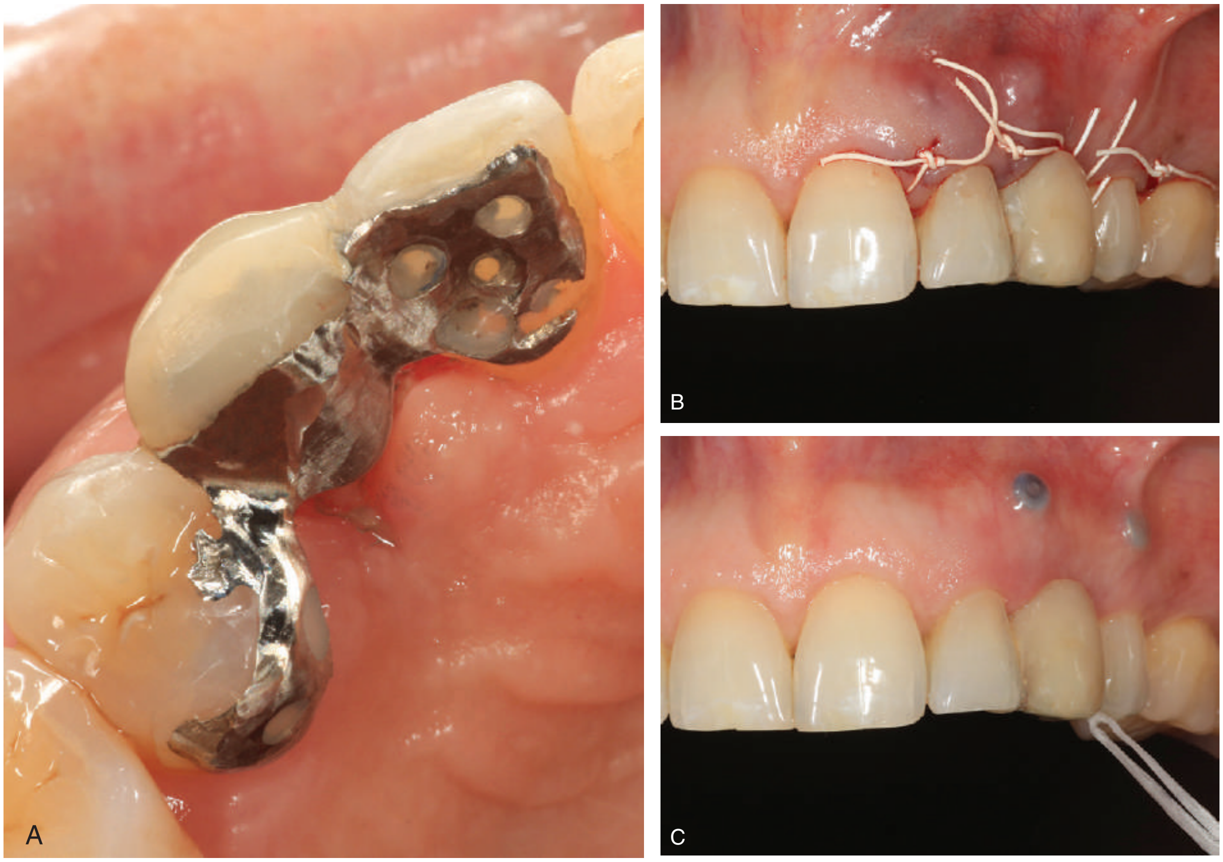

Fig. 26.5 (A) Rochette design interim fixed partial denture. (B and C) The Rochette design is straightforward to remove and replace for implant site development procedures.

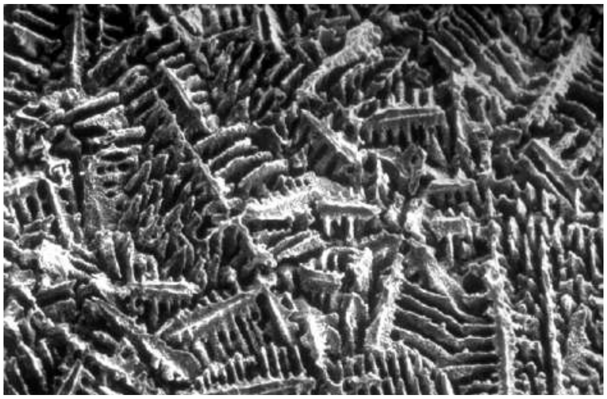

Fig. 26.6 Scanning electron micrograph at 1000× magnification of a nickel-chromium-molybdenum-aluminum-beryllium (Ni-Cr-Mo-Al-Be) alloy electrolytically etched. The microstructure is selectively removed to create a highly undercut surface that can be wetted by hydrophobic composite resins.

that have not been aged and thermally stressed should be viewed skeptically. Even particle abrasion provides initially high resin-to-metal bonds, yet these can degrade to almost zero with time.[29]

Well-researched and tested resin systems for direct adhesion to metal surfaces have now completely supplanted metal etching as retention mechanisms.[30]

A randomized clinical trial found that a one-retainer design outlasted the two-retainer design[31] with a mean service life of 216.5 ± 20.8 months. All single retainer FPDs survived without complications, whereas only 10% of the two-retainer design experienced no complications, and only 50% of the two-retainer design survived after 18 years.[31] There was no statistically significant difference between the two design groups in patient satisfaction or quality of life. However, the individuals with the one-retainer design had a higher satisfaction in cleaning of the prosthesis.[31]

A systematic review and meta-analysis have investigated the failure rate and complications of one retainer with a cantilever and two-retainer resin-bonded FPDs.[32] Failure rates were lower for the cantilever restorations, but there was not a significant difference between one or two retainers in regard to debonding.[32] If the two designs perform with equal success rates, fewer retainers would support the concept of minimally invasive practice.

In an additional study, 211 two-unit cantilevered resin-bonded FPDs were evaluated for 113.2 ± 33.5 months.[33] The cantilevered prostheses replaced both anterior and posterior single missing teeth. The study concluded that the restorations had success, with retention and survival rates of 84.4%, 86.7%, and 90.0%, respectively.[33] The mean service life of both anterior and posterior restorations was 9.4 years, with a higher failure rate in the posterior region.[33]

Ceramic Retainers (Zirconia Cantilever Resin-Bonded Fixed Partial Denture)

High-strength ceramics, particularly zirconia (see Chapter 25), have been used as retainers for resin-bonded FPDs.[34,35] These restorations exhibit better esthetics (Fig. 26.7) than metal retainers, which can discolor thin translucent teeth. Zirconia retainers and connectors can also be larger in size than metal ones since they are tooth colored, yet esthetics will not be compromised by display of metal (Fig. 26.8). The larger-sized retainer and connector can cover more tooth structure to increase the bonding surface area. In the anterior dental arch, zirconia resin-bonded FPD designs have also transitioned from two retainers to one.[34] Through the zirconia cantilever design, clinicians also have more flexibility in selecting which abutment to engage so esthetics and function are optimized. With only one zirconia retainer, a cantilevered pontic restores the edentulous space. The design facilitates hygiene, because floss may pass freely between one proximal contact, slide under the pontic, and clean the abutment tooth. Floss threaders are not needed for cleaning as with two-retainer design. In addition to improved plaque control, the biocompatibility of zirconia is superior to the nickel alloys that have been used historically, and favorable 5- to 10-year clinical performance of zirconia prostheses has been demonstrated.[36–40]

Chemical-Bonding Zirconia Resin-Bonded Fixed Partial Dentures

In the selection process for choosing a composite resin luting agent to bond a zirconia resin-bonded FPD, the following should be taken into consideration. 10-methacryloyloxydecyl dihydrogen phosphate-(MDP)-based primers and MDP-based composite resin cements increase the bond strength between the resin cement and zirconia.[41,42] Zirconia retainers typically have reduced translucency and may minimize the penetration depth of the polymerization light. A dual polymerizing system has some benefits that can be light polymerized as well as have the advantage of a chemical polymerization in areas that the polymerization light cannot reach.

Panavia (Kuraray Dental) resin luting agent contains MDP and has shown excellent bonds to airborne-particle abraded Ni-Cr and cobalt-chromium (Co-Cr) alloys,[43,44] tin-plated gold and gold-palladium alloys,[24,45] as well as zirconia.

Panavia has a tensile bond to etched enamel of 10 to 15 MPa, comparable with that of traditional bis-GMA composite resins with low film thickness (e.g., Comspan, Dentsply Sirona). The combination of metal electrolytic etching, followed by application of an adhesive resin such as Panavia, does not improve the tensile bond to the alloy, and its strength is actually slightly lower than that of the bond of Panavia to base metal alloys that

Fig. 26.8 Optimal esthetic with a large ceramic retainer with a ceramic resin-bonded fixed partial denture.

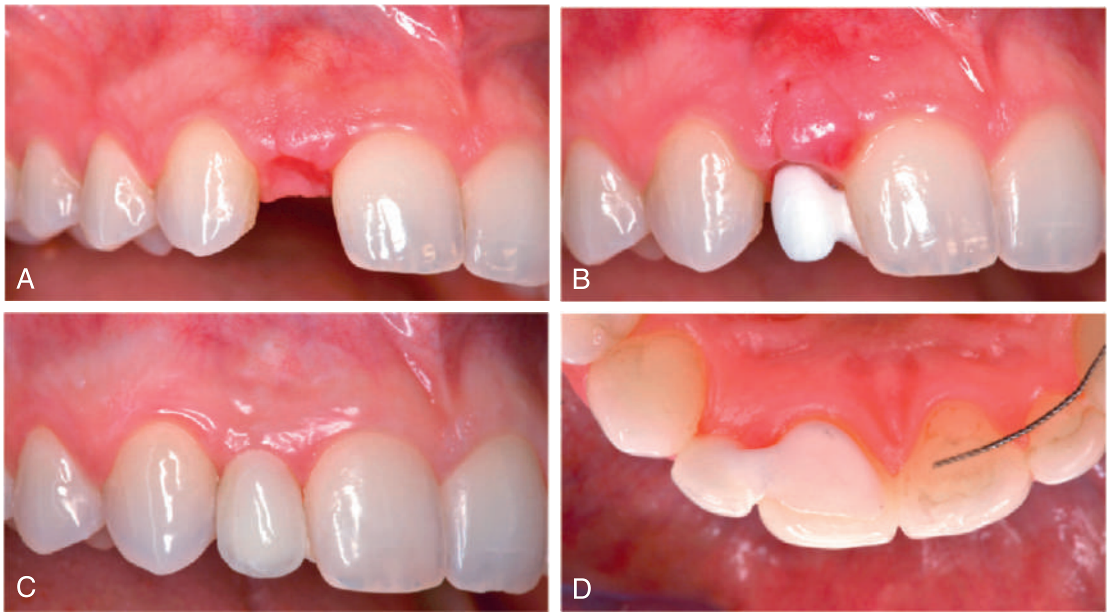

Fig. 26.7 Ceramic resin-bonded fixed partial denture. (A) Missing maxillary lateral incisor. (B) Zirconia framework evaluated intraorally. (C and D) Completed prosthesis. (Courtesy Dr. M. Kern.)

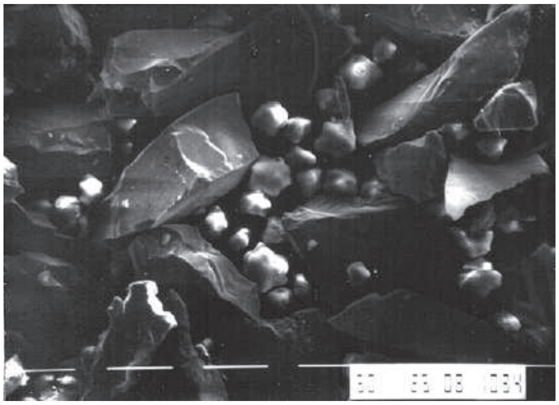

Fig. 26.9 Scanning electron micrograph of airborne abrasion particles (Rocatec Special, 3M ESPE Dental, Norristown, Pennsylvania) composed of a mixture of 50-µm alumina particles *(dark irregular particles)* and smaller silicate particles *(light color)* used for final abrasion of metals, during which a molecular coating of silicate is tribochemically deposited on the metal. This silicate layer on the metal allows reaction with a silane-priming solution for subsequent bonding of resin to the metal.

have been airborne-particle abraded.[46] Panavia V5 is a dual polymerizing system (chemical and visible light) that releases fluoride. It has separate primers that are applied to the tooth and the zirconia. Both primers contain 10-MDP which has been shown to result in improved bonding of zirconia.[39]

Airborne-particle abrasion of the alloy surface with 50-µm alumina before bonding creates a roughened substrate, with greater surface area substrate for bonding, and a molecular coating of alumina.[47] The alumina on the surface aids in oxide bonding of the phosphate-based adhesive systems (e.g., Panavia to alloy surfaces). Studies of this bonding mechanism are reinforced by laboratory data on bonding to alumina and zirconia surfaces.[48–50]

A laboratory method for resin bonding to zirconia, base, and noble metal is the tribochemical silica coating (Rocatec system, 3M ESPE Dental). In this method, the bonding surface is initially airborne-particle abraded with 120-µm alumina particles. This is followed by abrasion with a special silicate particle–containing alumina (Fig. 26.9). This results in a molecular coating of silica and alumina on the zirconia or alloy surface. Silane is then applied, which makes it adhesive to composite resin. Norling and colleagues[51] compared various silane application techniques. Tribochemical silica coating has been compared with Panavia for bonding to a range of surfaces and is adequate in this regard.[28,30,47] For optimal adhesion of zirconia retainers, a pretreatment of tribochemical silica coating on the zirconia coupled with an MDP and silane primer is desirable.[52]

DESIGN CONCEPTS AND PATIENT SELECTION

Since Rochette, the guidelines for optimum design and adhesion of resin-bonded FPDs have been extensively studied. The principle underlying these restorations has always been that it is necessary to cover as much enamel surface as possible, as

Fig. 26.10 Zirconia cantilever resin-bonded fixed partial denture: Note large wing style ceramic retainer with conservative retentive features.

long as occlusion, esthetics, and periodontal health are not compromised. To emphasize the significance of maximum enamel coverage, Crispin et al[53] reported 3-year failure rates of up to 50% with the use of two retainers with small bonded areas and minimally retentive designs. Through the concept of minimally invasive dentistry, resin-bonded FPDs have evolved from a two-retainer to a one-retainer design, independent of the framework material that is used (Fig. 26.10).

To maximize the function of the one-retainer designs, an “interproximal wraparound” concept was developed to resist occlusal forces and provide a broader area for bonding. Enamel preparations consisted of creating occlusal clearance, placing grooves or boxes, and creating a gingival finish line to minimize over contoured morphology and promote gingival health.

Posterior frameworks should have a positive seat in an occlusogingival direction and should have no facio-lingual displacement (Fig. 26.11A). Proximal extensions are created by lowering the lingual and proximal heights of contour somewhat analogous to guide plane preparation for RPDs (see Chapter 21). Contemporary design has improved retention with well-placed and precise grooves on abutment teeth (Fig. 26.11B).

ADVANTAGES

When used appropriately, resin-bonded FPDs offer several advantages over conventional FPDs (Box 26.1). Because of the preparation design, minimal tooth structure needs to be removed. In general, the preparation is confined to enamel only. Because of the conservative nature of the preparation, the potential for pulpal trauma is minimized. Anesthetics are not routinely used during tooth preparation (without anesthesia, it is possible to monitor the proximity of the preparation to the dentin-enamel junction by the patient’s comfort level). In many situations, zirconia retainers offer a larger bonding surface than metal ones since the ceramic can extend close to the incisal edge and wrap around the interproximal areas without spoiling esthetics. The prosthesis can often be kept entirely supragingival; as a result,

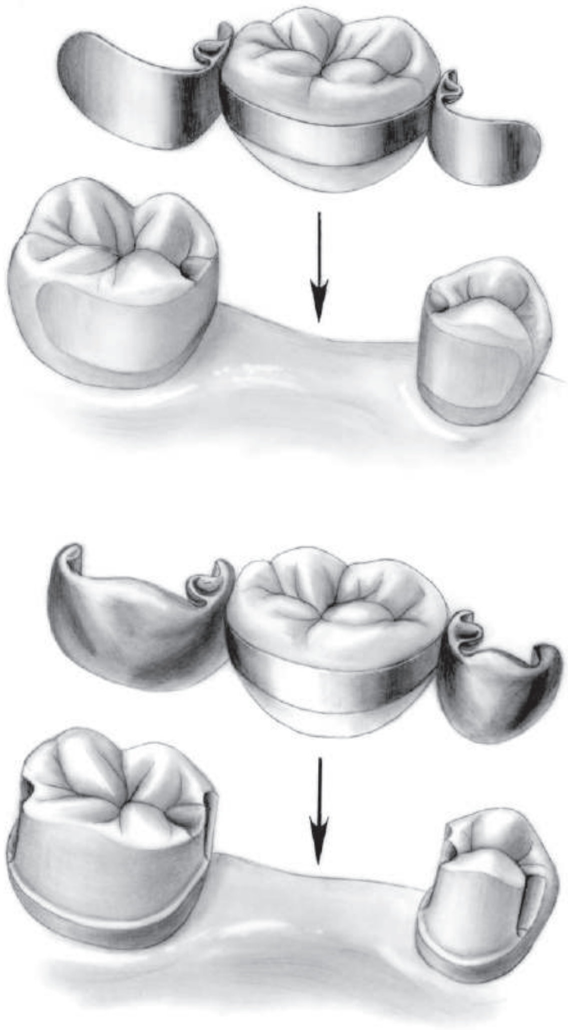

Fig. 26.11 Comparison of initial and contemporary posterior resin-bonded fixed partial denture designs. (A) Original design. Minimal modification of lingual and proximal enamel allowed sufficient buccal extension of the metal. Once seated, the retainer could not be displaced from buccal to lingual. (B) More extensive enamel preparation is now used with proximal grooves at the buccal-proximal line angles of the edentulous space. Note that with this design, the abutment teeth cannot be displaced from the retainer.

periodontal irritation is kept to a minimum. In a periodontal evaluation of restorations that averaged 10 years in service, the periodontal response was not significantly different from that for unrestored contralateral teeth.[54] Only when the retainer gingival margins were less than 0.5 mm from the gingival crest was there a correlation with a detrimental gingival response. Concurrently, impression-making or intraoral scanning is simplified because of the supragingival margins. Because the abutment teeth are, in addition to being nonsensitive, maintained with normal proximal contacts, fabrication of traditional interim restorations (see Chapter 15) is usually not required except for selected patients. However, judicious placement of composite resin is important to maintain occlusal clearances after the definitive impression has been made until the restoration is bonded (Fig. 26.12).[55]

BOX 26.1 Resin-Bonded Fixed Partial Dentures: Advantages, Disadvantages, Indications, and Contraindications

Advantages

Rebonding possible
Minimal removal of tooth structure
Minimal potential for pulpal trauma
Anesthesia not usually required
Supragingival preparation
Easy impression making
Reduced chair time
Reduced patient expense

Disadvantages

Maintenance cost of rebonding or replacement
Enamel modifications: required
Space correction: limited to one tooth as compared to three teeth with a classic fixed partial denture
Good alignment of abutment teeth: required

Indications

Anterior shallow vertical overlap if replacing a maxillary tooth
Replacement of missing anterior teeth in children and adolescents
Patient medical history contraindicates a dental implant
Short edentulous span
Unrestored abutments
Single posterior tooth replacement
Significant clinical crown length
Excellent moisture control

Contraindications

Anterior deep vertical overlap if replacing a maxillary tooth
Parafunctional habits
Long edentulous span
Restored or damaged abutments
Compromised enamel
Significant pontic width discrepancy
Nickel allergy (zirconia framework may be used)

Fig. 26.12 Interim replacement of occlusal stops is crucial whenever they have been removed as a result of enamel recontouring. The composite resin stops shown here were removed when this posterior inlay/onlay resin-bonded fixed partial denture was bonded.

Chair time is significantly reduced in comparison with that for conventional fixed prosthodontic treatment and dental implants. Furthermore, surgical intervention with site development and implant placement is avoided, and consequently the cost incurred by the patient is lower by as much as 50%.[56]

If dislodged, these restorations can often be rebonded, in which case airborne-particle abrasion and adhesive resin systems are used (as long as the debonding occurred with no sequelae involving the abutment teeth). If a two-retainer design is used and one retainer remains bonded, it can be gently loosened with a monobevel, single-ended instrument and a soft mallet. Slight flexure of metal frameworks will cause a crack to propagate through the luting composite resin. The monobevel chisel is positioned at an incisal or occlusal edge at an oblique angle to the long axis of the tooth along a mesial or distal line angle. The mallet should be used lightly (limited by patient response); repeated tapping will cause debonding. However, with mechanically retentive designs, which include grooves and slots, the framework may require sectioning and removal of the individual segments (Fig. 26.13). As an alternative, ultrasonic scalers with special tips are available to help remove partially debonded FPDs.[55] They are applied at the incisal and gingival margins, but the procedure requires a high-power setting and can take considerable time. Since subsequent debonding rates with rebonded restorations are high,[57] preparation design modifications and a new or alternative restoration should be considered.

DISADVANTAGES

The primary disadvantage associated with resin-bonded FPDs concerns their longevity, which is less than that of conventional FPDs. This has been the subject of considerable study. First-generation etched metal FPDs at the University of Iowa (more anterior FPDs than posterior) and at the University of Maryland (more posterior FPDs than anterior), have shown an average service time of more than 10 years. An estimated 50% failure occurred after 250 and 190 months, respectively (see Table 26.1).[17,58,59] These studies also indicate that the rate of debondings does not increase with time.

In a study conducted in a private practice setting, contemporary designs with a mean service time of 6 years achieved a 93% success rate.[5] This differs from the findings in a multicenter study in Europe, in which debonding rates increased with time after placement (almost 50% at 5 years) and were shown to be related to preparation design, luting agent selection, and the area of placement within the dental arch.[60] Another European study revealed retention rates of 60% at 10 years for early designs. In one study, posterior and mandibular resin-bonded FPDs demonstrated higher rates of dislodgment,[61] which may have resulted from occlusal forces (see Chapter 4) and increased difficulty in isolation during the bonding procedure.[57,62] In view of these findings, the possibility of eventual debonding should be discussed with the patient before treatment is initiated. In comparison, a meta-analysis of clinical studies of conventional FPDs indicated a doubling of the failure rate for every 5 years of service from 0 to 15 years.[63] When these results are projected from 15 years to 20 years, the failure rate for conventional FPDs would reach 50% in about 20 years.[59]

Extensive enamel modifications are required with retentive design to the proximal and lingual surfaces of the abutment teeth (see Fig. 26.11B). If the restoration is removed, composite resin bonding could restore the enamel contours, but transition to a more traditional FPD is likely. Because enamel is limited in thickness, precision and attention to detail are necessary in design and preparation.[64] Enamel lingual surfaces of anterior teeth are almost always thinner than 0.9 mm.[65]

Space correction is difficult with resin-bonded FPDs. When the pontic space is greater or less than the dimensions of a normal tooth, achieving an esthetic result with this restoration is challenging. As with conventional FPDs, treatment of diastemata is demanding, although a cantilever option may be appropriate.

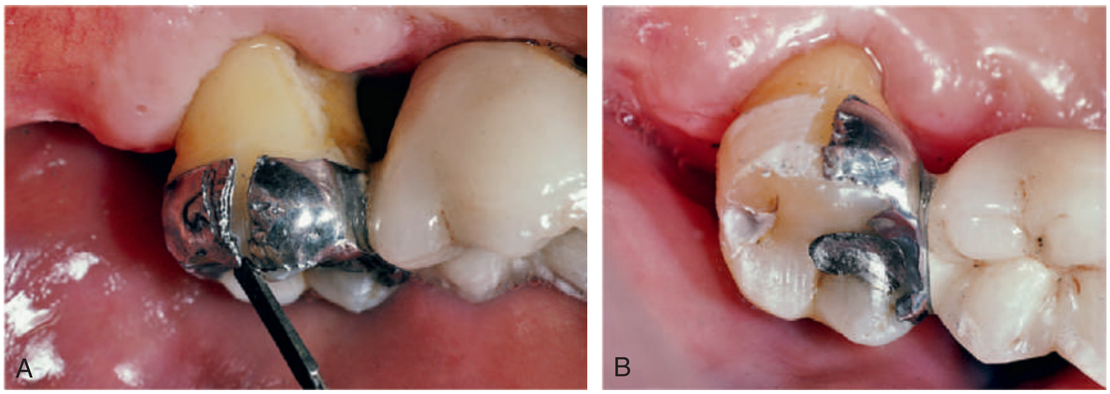

Fig. 26.13 Removal of a retainer with a contemporary design. (A) The retainer has been sectioned with a tungsten carbide bur to allow separation of the mesial and distal retentive features. The monobevel chisel is oriented to provide a wedging action between the metal and the enamel, which allows a crack to propagate through the brittle resin. (B) The cracking of the resin has enabled debonding between the metal and the resin. The mesial retainer half can now be removed in a similar manner. This retainer was removed because of fatigue fracture of the metal at the junction of the pontic metal with the premolar retainer arm (not shown), where the retainer was thinner than 1 mm. The poor periodontal support of the molar abutment allowed considerable lateral movements of the pontic and molar during function.

Good alignment of abutment teeth is required because the FPD's path of placement is limited by the potential risk of penetration of the enamel. However, some posterior teeth, which are mesially or mesiolingually tilted, can receive an onlay that consists of a bonded retainer (Figs. 26.14 and 26.15).

Esthetics is compromised on posterior teeth since the posterior resin-bonded FPD design requires the extension of the metal framework onto the occlusal surface of the teeth. These occlusal rests and occasional onlaying of cusps are visible, which may be objectionable to some patients (see Fig. 26.14).

Clinical indications and contraindications are quite specific. In the presence of any contraindications, a conventional FPD or an implant-supported crown should be considered.

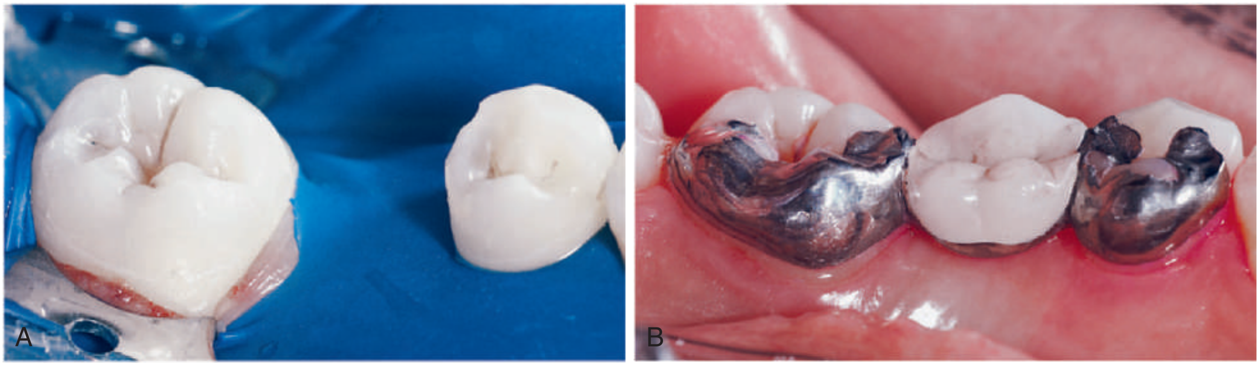

Fig. 26.14 (A) Preparation for large premolar pontic. The first premolar has been prepared with mesial and distal rests and a distobuccal groove. (B) The definitive restoration displays extensive metal on the occlusal surface of the premolar. This may be esthetically unacceptable to some patients.

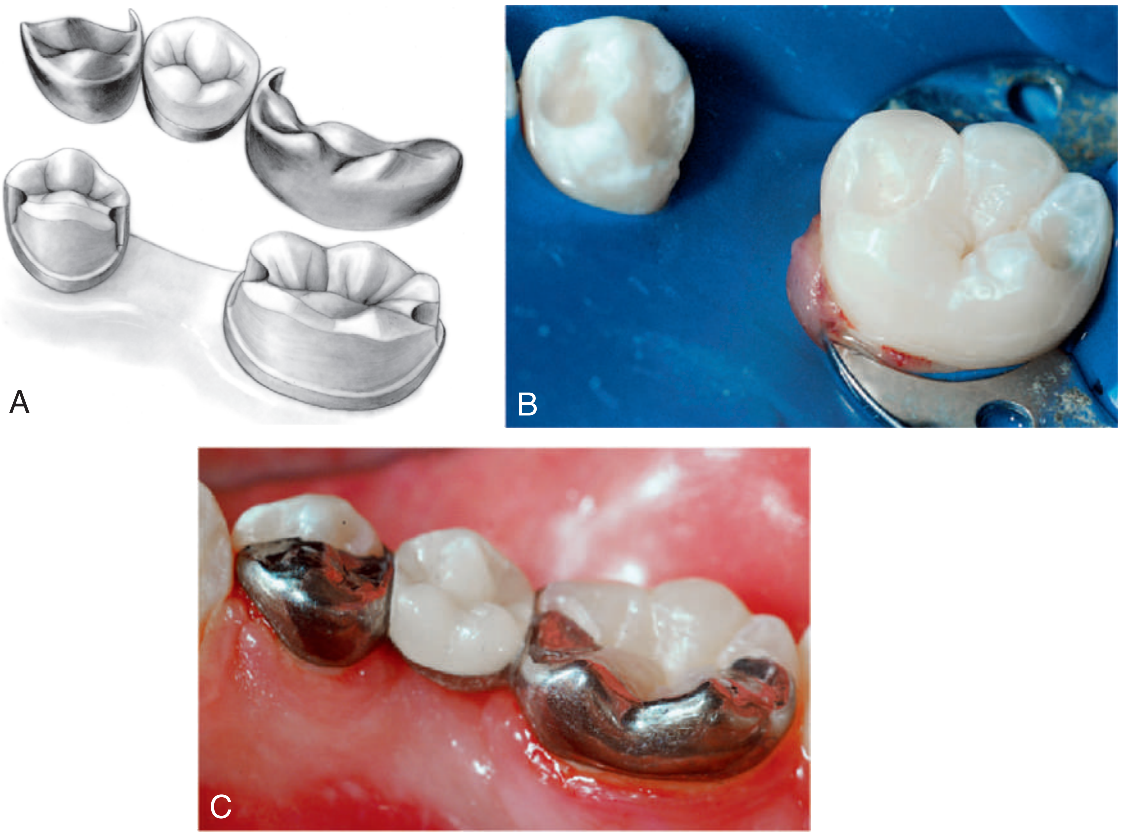

Fig. 26.15 (A) Schematic of a resin-bonded onlay design in a fixed partial denture. A thin veneer of metal is extended onto the occlusal surface of the teeth with approximately 0.5 mm reduction of the enamel where necessary. (B) Preparation of molar and premolar. The lingual cusp of the premolar is covered to add additional mechanical retention on this short clinical crown. (C) Completed restoration. Onlays also could have been placed on the lingual cusps of the molar; however, the mesial and distal rests were deemed sufficient in this situation.

INDICATIONS

In the treatment plan for any FPD, the patient's individual needs must be properly identified. The presence of any existing disease, its causes, and how it relates to the prognosis must be assessed. Periodontal and general dental health must be established.

Resin-bonded restorations have been used for many years to replace missing anterior teeth in children (Fig. 26.16).[15] Conventional fixed prosthodontic techniques are generally contraindicated in young patients because of growth, continuation of passive eruption of the teeth, the large size of the pulps, and the fact that children routinely participate in sports. Overall, the youthful patient has a long life ahead of them and one has to take into consideration how many invasive procedures a patient will undergo over a lifetime. For young patients with a single missing anterior tooth, a zirconia cantilever FPD is a conservative option. Even two anterior teeth with mesial and distal abutments can generally be replaced with two resin-bonded FPDs, both of which have a single retainer bonded to an abutment with a cantilevered pontic.

Fig. 26.16 Teenage patient with congenitally missing maxillary lateral incisor, immediately after orthodontics.

Sound teeth or those with minimal restorations are suitable as abutments with resin-bonded retainers. For bonding to anterior teeth, the presence of interproximal restorations is not necessarily a contraindication. In the posterior region, existing interproximal lesions adjacent to the edentulous space can often be incorporated into the retainer design. Minimal or moderate alloy restorations in the abutment teeth should be replaced with dentin bonding and composite resin, or they too can sometimes be incorporated into the preparation design. The incorporation of a mesio-occlusal amalgam into the retainer design, shown in Fig. 26.17, was placed before the advent of high-strength dentin-bonding systems. The appearance of the restoration at the 9-year recall appointment is also shown.

Clinical studies have demonstrated that successful replacement of single posterior teeth with resin-bonded FPDs.[5,58] Significant clinical crown length should be present to maximize retention and resistance form. In addition, resin-bonding metal retainers can be used for periodontal splinting or post-orthodontic fixation.

Excellent moisture control is critical during cementation. Although these restorations can be used both anteriorly and posteriorly, compromised isolation will adversely affect long-term clinical success.

Patient compliance with frequent, ongoing postoperative appointments is important to ensure early detection of any debonding and associated caries, even though the incidence of caries rates on bonded retainers has been shown to be low.[66,67]

CONTRAINDICATIONS

The apparent advantages associated with resin-bonded FPDs led to use in inappropriate circumstances, and associated failures reduced confidence in the technique. Four principles are fundamental to achieve predictable results with resin-bonded FPDs: proper patient selection, correct enamel modification to achieve prosthetic space, framework design, and using a bonding protocol that is compatible with the framework material and

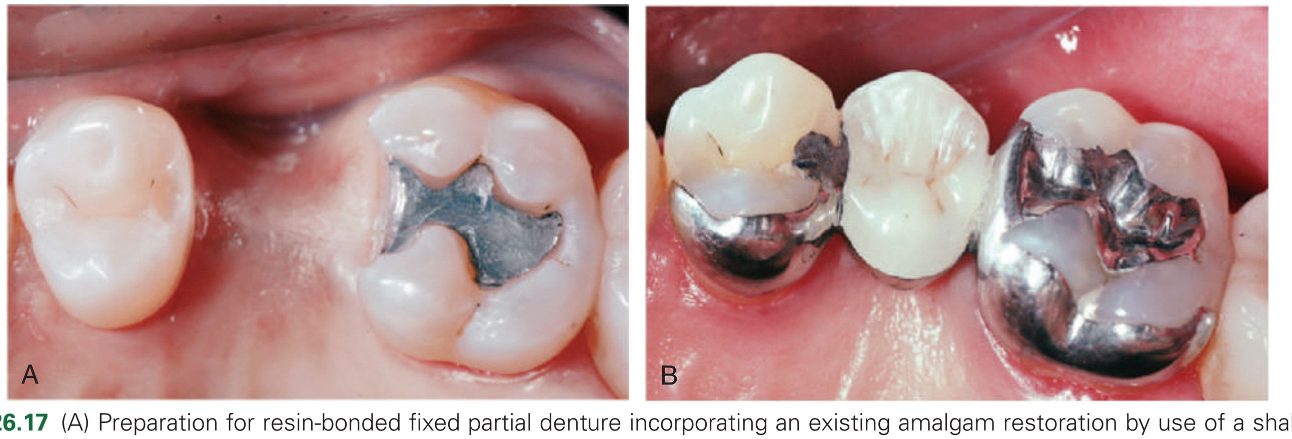

Fig. 26.17 (A) Preparation for resin-bonded fixed partial denture incorporating an existing amalgam restoration by use of a shallow inlay preparation, in which the amalgam reduction is short of the depth of the dentoenamel junction (with current dentin-bonding technology, a composite resin base would be substituted for the amalgam). Note the shallow distal rest on the premolar and the lack of mesiolingual slot/groove preparation on the premolar abutment. (B) Appearance of the restoration at 9-year recall appointment, in which luting resin is still present as a sealant in the molar lingual groove.

tooth substrate. If any contraindications are present, the patient should be informed of the increased risk of potential debonding requiring further discussion of treatment alternatives.

Although not necessarily contraindicated in the presence of parafunction, cautious evaluation of loads to which these prostheses will be subjected is warranted because these retainers are less resistant to displacement than conventional FPD retainers. Similarly, in the absence of posterior support, or other situations where above-average lateral forces can be reasonably anticipated, all possible means to enhance framework retention and resistance (grooves, boxes, occlusal rests, interproximal wrapping of metal; see Fig. 26.11B) should be used. Patients should be cautioned about potential debonding. Bonded periodontal splints can also be fabricated, but they necessitate strict attention to mechanical retention.[68,69]

Resin-bonded prostheses are generally contraindicated for long edentulous spans because the associated excessive loads are more likely to exceed the adhesive and retentive properties of the retainers.

Retention is dependent on adequate enamel surface area, sufficient coronal bulk, and height to permit proximal reshaping and placement of grooves and finish lines. This is challenging on teeth with short clinical crowns (Fig. 26.18). Surgical crown lengthening may then be indicated as subgingival margins must be avoided.

Fig. 26.18 Minimal clinical crown length is available for adequate retention as a result of hyperplastic gingival tissue on the maxillary canines. Surgical crown lengthening is indicated.

Extensively restored and damaged teeth are contraindications for resin-bonded prostheses. Compromised enamel on abutment teeth as a result of hypoplasias, demineralizations, or congenital problems (e.g., amelogenesis imperfecta or dentinogenesis imperfecta) adversely affect resin bond strength.[70]

Edentulous spaces that are larger or smaller than normal tooth size often present a challenge. However, with a cantilever design, diastemas can be maintained if esthetically desired. The labiolingual thickness of anterior abutment teeth and the associated translucency of tooth enamel should be evaluated to anticipate the probability of color change of the abutment teeth. For instance, reduced tooth translucency can be caused by the metal retainers.[71,72] This can be minimized through the use of zirconia retainers that do not extend to the incisal edge. Translucent resins optical couple the ceramic to non-stained, translucent teeth. A trial insertion of the zirconia with water between the retainer and the tooth can be helpful to preview the potential opacifying impact. Similarly, use of trial resins can be useful when custom staining of a pontic of a resin-bonded FPD is necessary to help visualize the final shade of the abutment teeth (Fig. 26.19).

Before the introduction of zirconia, nickel-based alloys were the primary framework material for resin-bonded FPDs. Nickel allergies should be identified, and affected patients offered an alternative.[73] Tin plating and laboratory-applied bonding systems permit the use of noble alloys. However, the lower elastic modulus of most noble alloys requires increased metal thickness by approximately 30% to 50% so noble metal framework rigidity is equal to that of base metal.[74] This is an important consideration in treatment planning as it influences the amount of occlusal clearance required (which is critical in patients with an increased vertical overlap).

FABRICATION

In the fabrication of resin-bonded FPDs, attention to detail in the following three phases is necessary for predictable success:

1. Preparation of the abutment teeth
2. Design of the restoration
3. Bonding

Fig. 26.19 (A) Evaluation of resin-bonded fixed partial denture for characterization of the pontic. Graying of the central incisor abutment is extensive when translucent resin optically couples the dark metal to the tooth. (B) Use of opaque resin prevents the darkening of the abutment and raises the value slightly. Opaque and translucent resins can be combined to provide the correct shade for the abutment; the pontic can then be characterized accordingly.

Abutment Preparation

John Locke

A cantilever pontic design for resin-bonded FPDs is recommended. This has been successful in the anterior region[75] and is particularly useful for replacement of lateral incisors, for which cantilevers from either the central incisor or canine are possible. The choice is based on providing the best retention and the best esthetics (Fig. 26.20). When properly designed, the cantilever approach has been shown to have better fatigue bond strength than a two-abutment design.[76]

Cantilevered designs have significant advantages:

- The preparation is simplified.
- The problems associated with the occlusion and differing mobilities of abutment teeth, which tend to place excessive stresses on the cement and retentive features, are avoided. Cantilevered resin-bonded FPDs work well on mobile teeth.
- If a cantilevered resin-bonded FPD with a single abutment becomes loose, it falls out of the mouth. The dentist can then reassess the situation in terms of occlusion, retentive features, and cementation. A much more difficult situation is if a resin-bonded FPD becomes loose at one end. Many patients return to the dentist only when caries is established under the loose abutment. A cantilevered resin-bonded FPD is either cemented in place or not. The risk to the patient of caries under a loose retainer is eliminated.

The most effective way to replace a missing mandibular incisor with a resin-bonded FPD is an FPD cantilevered from the adjacent tooth. If two mandibular incisors are being replaced, it is recommended that two separate FPDs are made. Connecting the pontics increases the risk of failure (Fig. 26.21).

On an anterior abutment, the preparation for the retainer is similar in many ways to a labial porcelain laminate veneer, except it is on the lingual surface. The enamel must be preserved. Where possible, the retainer can extend onto both the mesiolingual and distolingual surfaces to improve resistance and retention.

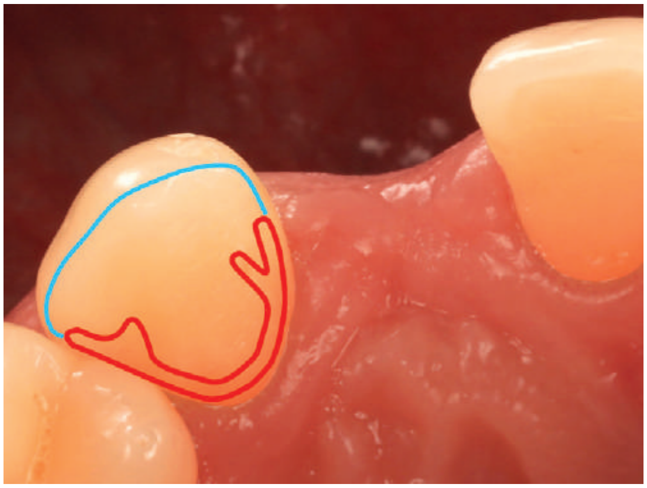

Fig. 26.20 Preparation design for a zirconia cantilever resin-bonded fixed partial denture. The *red lines* mark areas of tooth preparation. A gingival finish line minimizes over contouring the retainer and to promote gingival health. Shallow but broad grooves deliver a positive seat during cementation. The *blue line* highlights the incisal extension of the retainer.

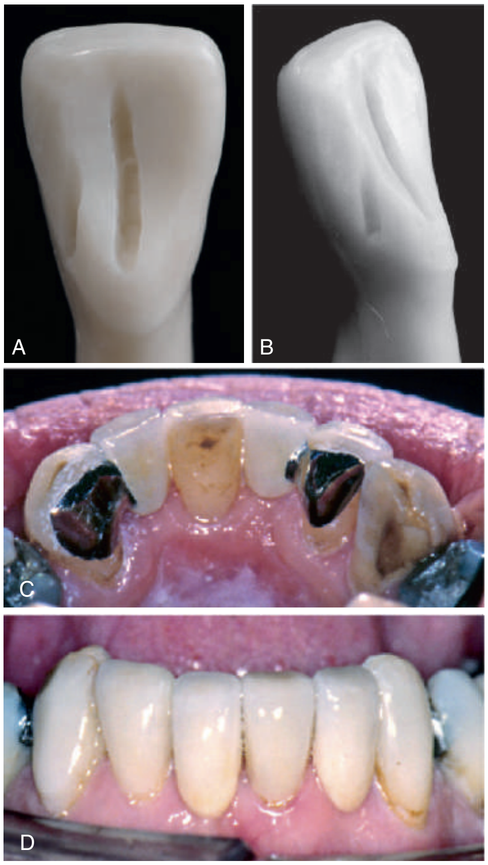

Fig. 26.21 Replacement of missing mandibular incisors. (A) Alternative preparation design with deep mechanical retentive grooves. (B) Proximal view of similar preparation. (C and D) Completed prostheses.

Zirconia is the current material of choice. Frameworks made of zirconia are strong and have minimal complications with fractures. Minimal zirconia thickness is 0.7 mm.

Often, opposing teeth can be recontoured to increase interocclusal clearance. There must be sufficient enamel area for successful bonding, and the ceramic retainer(s) must encompass enough tooth structure and have light resistance form to aid in seating the prosthesis in the correct position during cementation (Fig. 26.22).

Step-by-Step Procedure

1. On the lingual surface of the abutment, create 0.7 to 1.0 mm of occlusal clearance. Minor enameloplasty may be performed on the opposing tooth to preserve enamel for bonding to the abutment.
2. A small gingival finish line to define the termination of the retainer is done. The finish line can be placed with a #6 round diamond rotary instrument to develop a light chamfer.
3. An additional groove is placed on the interproximal surface next to the pontic space. This groove extends vertically from the gingival margin and exits on the lingual side of the incisal edge. The size and shape of the grooves are critical for retention. Large grooves are less effective, but they need to be wide enough so that the milling unit can mill the zirconia retainer. An ideal groove is shaped with a parallel round tipped cylinder fine diamond rotary instrument. The length of this groove can vary considerably, depending on the size of the

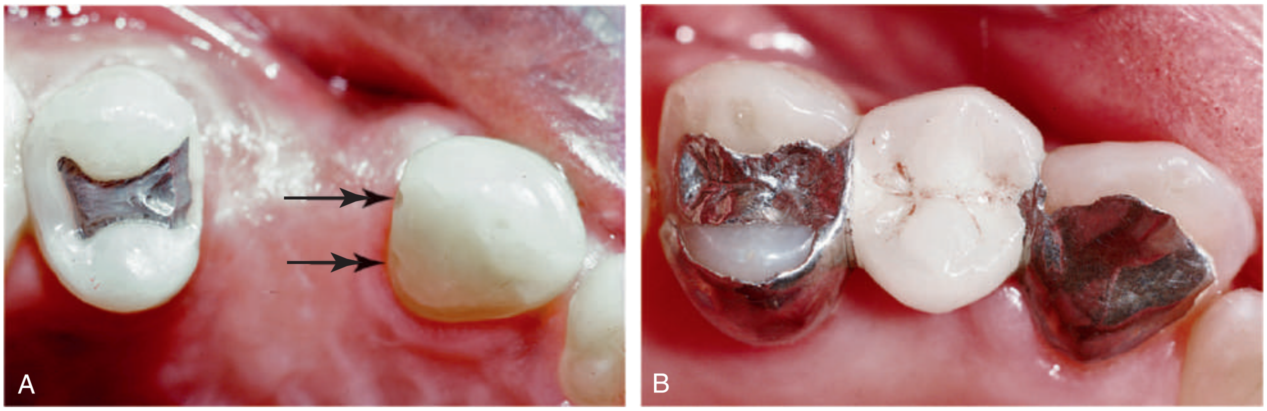

Fig. 26.22 (A) Incorporation of an amalgam restoration into a resin-bonded fixed partial denture (FPD). Note the margin placement at the gingival level, the use of two distal grooves *(arrows)*, and a distinct gingival finish line on the canine abutment. (B) Another resin-bonded FPD with an inlay component.

interproximal surface. The position of this groove is usually more lingual to avoid involving or undermining the incisal enamel.

4. Make an accurate scan or impression. Marginal fit is as crucial for a resin-bonded restoration as for a conventional FPD. Bond strengths are reduced with thick resin layers.[77]
5. Provide interim occlusal stops. Significant supraocclusion of the abutment teeth can occur rapidly, particularly in younger patients and in patients with reduced periodontal support. This can be avoided on anterior teeth by placement of a small amount of composite resin on the opposing mandibular teeth. This is rarely needed for posterior teeth unless significant onlays are planned for the abutment (in which case small composite resin stops can be bonded to the enamel; see Fig. 26.12). The resin is removed just before placement of the resin-bonded FPD.

■ ■ ■

Posterior Tooth Preparation and Framework Design

The basic framework for the posterior resin-bonded FPD consists of three major components: the occlusal rest (for resistance to gingival displacement), the retentive surface (for resistance to occlusal displacement), and the proximal wrap and proximal slots (for resistance to torquing forces; see Fig. 26.11B).

A spoon-shaped occlusal rest seat, similar to that described for a partial removable partial denture (see Chapter 21), is placed in the proximal marginal ridge area of the abutments adjacent to the edentulous space. An additional rest seat may be placed on the opposite side of the tooth (see Fig. 26.14). The rest is an important retention feature and simultaneously provides resistance to both occlusal and lateral forces. It should be designed to function as a shallow "pin."

To resist occlusal displacement, the restoration is designed to maximize the bonding area without unnecessarily compromising periodontal health or esthetics. Proximal and lingual axial surfaces are reduced to lower their height of contour to approximately 1 mm from the crest of the free gingiva. The proximal surfaces are prepared so that parallelism results without undercuts. In the interproximal area, a gingival chamfer margin is not desirable; a knife-edge margin is better to avoid enamel penetration. Occlusally, the framework should be extended high on the cuspal slope, well beyond the actual area of enamel recontouring (provided that it does not interfere with the occlusion) (Fig. 26.23).

Resistance to lingual displacement is more easily managed in the posterior region of the mouth. A single path of placement should exist. The framework should be designed to engage at least 180 degrees of tooth structure when viewed from the occlusal aspect. This proximal wrap enables the restoration to resist lateral loading by engaging the underlying tooth structure and is assisted by grooves in the proximal surface just lingual to the buccal line angle. Distal to the edentulous space, retainer resistance

Fig. 26.23 (A) Preparation for a maxillary premolar prosthesis. A groove has been placed at the mesial extension of the premolar retainer arm to eliminate the use of a mesio-occlusal rest. This could compromise esthetics. Note that the lingual groove preparation on the molar extends gingivally as the preparation is carried down the buccal slope of the groove, which adds mechanical retention. (B) The completed prosthesis.

is augmented by a groove at the linguo-proximal line angle. Moving a properly designed resin-bonded FPD in any direction except parallel to its path of placement should not be possible, nor should it be possible to displace any tooth to the buccal aspect from the framework (see Figs. 26.11B; 26.14; and 26.23).

In general, preparation differences between maxillary and mandibular molar teeth exist only on the lingual surfaces. The lingual wall of the mandibular tooth may be prepared in a single plane. The lingual surface of the maxillary molars requires a two-plane reduction because of occlusal function and the curvature of these functional cusps in the occlusal two-thirds. However, the mandibular lingual retainer may be carried over the lingual cusps to augment resistance and retention form, which is particularly helpful on short clinical crowns of mesially and lingually inclined molars (this extension may necessitate a two-plane modification[64,78]; see Fig. 26.15).

A wide range of extensions of the casting onto the occlusal surfaces of posterior teeth is possible. They include shoeing of cusps, encircling of cusps, and extensions of metal through the central fossa in a mesial-to-distal direction with the lingual cusps exposed. The clinician is limited only by imagination, available enamel, occlusion, and any resulting display of metal that the patient will accept. Several examples of preparations and restorations are presented in Figs. 26.22 and 26.24.

Periodontal splinting is the most demanding of the restoration designs; splints and splint-FPD combinations necessitate care in designing adequate mechanical retention. An example of a multiple-rest design with interproximal extension of the metal is shown in Fig. 26.25. The posterior splint-FPD combination entails the use of multiple rests and distinct mechanical retention of the abutment in the retainer, which can be important when the abutment is the most distal tooth in the arch (Fig. 26.26). Anterior splints must engage as much enamel as possible to enhance retention (Fig. 26.27), which can be complicated in the absence of optimal tooth alignment.

Laboratory Procedures

1. The zirconia framework is fabricated with CAD-CAM technology. Design the framework to wrap around the abutment to maximize the surface area of the retainer (Fig. 26.28A). The pontic design must support the ceramic veneer (Fig. 26.28B).
2. The minimal dimensions for a zirconia retainer are 3 mm in height and 2 mm in width.
3. Build up the pontic in porcelain, fire and contour it.
4. Evaluate the restoration clinically; when the fit is satisfactory, characterize and glaze it. Evaluation pastes are helpful to evaluate abutment value. Depending on resin opacity and tooth translucency, abutment value may be decreased, even with tooth-colored ceramics.
5. Place the prostheses in a small plastic bag with alcohol and place in an ultrasonic cleaner for 5 minutes.
6. Clean the fitting surface with an airborne-particle abrasion unit, using aluminum oxide (50 µm at 0.3 MPa [40-psi] pressure).
7. Tribochemical silicate coat the adhesive surface. Do *not* re-evaluate in the mouth.

Bonding the Restoration

Cements (Bonding Agents)

Composite resins play an important role in bonding the ceramic or metal framework to etched enamel. A variety of resin adhesives have been introduced specifically for this purpose. As for any adhesive luting system, the manufacturer's instructions must be closely followed to maximize the cemented restoration's prognosis (Fig. 26.29).

Conceptual Step-by-Step Bonding Procedures With Adhesive Cement

Major finishing, polishing, and occlusal adjustments should be performed before the restoration is bonded. The tensile strength of the bonded FPD can be adversely affected by the heat or vibrations produced with rotary instruments.[79]

1. Clean the teeth with pumice and water. Isolate them with the dental dam, and acid etch the enamel with 37% phosphoric acid for 30 seconds. Rinse, dry, and maintain air drying until the primer is applied (Fig. 26.29A).
2. Follow the manufacture instructions for a dual polymerizing resin composite cement that contains MDP. A hybridized layer needs to be formed on the zirconia and tooth interface before receiving the resin cement. Again, it is imperative to follow manufacturer instructions. Each manufacturer has their own proprietary recommended technique.

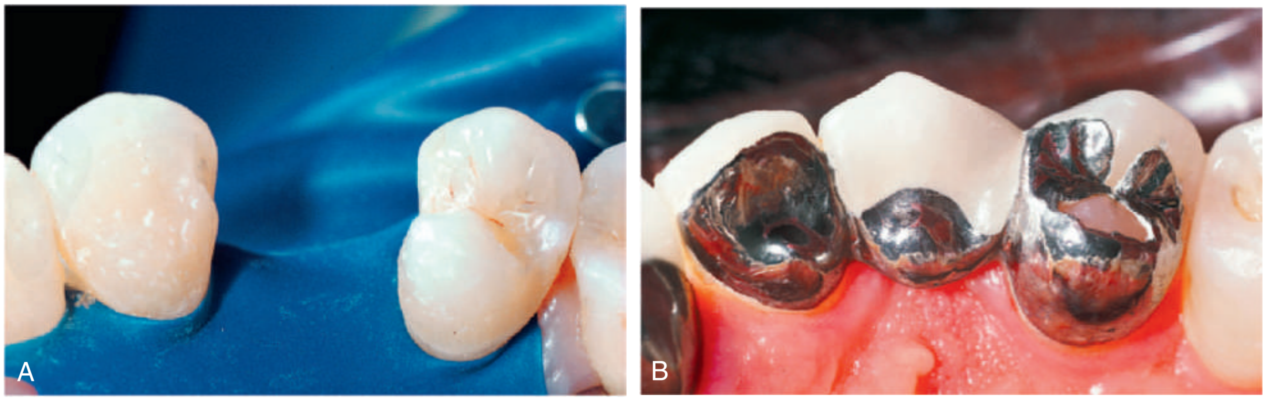

Fig. 26.24 (A) Preparations for a premolar resin-bonded fixed partial denture. The distal aspect of the canine had a small class III composite resin restoration. This has been replaced and modified to create a distal slot for the retainer. The premolar has both mesial and distal occlusal rest preparations. (B) Bonded prosthesis. The gingival margin of the restoration is very close to the free gingival crest (the ideal is 1 mm above the gingival crest). Meticulous plaque control is essential.

Fig. 26.25 (A) One portion of the mandibular arch with teeth prepared as abutments for a resin-bonded splint replacing the mandibular incisors. Here both mesial and distal rests are used, in addition to extending the preparation into the proximal contact area. (B) A bonded restoration. The extension to the second premolar was intended to help stabilize these mobile teeth, on the basis of a consultation with the periodontist. (C) The completed restoration. The use of multiple rests on each posterior abutment is evident.

Fig. 26.26 Long-term recall of a resin-bonded fixed partial denture. Particular care has been exercised in providing mechanical engagement of the second premolar, which is the most distal abutment in the arch.

Fig. 26.27 Anterior splint, viewed at 12-year recall appointment. Note the extension of the metal to engage as much lingual enamel as possible, extending over marginal ridges and into the interproximal areas wherever possible.

3. Apply the resin cement onto the retainer and a small amount on the tooth. Seat the FPD firmly and maintain pressure while removing the excess resin cement with a microbrush.
4. Have the assistant floss the proximal contact to remove excess cement while the FPD is held still in its seated position.
5. Tack polymerized resin for 2 seconds with a composite resin polymerization light and remove any residual cement with a sharp hand instrument.
6. Apply glycerin over the abutment and zirconia retainer to eliminate the oxygen inhibited layer at the cement interface.
7. Finalize the polymerization with the light on all surfaces.
8. Polish the resin cement interface with polishing points and diamond paste to minimize bacterial adhesion. Rough, unpolished composite resin cement margins form more colonies of bacteria than polished ones.

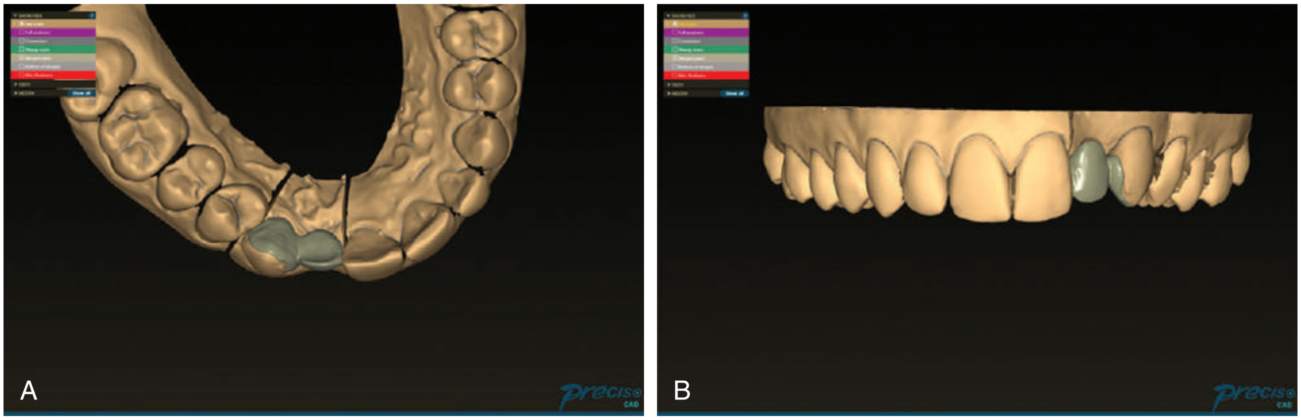

Fig. 26.28 Digital design of zirconia ceramic retainer. (A) Evaluation of retainer and connector dimensions. (B) Evaluation of the dimensions of the pontic to support the veneering ceramic.

Fig. 26.29 Bonding procedures with an adhesive resin. (A) Preparation of an anterior resin-bonded fixed partial denture with mesial and distal groove retention, which was based on the presence of incisal wear facets. Note the use of dental dam for moisture control. (B) Dispensing system for anaerobic-setting adhesive composite resin paste. (C) Use of both opaque and translucent composite resin with the opaque resin on the lingual aspect and the translucent resin in the interproximal aspect for esthetics. (D) The restoration has been seated, and the excess resin has been removed while the resin between the retainers and the enamel polymerizes anaerobically. The margin resin and excess have not polymerized. (E) Oxygen-barrier gel is applied for polymerizing the margin resin. (F) The definitive restoration, which was cast from a high–gold content alloy and then tin plated. To provide good mechanical retention, the casting is increased in thickness by 50%, in comparison with a higher stiffness (elastic modulus) base metal alloy.

Occlusion

The occlusion is adjusted so that there is a centric stop on the pontic but minimal, if any, contact in excursive movements. Other existing occlusal contacts on the abutment teeth are maintained (Fig. 26.30). Occlusal contact on the retainers is ideally in the direction of the path of placement of the prosthesis rather than oblique to it.

Fig. 26.30 Evaluation of occlusion after the zirconia resin-bonded fixed partial denture has been adhesively retained. The occlusion cannot be confirmed before cementation.

POSTOPERATIVE CARE

All resin-bonded restorations should be carefully evaluated at regular maintenance examinations (see Chapter 31). In the event a bonded prosthesis being dislodged, patients need to be seen as soon as possible to rebond the prosthesis before adjacent teeth have the opportunity to migrate. Even minimal tooth movement can prevent the FPD from re-seating. When addressed promptly, however, the failure can be managed by simply re-bonding the prosthesis. Rebonding appointments are low stress and economical for the patient in comparison to other types of catastrophic failures seen with dental implants and conventional FPDs.

With a two-retainer design, partial debonding can occur without complete dislodgement of the prosthesis; visual examination and gentle pressure with an explorer should be performed to confirm the diagnosis. Because debonding is most commonly associated with masticating hard foods,[80] patients should be warned about this danger. If the patient perceives any changes in the restoration, he or she should seek early attention. Early diagnosis and treatment of a partially debonded FPD can prevent significant complications.[80] Fig. 26.31 describes the management of a patient with a loose two-retainer resin-bonded FPD.

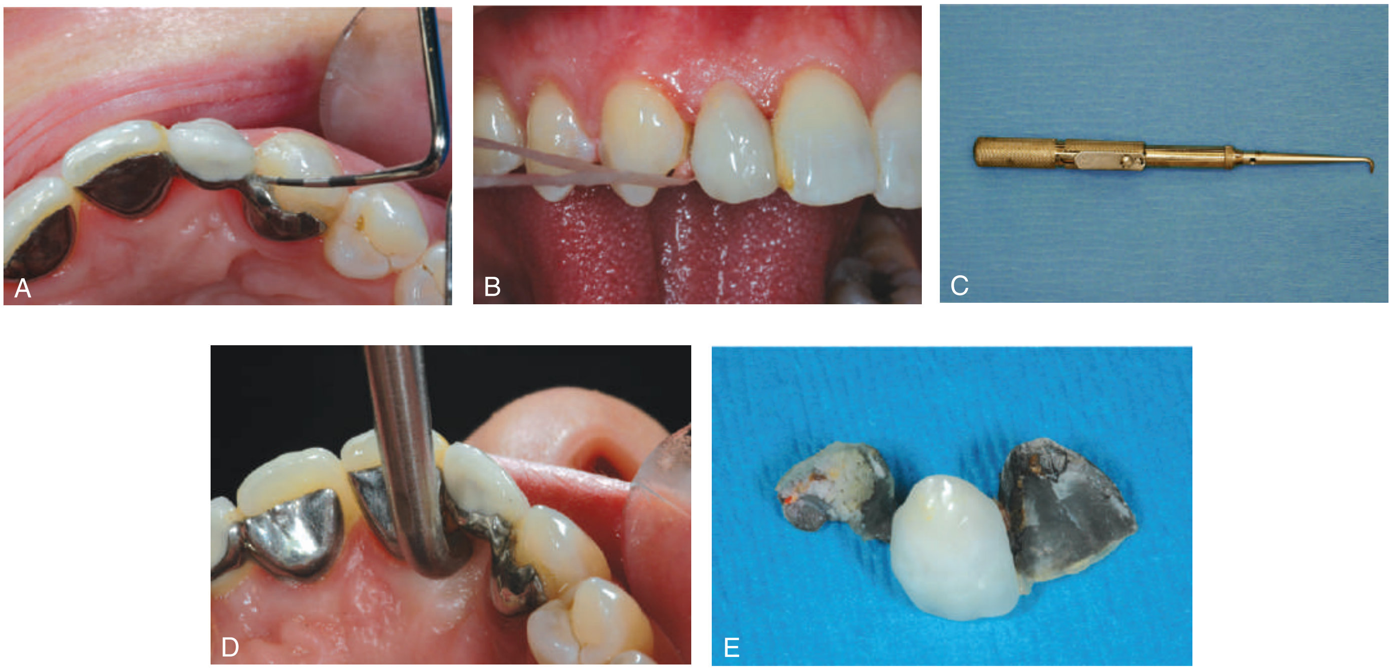

Fig. 26.31 (A) Patients with resin-bonded fixed partial dentures (FPDs) need to be cautioned that a loose retainer is a dental emergency and immediate attention is essential. A bonding failure of one retainer of a two-retainer FPD was confirmed. The second retainer was still firmly bonded and retained the FPD. (B) As an important safety measure, floss must be tied to the FPD and the opposite end of the floss should be held by an assistant, avoiding aspiration if dropped. (C) A spring-loaded crown remover is used to remove the remaining bonded retainer with an accelerated tap. When a firm quick snap is applied directly to a 100% bonded surface and not against the tooth, the resin bond will fail. (D) The spring-loaded crown remover is engaged at the connector. The handle of the crown remover is held parallel with the long axis of the abutment so that the force is not applied against to tooth but down its long axis. (E) Failed resin-bonded FPD removed from its abutments.

Fig. 26.31 Cont'd (F) Lingual bonding surface of the maxillary canine abutment that had failed. If patients are not educated about the importance of coming in to see their dentist when a bonded retainer comes loose, caries may form under the failed retainer. The patient was seen soon after the FPD failed, and no caries was detected. (G) Lingual bonding surface of maxillary central incisor abutment immediately after removal of failed FPD. Note the minimal preparation and conservation of enamel for bonding. (H) The original resin-bonded FPD after airborne-particle abrasion and acid etching. (I) Soft red wax placed in the gingival embrasure areas to prevent bonding agents from penetrating difficult to clean areas after bonding. (J) Rebonded FPD. The procedure was a low stress, time efficient, and economical solution.

Debonded restorations can often be rebonded successfully. The bonding surface and the abutment should be cleaned with airborne-particle abrasion, followed by etching. If a prosthesis debonds more than once, reevaluation of the occlusion, the bonding protocol, and preparation design should be done. If the prosthesis itself is damaged, remaking the FPD is usually necessary.

In prosthesis design, it is important to allow proper maintenance of periodontal health. These retainers have the potential of accumulation of excess plaque because of lingual over-contouring and the gingival extension of the margins.[54] The patient should be taught appropriate plaque-control measures (see Chapter 31). Calculus removal should be done cautiously to reduce the risk of debonding.

REVIEW OF TECHNIQUE

The following list summarizes the steps involved in preparation and placement of a resin-bonded FPD:

- Eligible patients are those with sound abutments with minimal or no restorations. Occlusion must be stable.
- Tooth preparations consist of creating a large lingual enamel bonding area with proximal wrap.
- An accurate scan or elastomeric impression material should be used.
- Careful laboratory technique is necessary to ensure a well-fitting and esthetic framework.
- Specially formulated resin-luting agents that are capable of adhering to zirconia or the prescribed alloy should be used to bond the prosthesis.

SUMMARY

Conservation of tooth structure is one of the fundamental biologic principles of tooth preparation for fixed prosthodontics. This is the primary advantage of resin-bonded FPDs. Precision and attention to detail are just as important for resin-bonded FPDs as for any other fixed prosthodontics procedure. To provide a durable and lasting prosthesis, enamel must be conserved, and an appropriate adhesive system and protocol selected. When executed with appropriate care, the results can be very rewarding. Careful patient selection is critical to achieve clinical success, and patient education is equally important to ensure prosthesis longevity.

STUDY QUESTIONS

1. Discuss the indications and contraindications of resin-bonded FPDs.
2. When the replacement of a congenitally missing lateral incisor with a resin-bonded FPD is planned, a cantilevered design is considered. Is a single-abutment design better or worse than a two-abutment design? Why?
3. What is the typical mode of failure of a resin-bonded FPD? How is the failure managed?
4. List the various bonding techniques used for resin-bonded FPDs. Which one is currently recommended for the zirconia cantilever resin-bonded FPD? Why?
5. Discuss the tooth preparations needed for anterior resin-bonded FPDs. How does the preparation differ for posterior abutments?

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27

Connectors for Fixed Partial Dentures

Connectors are the components of a fixed partial denture (FPD) or splint that join the individual retainers and pontics together. Usually this is accomplished with rigid connectors (Fig. 27.1), although nonrigid connectors are occasionally used. The latter are usually indicated when it is impossible to prepare a common path of placement for the abutment preparations for an FPD (Fig. 27.2A and B). Their use has been reported to be associated with significantly reduced failure rates.[1]

RIGID CONNECTORS

Rigid connections in metal can be made by casting, milling, laser sintering, soldering, or welding. Cast connectors are shaped in wax as part of a multiunit wax pattern. Milled or laser-sintered connectors are shaped in the computer processing when computer-aided design and computer-aided manufacturing (CAD-CAM) is used.[2] Cast connectors are convenient and minimize the number of steps involved in the laboratory fabrication. However, the fit of the individual retainers may be adversely affected because distortion more easily results when a multiunit wax pattern is removed from the die system. Soldered connectors involve the use of an intermediate metal alloy whose melting temperature is lower than that of the parent metal (Fig. 27.3). The parts being joined are not melted during soldering but must be thoroughly wettable by liquefied solder.[3] Dirt or surface oxides on the connector surfaces can interfere with wetting and impede successful soldering; for example, the solder may melt but does not flow into the soldering gap. Welding is another method of rigidly joining metal parts. In welding, the connection is created by melting adjacent surfaces that are often in contact with each other, with heat or pressure. A filler metal whose melting temperature is about the same as that of the parent metal can be used in welding.

In industrial metalworking, a distinction is made between *soldering*, in which the filler metal has a melting point below 450°C (842 °F), and *brazing*, in which the filler has a melting point above 450°C.[4] Rigid connections in dentistry are generally fabricated at temperatures above 450°C, but the process has almost always been referred to in the dental literature as *soldering*. However, in a proposed international standard, the term *brazing* is used. With time, the latter term may become more generally accepted. In this text, however, the term *soldering* is used.

NONRIGID CONNECTORS

Nonrigid connectors are indicated when it is not possible to prepare two abutments for an FPD with a common path of placement. Segmenting the design of large, complex FPDs into shorter components that are easier to replace or repair individually is advisable. This can be helpful if an abutment's prognosis is uncertain. If the abutment fails, only a portion of the FPD may need to be remade. In the mandibular arch, nonrigid connectors are indicated when a complex FPD consists of anterior and posterior segments. During the mandibular opening and closing stroke, the mandible flexes mediolaterally.[5,6] Rigid FPDs have been shown to inhibit mandibular flexure, and extensive splints have been shown to flex during forced opening.[7,8] The associated stresses can cause dislodgment of complex FPDs. Segmenting complex mandibular FPDs can minimize this risk (Fig. 27.4).

Nonrigid connectors are generated through incorporation of prefabricated inserts in the wax pattern or through custom milling procedures after the first casting has been obtained. The second part is then custom fitted to the milled retainer and cast. They are often made with prefabricated plastic patterns. The retainers are then cast separately and fitted to each other in metal.

CONNECTOR DESIGN

The size, shape, and position of connectors all influence the success of the prosthesis. Connectors must be sufficiently large to prevent distortion or fracture during function but not too large; otherwise, they interfere with effective plaque control and contribute to periodontal breakdown over time. Adequate access (i.e., embrasure space) must be available for oral hygiene aids cervical to the connector. If a connector is too large incisocervically, hygiene is impeded, and over time, periodontal failure will result (Fig. 27.5A). For esthetic FPDs, a large connector or inappropriate shaping of the individual retainers may result in display of the metal connector, which may compromise the appearance of the restoration and cause patient dissatisfaction (see Fig. 27.5B).

In addition to being highly polished, the tissue surface of connectors is curved faciolingually to facilitate cleaning. Mesiodistally, it is shaped to create a smooth transition from one FPD component to the next. A properly shaped connector

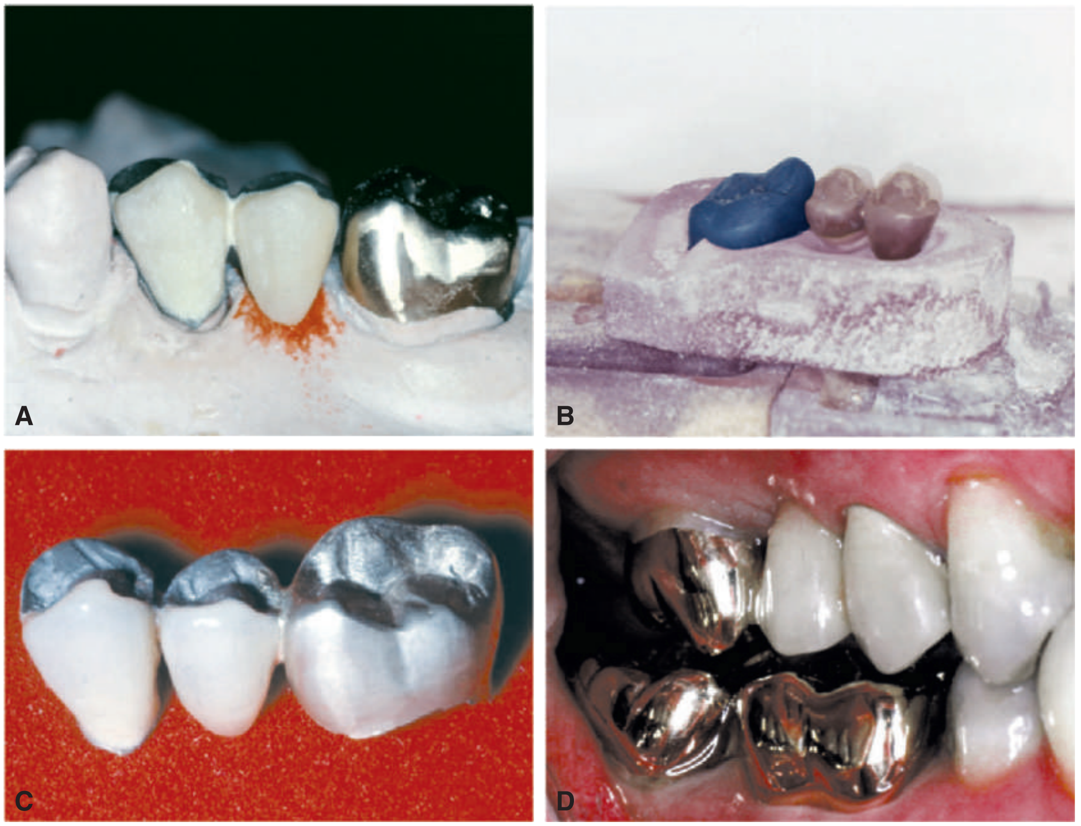

Fig. 27.1 Rigid connectors: a three-unit fixed partial denture (FPD) replacing the maxillary second premolar. (A) The anterior abutment and the pontic are connected with a rigid cast connector. These two FPD components are fabricated separately from the posterior abutment, which is cast in gold. (B) The components are placed in relation to one another by a soldering assembly. (C) The connected components. (D) The FPD in place.

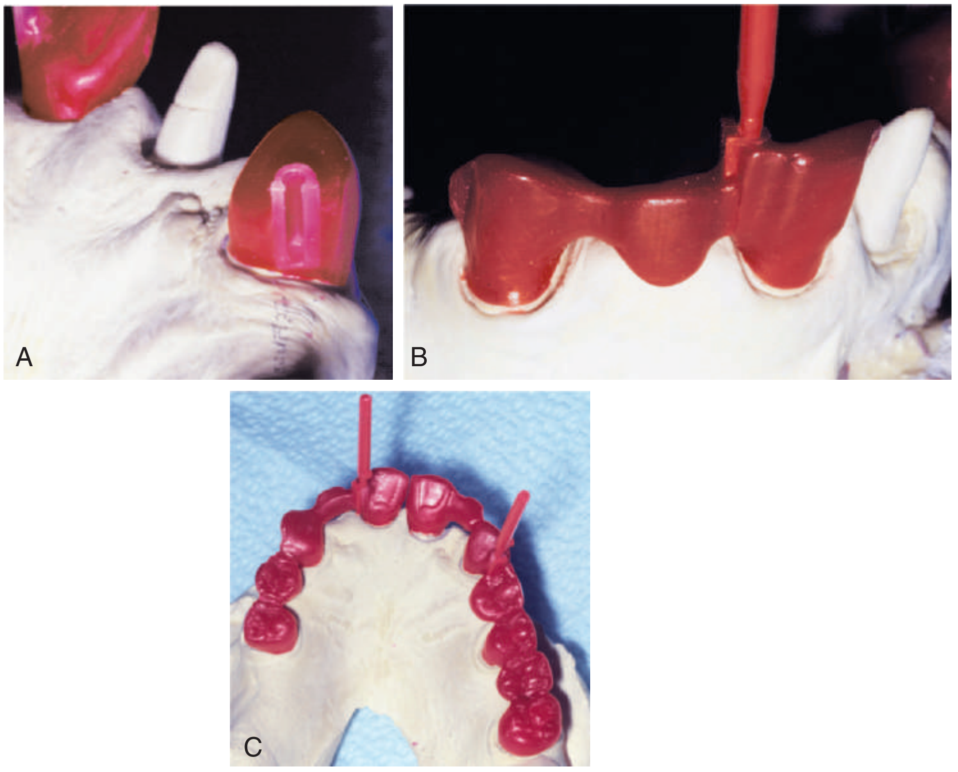

Fig. 27.2 Fixed partial denture (FPD) with nonrigid connector. (A) Mortise pattern ("female" component) positioned on the distal surface of the canine retainer. (B) FPD assembled with prefabricated resin tenon ("male" component) on the mesial surface of the pontic. (C) Nonrigid connectors used to allow the fabrication of an extensive FPD having abutments prepared with divergent paths of placement. (Courtesy Dr. M. Chen.)

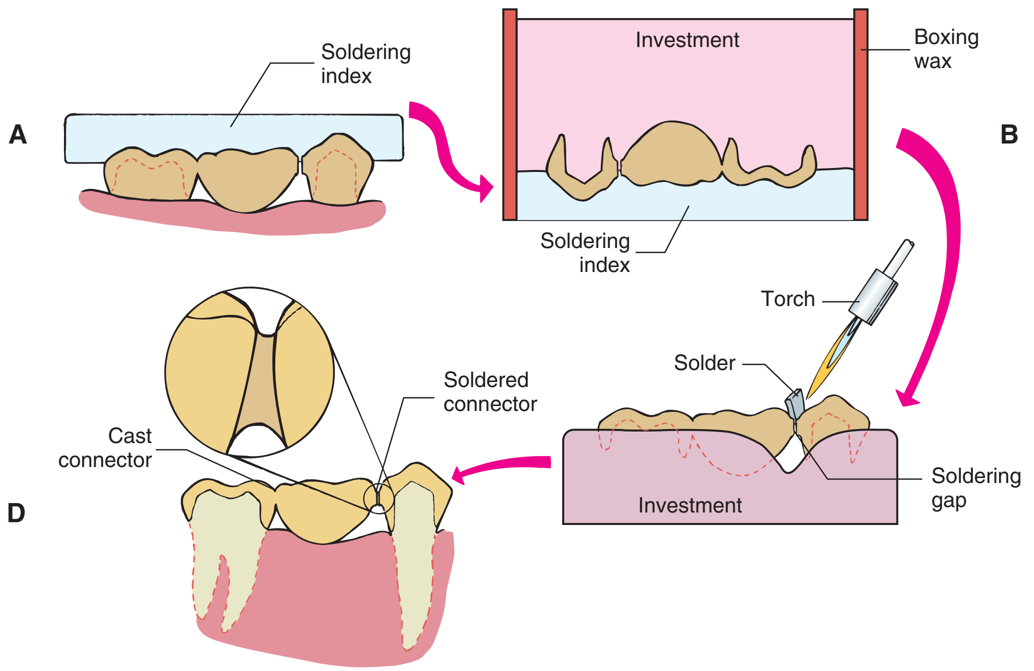

Fig. 27.3 The soldering process. (A) Fabrication of occlusal soldering index. (B) Investment of fixed partial denture components. (C) Torch soldering. (D) Clinical evaluation.

Fig. 27.4 This complex fixed partial denture has been segmented through the use of a nonrigid connector *(arrow)* on the distal surface of the first premolar.

Fig. 27.5 Restorative failure. (A) An excessively large incisocervical connector *(arrows)* impedes proper plaque control, which has led to periodontal breakdown. (B) A connector *(arrow)* that displays metal, although perhaps acceptable from a biologic and mechanical perspective, can prove to be esthetically unacceptable.

has a configuration similar to a meniscus formed between the two parts of the prosthesis.

In a buccolingual cross section, most connectors are somewhat elliptical. Elliptical connectors are strongest if the major axis of the ellipse parallels the direction of the applied force. Unfortunately, because of anatomic considerations, this cannot always be achieved. In fact, because of space constraints, the greatest dimension of most connectors is perpendicular to the direction of applied force, which tends to weaken the connectors. For ease of plaque control, the connectors should occupy the normal anatomic interproximal contact areas because encroaching on the buccal, gingival, or lingual embrasure restricts access. However, to improve appearance without significantly affecting plaque control, anterior connectors are normally placed toward the lingual embrasure. Fig. 27.6 depicts typical locations for connectors on selected teeth.

Optimal connectors are easy to clean, strong, and esthetically pleasing.

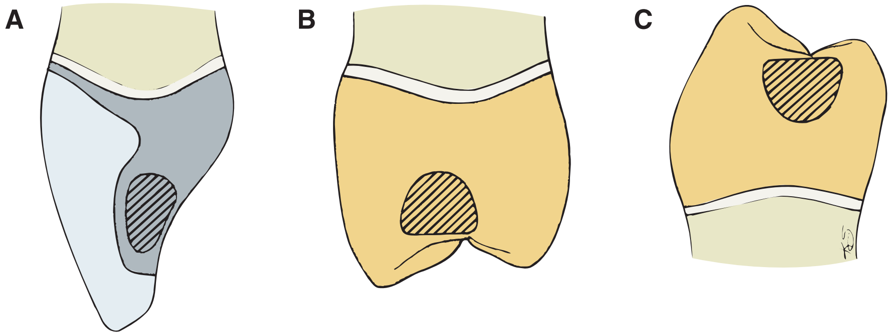

Fig. 27.6 Cross-sectional views through fixed partial denture connectors. (A) Maxillary anterior view. (B) Maxillary posterior view. (C) Mandibular posterior view. Note the convexity of the gingival surface of the connectors. To prevent excessive display of metal, anterior connectors should be placed toward the lingual embrasure.

Pulp size and clinical crown height can be limiting factors in the design of nonrigid connectors. Most prefabricated patterns require the preparation of a fairly sizable box. This allows incorporation of the mortise (see the section Nonrigid Connectors and Fig. 27.8) in the cast restoration without overcontouring of the interproximal emergence profile. Short clinical crowns do not provide adequate occlusocervical space to ensure adequate strength. Most manufacturers recommend 3 to 4 mm of vertical height, which is supported by empirical clinical findings.

TYPES OF CONNECTORS

Rigid Connectors

Rigid connectors must be shaped and incorporated into the wax pattern after the individual retainers and pontics have been completed to definitive contour but before reflowing of the margins for investing (see Chapter 18). When a CAD-CAM process is used, the connectors are designed as part of the framework with the computer software program.[2]

Cast Connectors

Connectors to be cast are also waxed on the definitive cast before reflowing and investing of the pattern. The presence of a cast connector makes the process of investing somewhat more awkward: Access to the proximal margin is impeded, and the pattern cannot be held proximally during removal from the die. Restricting cast connectors to complete coverage restorations, which can be gripped buccolingually, is therefore advisable. Partial-coverage wax patterns are easily distorted, particularly when they are part of a single-cast FPD. One-piece castings often appear to simplify fabrication but tend to create more problems than do soldered connectors, especially as pattern complexity increases.

Soldered Connectors

As with cast connectors, connectors to be soldered are waxed to final shape but are then sectioned with a thin ribbon saw (Fig. 27.7A and B); therefore, when the components are cast, the surfaces to be joined are flat, parallel, and a controlled distance apart. This allows accurate soldering with a minimum of distortion.[9] Molten solder flows toward the location where the temperature is highest. In metal, the two flat surfaces previously created in wax retain heat, which ensures that the highest temperature is in the connector area.

Soldering gap width. As gap width increases, soldering accuracy decreases.[10] Extremely small gap widths can prevent proper solder flow and cause the joint to be incomplete or weak.[11] An even soldering gap of about 0.25 mm is recommended. If a connector area has an uneven soldering gap width, obtaining a connector of adequate cross-sectional dimension without resulting distortion is more difficult.

Nonrigid Connectors

The design of nonrigid connectors that are incorporated in the wax pattern stage consists of a mortise (also referred to as the *"female" component*) prepared within the contours of the retainer and a tenon *("male" component)* attached to the pontic (Fig. 27.8). The mortise is usually placed on the distal surface of the anterior retainer. Accurate alignment of the dovetail or cylindrically shaped mortise is crucial; it must parallel the path of placement of the distal retainer (see Fig. 27.2). Paralleling is normally accomplished with a dental surveyor. When the cast is aligned, the path of placement of the retainer that will be contiguous with the tenon is identified. The mortise in the other retainer is then shaped so that its path of placement allows concurrent seating of the tenon and its corresponding retainer.

The mortise can be prepared freehand in the wax pattern or with a precision milling machine. Another approach is to use

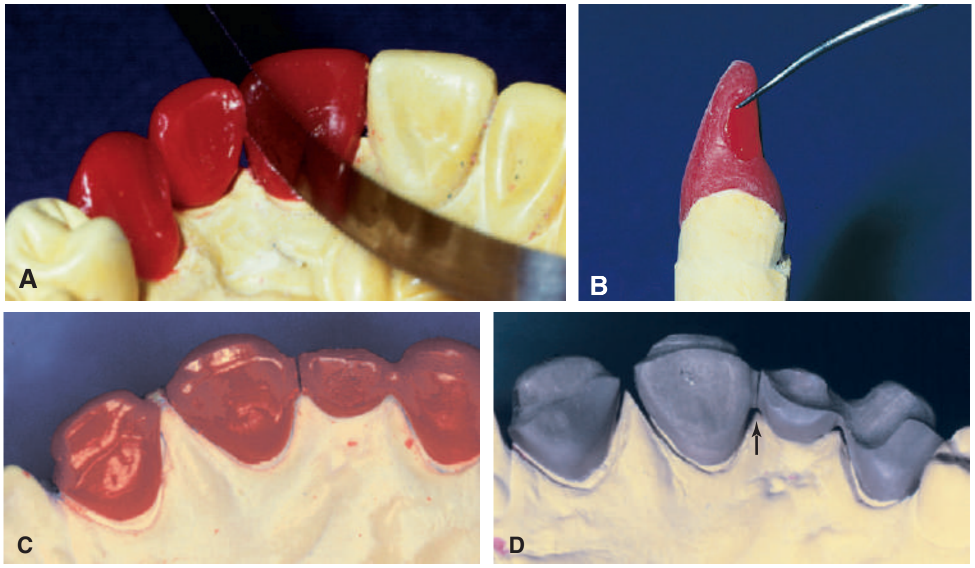

Fig. 27.7 Connector design. (A) A ribbon saw is used to section the wax pattern. (B) The sectioned surface should be flat and located far enough incisally and lingually to allow adequate hygiene and esthetics of the completed fixed partial denture (FPD). (C) A three-unit FPD after sectioning. (D) Framework ready for porcelain application. Note the uniform gap width *(arrow)*.

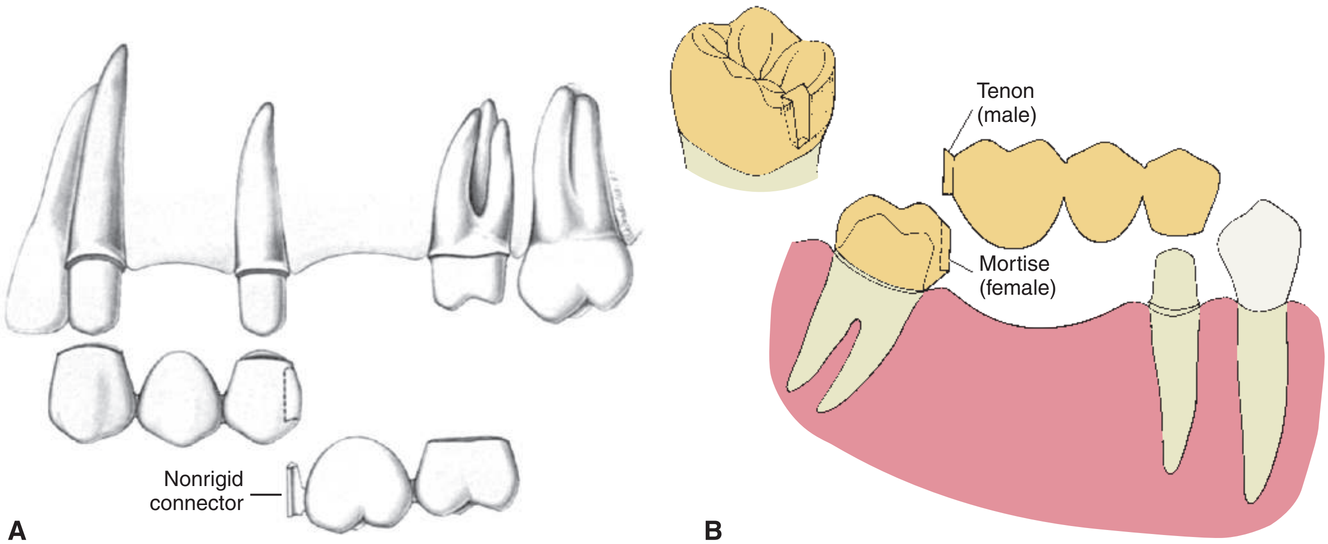

Fig. 27.8 Illustrations of fixed partial dentures with nonrigid connectors. This type of connector may be indicated to overcome problems with intermediate or pier abutments (A) and abutment alignment (B).

prefabricated plastic components for the mortise and tenon of a nonrigid connector (Fig. 27.9).

MATERIALS SCIENCE

M.H. Reisbick

Solder

Dental gold solders are given a fineness designation to indicate the proportion of pure gold contained in 1000 parts of alloy. For example, a 650-fine solder contains 65% gold. In an earlier designation,[12] the solder was assigned a carat number, which indicated the gold content of the castings that were to be joined with the solder; an 18-carat solder could be used to solder castings fabricated of an alloy containing 75% gold. Because numerous alloys other than type IV gold are available today, many of which contain platinum-group metals, the carat designation is of little value.

Modern casting alloys have become so metallurgically complex that most manufacturers now recommend specifically formulated solders. One manufacturer (Kulzer GmbH) classifies traditional gold-containing solders as group I and others (termed *special solders*) as group II. Most of these have the brand name with a "pre" or "post" designation to indicate whether the solder is to be used for joining the components before or after porcelain application. The so-called preceramic solders are obviously high-fusing alloys, sometimes fusing only slightly beneath the softening point of the parent alloy

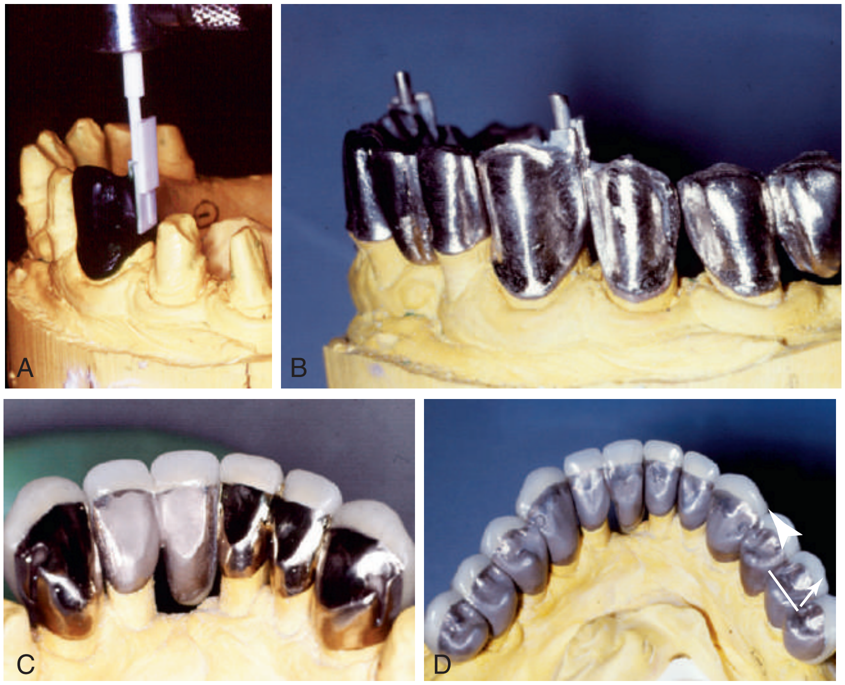

Fig. 27.9 (A) Prefabricated plastic patterns are available for incorporation in the wax pattern. (B) The metal substructure. (C and D) The completed prosthesis incorporates bilateral nonrigid connectors *(arrows)*. (Courtesy Dr. F. Hsu.)

TABLE 27.1 Composition and Flow Temperatures of Dental Solders

	METAL					
Fineness	**Gold (%)**	**Silver (%)**	**Copper (%)**	**Tin (%)**	**Zinc (%)**	**Flow Temperature (°C)**
490	49.0	17.5	23.0	4.5	6.0	780
585	58.5	14.0	19.0	3.5	4.5	780
615	61.5	13.0	17.5	3.5	4.5	790
650	65.0	12.0	16.0	3.0	4.0	790
730	73.0	9.0	12.5	2.5	3.0	830

Courtesy Ivoclar AG, Amherst, NY.

to be joined. Ideally, they flow well above the fusion range of the subsequently applied porcelain. Postceramic solders must flow well below the pyroplastic range of the porcelain. For example, one popular silver-palladium (Ag-Pd) casting alloy has a specified melting range between 1232°C and 1304°C (2250°F to 2380°F). The recommended special presolder melts at 1110°C to 1127°C (2030°F to 2061°F), whereas the postsolder melts at 710°C to 743°C (1310°F to 1369°F). The porcelain fuses at about 982°C (1800°F), depending on time and temperature.

The composition of the solder determines its melting range, among other things. Some typical compositions and melting ranges are given in Table 27.1. The main requirement in soldering is to fuse safely below the sag or creep temperature of the casting to be soldered. Newer palladium casting alloys, by virtue of their higher melting ranges, have somewhat increased the reliability of the presoldering technique.[13]

However, preceramic soldering is relatively difficult and can be structurally hazardous (Fig. 27.10). This may be because base metal solder constituents volatilize with overheating,[14] which then results in microporosity, or pitting. The melting range of presolders is quite narrow because silver and copper (the usual modifiers of temperature range) cannot be used in the alloy; these elements discolor porcelain on contact. Another consideration is the oxide necessary for the chemical adherence of porcelain. Porcelain does not chemically bond equally well to all solders.

Other requirements of solders are their ability to resist tarnish and corrosion, to be free flowing, to match the color of the units that will be joined, and to be strong. These factors also depend on the chemical composition of the solder.

Resistance to tarnish and corrosion is determined by a solder's noble or precious metal content and its silver-to-copper (Ag/Cu) ratio.[15] In addition, if the compositions of the solder and workpiece differ, galvanic corrosion may occur.

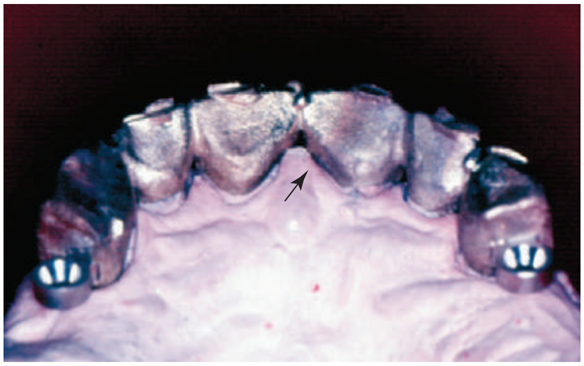

Fig. 27.10 Metal substructure for an anterior prosthesis. The preceramic soldering procedure in this case led to partial melting of the framework *(arrow)*, which can result in distortion, premature failure, or both.

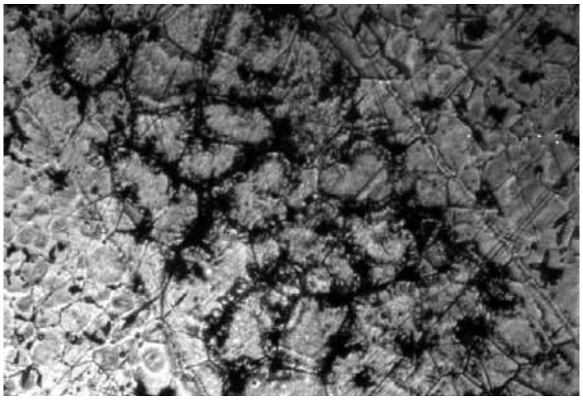

Fig. 27.11 Photomicrograph of a properly made solder joint connecting two castings.

During the soldering procedure, the solder must flow freely over clean and smooth surfaces. These surfaces should be smoothed with abrasive disks, not with rubber wheels or polishing compounds. The phenomenon of free flow is termed *wetting*, during which remelting or realloying of the surface of the units to be joined must not occur.[16] Solder flow is increased by the addition of silver and decreased by the presence of copper. Fig. 27.11 depicts a properly made solder joint. Note that the filler metal has joined the surfaces of the two castings without penetrating either one.

Lower-fineness gold solders are often more fluid and are generally chosen for joining castings. If necessary, proximal contacts with a solder of higher fineness can also be added because this tends to flow less freely. However, the exact minimally acceptable fineness necessary for resisting tarnish and corrosion has not been conclusively established; 615 or 580 fineness is probably the lower limit of clinical acceptability.

The last requirement, strength, is easily satisfied by most solders and is usually greater than that of the soldered parent metal, provided that the procedure is followed carefully.[10] In addition, most solders harden during cooling because of the "order-disorder" transformation and the formation of other intermetallic phases, which occur at grain boundaries. Brittleness is frequently encountered with gold-based copper-containing solders. As with type III and type IV gold casting alloys, the gold-copper order-disorder (or discontinuous phase-hardening) mechanism causes similar changes in the solder's microstructure.[17] Simply stated, with these solders, cooling to room temperature results in a brittle joint. The joints are strong but have no ductility. Some solder joints are weakened by notches.[18] This means that soldered connectors should be well polished to prevent fracture.

FPDs fabricated with type III gold alloys and joined interproximally with traditional gold-based solders are usually water quenched 4 to 5 minutes after soldering is complete. Quenching immediately after soldering causes the FPD to warp; failure to quench results in a joint with little or no ductility. A brittle joint may easily fracture. Thus a disadvantage of postceramic soldering is the loss of joint ductility. Because the components are partially porcelain, quenching is not done, because porcelain fracture would occur.

Soldering Flux and Antiflux

Soldering Flux

Soldering flux is applied to a metal surface to remove oxides or prevent their formation. When the oxides are removed, the solder is free to wet the clean metal surface.

Borax glass ($Na_2B_4O_7$) is frequently used with gold alloys because of its affinity for copper oxides. An often-cited soldering flux formula[19] is borax glass (55 parts), boric acid (35 parts), and silica (10 parts). These ingredients are fused together and then ground into a powder.

Fluxes are available in powder, liquid, or paste form. The paste is popular because it can be easily placed and confined. To make pastes, the flux powder is mixed with petrolatum. The petrolatum excludes oxygen during heating and eventually carbonizes and then vaporizes.

New fluxes are available for use with non–gold-based alloys. Their formulas are not generally published. At present, none of the new fluxes are totally capable of preventing oxide formation during heating of the base metal or nonnoble alloys. An example of a rapidly forming oxide on a base metal occurring during a simulated postsoldering is shown in Fig. 27.12. Soldering of base metal alloys is still unpredictable.[20]

All fluxes should be prevented from contacting porcelain-veneered surfaces. The contact causes pitting and porcelain discoloration.

Soldering Antiflux

Antiflux is used to limit the spreading of solder. It is placed on a casting before the flux application to limit the flow of molten solder. When the metal surfaces are clean, any excess solder introduced into the work gap tends to flow into undesirable areas. The antiflux helps prevent this.

Graphite (from a pencil) is often used as an antiflux. However, the carbon easily evaporates at higher temperatures, leaving the workpiece unprotected. A more reliable antiflux is iron oxide (rouge) in a suitable solvent such as turpentine, which can be painted on the casting with a small brush.

Fig. 27.12 Simulated base metal–to–base metal postceramic soldering procedure. Excessive oxide formation prevented wetting by the solder. (From Sloan RH, et al: Post-ceramic soldering of various alloys. J Prosthet Dent 48:686, 1982.)

Soldering Investment

Soldering investments are similar in composition to casting investments (see Chapter 22). Casting investments, both gypsum and phosphate bonded, mixed with water only, have been used for soldering. However, the refractory component in casting investments usually creates unwanted thermal expansion and therefore excessively separates the units to be joined. Soldering investments ideally contain fused quartz (the lowest thermally expanding form of silica) as their refractory component.

Invested units expand during heating, and they should do so at the same rate as the castings. The units must be correctly gapped so that they do not touch. When the work units are allowed to touch, distortion and porous, inadequate joints result.[12] Alternatively, excessive gap spaces cause undersized mesiodistal FPD widths because of solder solidification shrinkage. However, Ryge[12] showed that the gap space closes somewhat during heating, and so it is doubtful that the alloy and investment truly expand equally or at the same rates. Several commercial soldering investments are available; these should be used whenever possible.

Joining Base Metals

Titanium and Titanium Alloys

The advent of titanium and its alloys, as with cobalt-chromium-nickel, has brought a new challenge to joining cast units. Titanium also responds to high heat with an increased oxide formation, which results in a poor union between components to be joined. A reasonable solution has proved to be welding, by either laser or plasma.[21] Advantages include less heat distortion and a compositionally uniform joint. Joining with the same chemical element or elements thus minimizes detrimental galvanic degradation. Much work yet remains to render titanium a suitable replacement for noble casting alloys.

■ ■ ■

SELECTION OF SOLDERING TECHNIQUE

When FPDs are assembled by soldering, the relative position of the components is recorded with a soldering index (Fig. 27.13) on the definitive cast or intraorally (Fig. 27.14). If pontics are made individually, they can be difficult to position properly in relation to the abutment teeth. Although a positioning index made previously upon completion of the wax pattern can be helpful (Fig. 27.15), the pontics should be connected to one of the retainers with a cast connector because this stabilizes them and makes accurate positioning in relation to the other retainer much easier. To understand the selection of soldering technique, a thorough knowledge of the fusing ranges of all materials involved in the FPD is essential (Fig. 27.16).

Soldering of all-metal FPDs consisting of type III or IV gold units requires the use of a low-fusing solder. The procedure is referred to as *conventional soldering*. Through the use of the same low-fusing solder, regular gold retainers can also be connected with metal-ceramic components. A gas-air torch is used for either of these procedures.

For FPDs consisting of metal-ceramic units, the soldered connectors may be made either before the ceramic application with high-fusing solder (≈1100°C [2012°F]) or after the ceramic application with lower-fusing solder (750°C [1382°F]). Soldering before ceramic application is called *pre–ceramic application soldering* or *presoldering*. Soldering of metal-ceramic crowns after their completion is referred to as *postsoldering*. Many alloys can be combined by means of either presoldering or postsoldering. However, presoldering has been found to be less reliable,[10] with a number of apparently sound connectors exhibiting negligible tensile strength. Considerable variation in solder joint strength has also been recorded after laboratory testing,[22] which emphasizes the special care needed to avoid defective connectors.

Base metal alloys can be difficult to solder because they oxidize; oxidation must be controlled with special fluxes, although excessive fluxing can lead to undesirable inclusions and weak connectors. In one study,[23] investigators found that 20% of postsoldered joints involving base metal alloys had to be resoldered because they were so weak that they broke with finger pressure. In another study, Anusavice et al.[24] demonstrated great variability in solder joint quality with these alloys, with no consistent relationship of strength to gap width. These authors found that most failures occurred through the solder and were attributable to voids caused by gas entrapment or localized shrinkage. With experience and careful adherence to the manufacturer's recommended techniques and materials, soldered connectors made of base metal alloy can be reliable.[25] However, because of the problems of soldering base metal alloys, various alternative procedures have been advocated. These include making the soldered joint through the center of the pontic to increase the area soldered[26] and connecting the parts by a second casting procedure, with the molten metal flowing into undercuts in the sectioned pontic.[27]

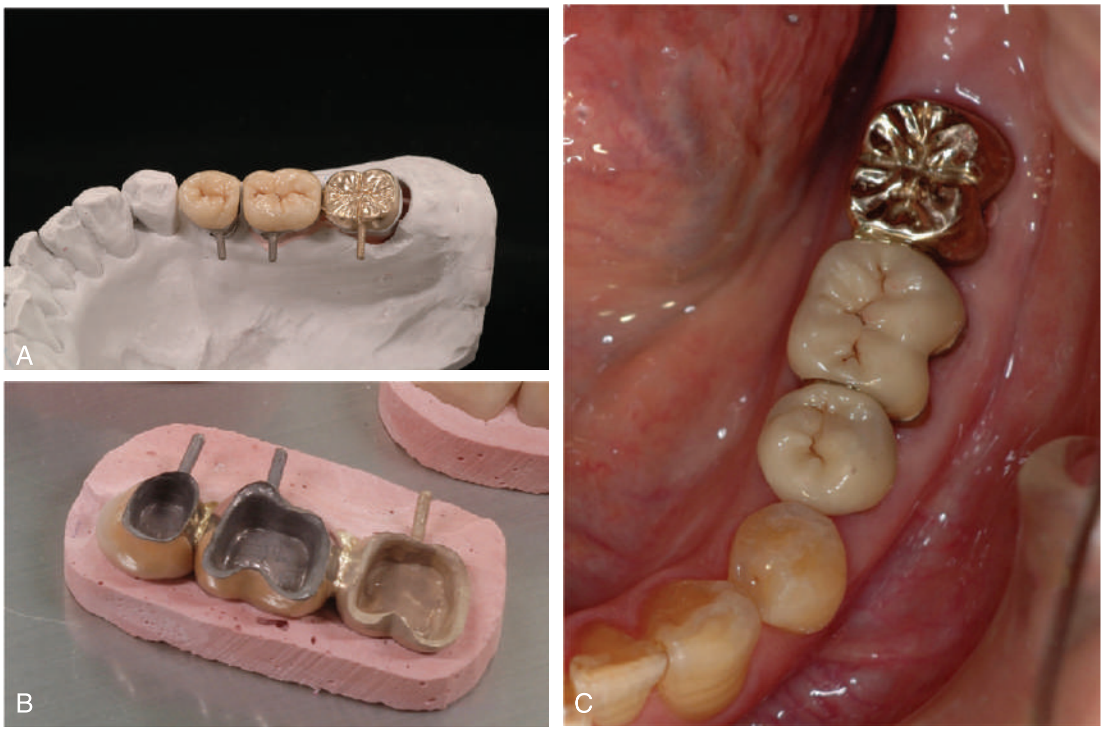

Fig. 27.13 (A) 3-unit fixed partial denture invested for post-ceramic application soldering. (B) Accuracy assessed with the gypsum index. (C) Cemented 3-unit fixed partial denture with minimum display of solder.

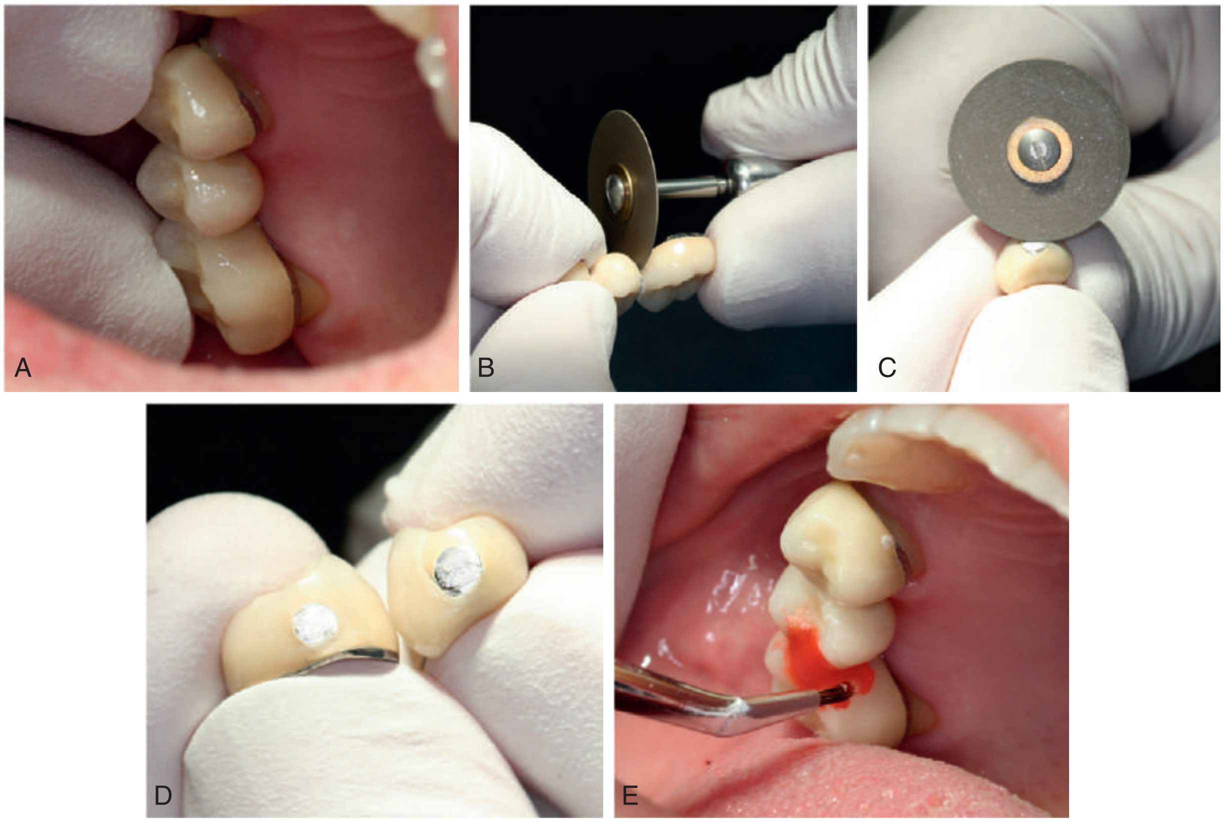

Fig. 27.14 Indexing a metal-ceramic fixed partial denture before soldering. (A) Incomplete abutment seating was detected during the clinical evaluation of this maxillary three-unit prosthesis. (B) Sectioning with an extra-thin separating disk. (C) Adjusting the connector area to optimum gap distance. (D) Surfaces to be soldered should be clean and free of debris. (E) The restoration is indexed intraorally with autopolymerizing resin.

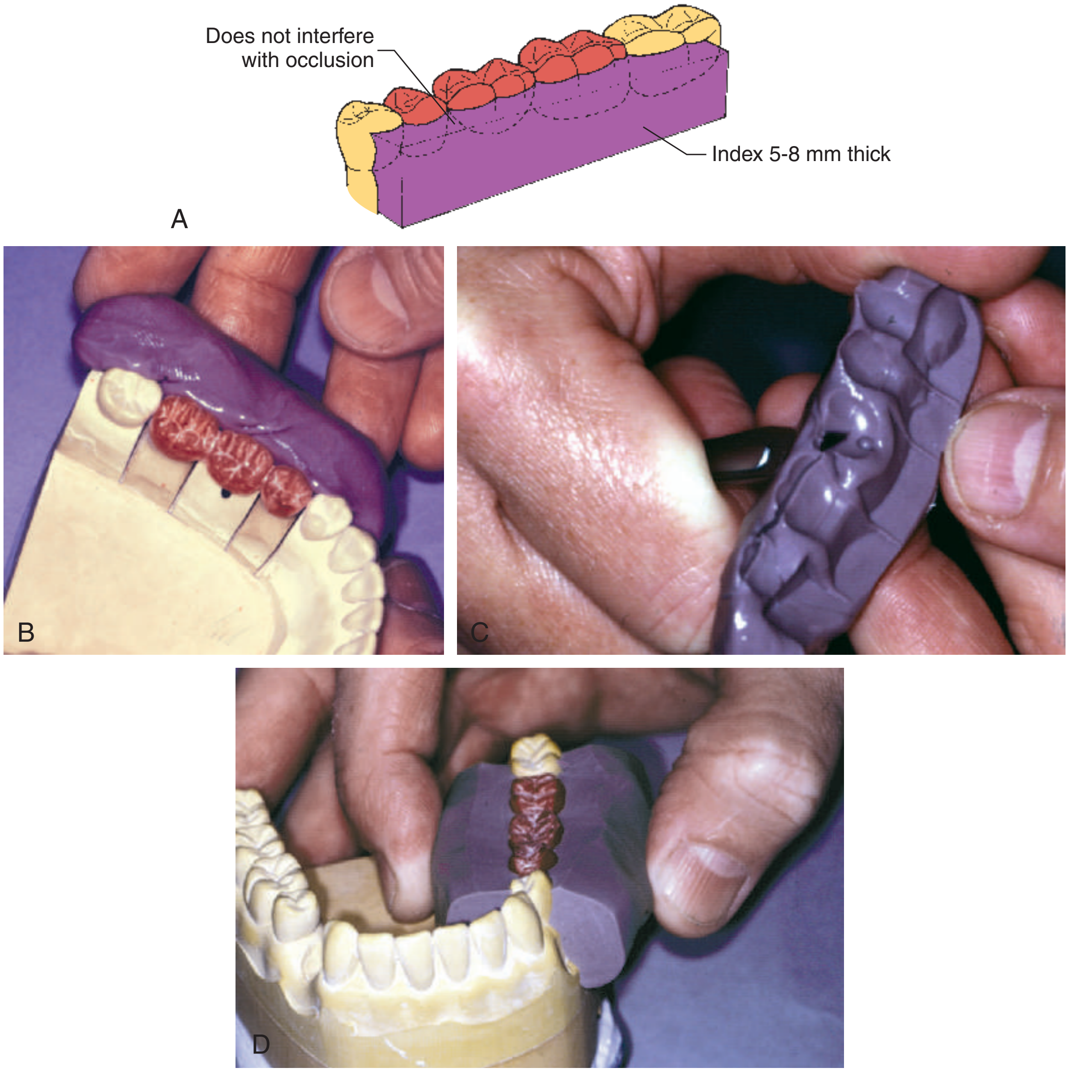

Fig. 27.15 Once the fixed partial denture has been waxed to anatomic contour, a silicone putty buccal index (A) can be made. This can be helpful for relating the castings. (B) Putty is applied to the buccal surface of the completed waxing. (C) Excess is trimmed away with a scalpel blade. (D) The flat surface makes verification of accurate reseating of the index much easier.

Soldering Metal Fixed Partial Dentures

Type III and type IV gold retainers of FPDs are soldered with gold solder with fineness ranging from 615 to 650. An occlusal plaster index or autopolymerizing resin index is fabricated intraorally or in the dental laboratory; after investment, a gas-air torch can be used to solder the components. A disadvantage of the soldering procedure is that it requires an additional step, in comparison with a one-piece casting. However, soldering simplifies the manipulation of wax patterns. For instance, when a three-abutment FPD with two splinted abutments (e.g., two premolars) is fabricated, access to the interproximal margins of the two splinted abutments is often very difficult during the reflowing and finishing steps. Soldering such retainers enables the dentist to shape and adjust the retainers individually, with improved access for finishing procedures. Conventional soldering requires a gas-air torch; soldering can also be performed in a furnace.

Soldering Metal-Ceramic Fixed Partial Dentures

Presoldering

Once a metal-ceramic framework has been assembled by presoldering, the subsequent procedures are the same as if it had been cast in one piece. This has the advantage of allowing the connected prosthesis to be evaluated in the mouth in the unglazed state. Any necessary adjustments can be made to the porcelain, which fuses at a lower temperature than does the presoldered connector. However, with presoldering, contouring the proximal embrasures so that the units resemble natural teeth may be more difficult. A very thin diamond disk is helpful in such contouring.

A disadvantage results from having to apply the porcelain to a longer structure, which needs support during firing to prevent high-temperature deformation or sag. Sag can be a particular problem with the high–gold content ceramic alloys because they have a lower melting range. High–palladium content or

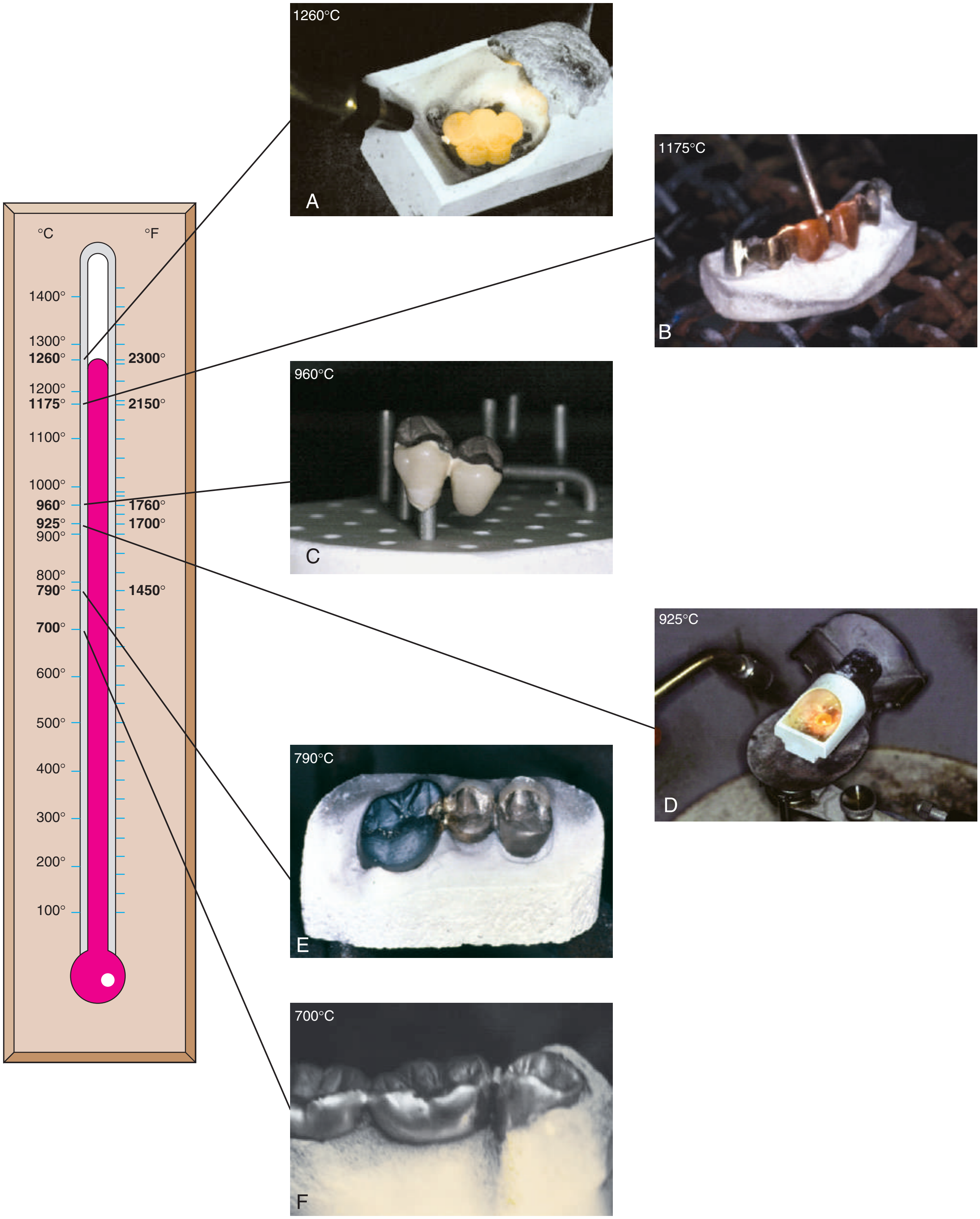

Fig. 27.16 (A) Casting metal-ceramic alloys. (B) Presoldering. (C) Porcelain firing. (D) Casting type III and type IV gold alloys. (E) Postceramic soldering. (F) Conventional soldering.

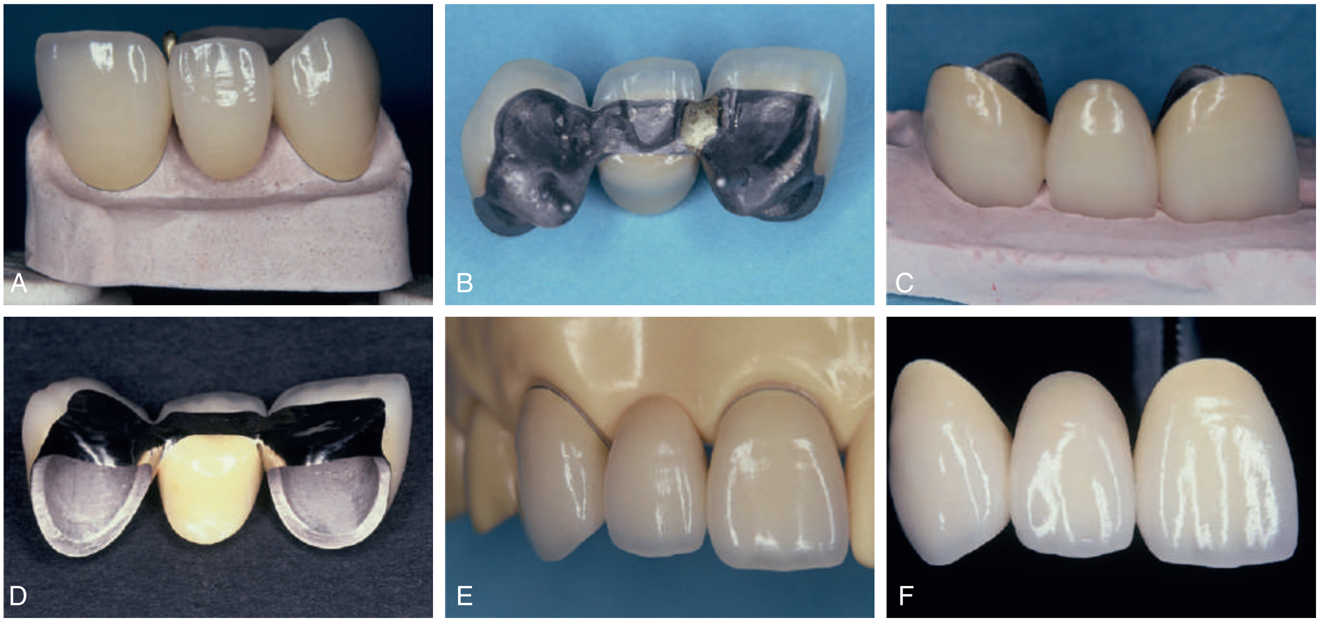

Fig. 27.17 Postceramic soldering of an anterior fixed partial denture (FPD). (A) The prosthesis has been assembled with a plaster index. (B) After heating in a porcelain furnace, the solder is applied from the lingual. Complete flow of the solder into the connector area. (C) Accuracy of the soldering procedure is verified by reseating the FPD into the index. (D) Completed restoration with highly polished connectors. (E and F) The assembled FPD. The connector is designed to be invisible from the facial view.

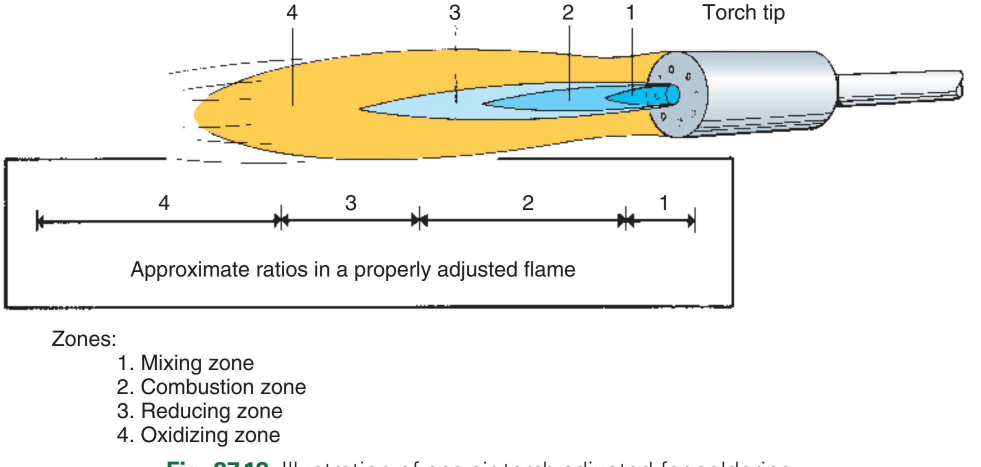

Fig. 27.18 Illustration of gas-air torch adjusted for soldering.

base metal alloys exhibit little sag during firing. Presoldering requires a gas-oxygen torch.

Postsoldering

Postsoldering is necessary when regular gold and metal-ceramic units are being combined in an FPD. The regular gold melts if it is subjected to the high temperatures needed for porcelain application; therefore, all porcelain adjustment and firing, including that for the final characterization and glazing, must be completed before the soldering. If further corrective adjustment is needed after soldering, the porcelain must be polished, or the joint must be separated, after which additional porcelain can be added as needed, the restorations can be reglazed, a new index can be made, and the FPD can be resoldered.

Because the proximal areas are shaped before soldering, a post-soldered connector can often be made to look more natural than a presoldered or cast connector (Fig. 27.17). In addition, customized firing supports are not needed because sag is not a problem (the lengths of the individual components are shorter). Postsoldering is performed either in a porcelain furnace or with a gas-air torch.

HEAT SOURCES

Torch Soldering

When a gas-air torch is used as the heat source to melt the solder, metal-ceramic restorations are preheated in an oven to minimize the risk of cracking of the porcelain veneer. To prevent oxidization of the joint surfaces, the reducing (non-oxidizing) portion of the flame is used (Fig. 27.18), and an appropriate

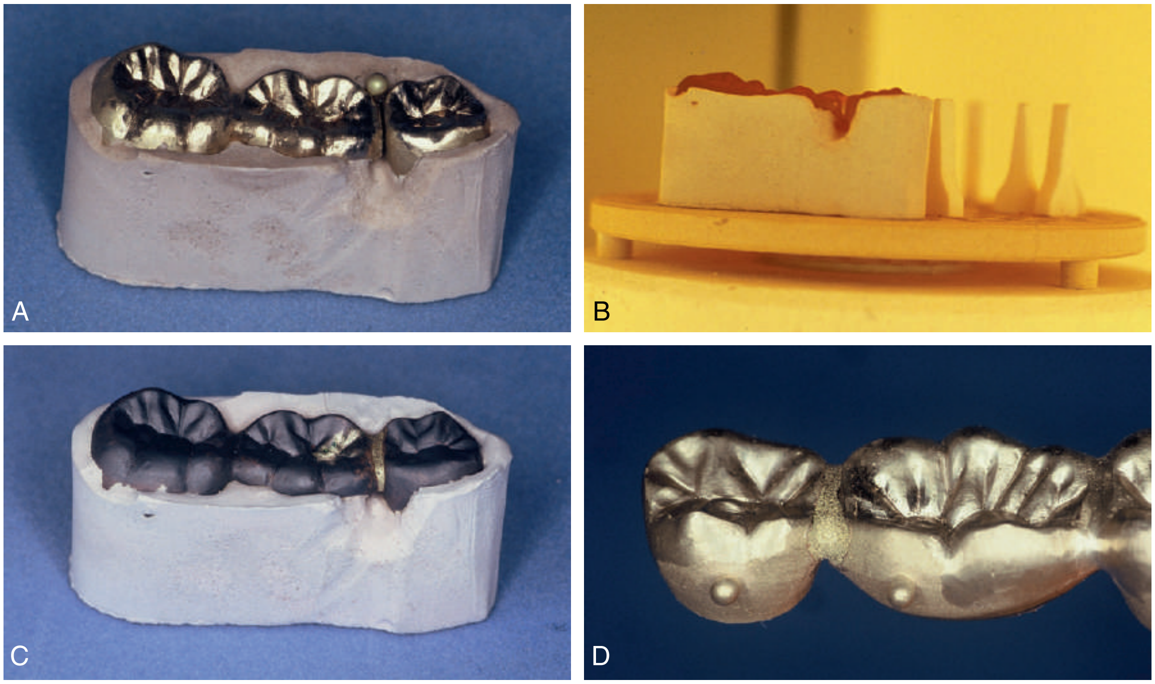

Fig. 27.19 Oven soldering a three-unit fixed partial denture. (A) Prosthesis invested. (B) Furnace temperature raised to the solder's melting range. (C and D) Oven-soldered prosthesis.

flux is applied (some soldering fluxes are unsuitable because they discolor the porcelain). To prevent uneven heat distribution, which could result in fracture, the flame is never concentrated in one area but is kept in constant motion.

Some dental technicians believe that the flow of solder is more controllable during torch soldering than during oven soldering because a slight temperature differential can be created and the solder always flows toward the hotter point. This makes torch soldering useful when the connector has not been well designed in wax, and a minor temperature difference can deliberately be created in the assembly to help direct the flow of the molten solder to ensure adequacy of the connector.

Oven Soldering

Furnace or oven soldering is performed under vacuum pressure or in air. A piece of solder is placed at the joint space, and the casting and solder are heated simultaneously.

Criticism of this technique has been based on earlier observations[28] that less porosity resulted when castings were brought to soldering temperature before the solder was applied. The method does not allow the moment of solder fusion to be observed. (Some porcelain furnaces have an observation window for postsoldering.) This may be important because the longer the solder remains molten, the more it dissolves the parent metal and consequently weakens the joint.[11] Nevertheless, joints with strength similar or superior to that of the parent metal have been demonstrated[10] when oven soldering was used.

A different technique may be appropriate if the porcelain furnace has a horizontal muffle with a fixed floor. The soldering assembly is heated above the fusion point of the solder, the muffle door is opened, and the solder is fed into the joint space (Fig. 27.19).

Fig. 27.20 Laser welding. Individual titanium components are carefully aligned in the laser welding unit. The joining procedure is monitored with high-magnification video. (Courtesy Crafford-LaserStar Technologies, Riverside, Rhode Island.)

Microwave Soldering

Microwave heating has been used for dental soldering on an experimental basis.[29,30] The process has the advantage of using less energy than conventional oven soldering, and joint strength has been found to be comparable with that produced by traditional methods.[29,30]

Laser Welding

Laser energy is extensively used for welding (Fig. 27.20) in many industries and has been described in dentistry since the 1970s.[31,32] Laser assembly of FPDs has been reported to have higher strength[33] and reduced corrosion[34] in comparison with conventional soldering, although laser-welded connectors seem as susceptible to fatigue failure[35] and may be less suitable for joining noble-metal alloys than for base-metal alloys.[29] Laser welding is a practical way to join cast or milled titanium or cobalt-chromium components (i.e., if these are to be used for implant-supported prosthesis frameworks[36–39]).

SOLDERING ACCURACY

Controversy exists as to the relative accuracy of FPDs that are cast in one piece, presoldered, or postsoldered. Individual dental laboratory technicians often obtain consistently better results with one particular technique, but scientific evidence is conflicting.[40–43] In evaluating clinical work to determine whether cast or soldered connectors provide better results, the determining factor should be the fit of the individual retainers. This should be optimized through the investing and casting process (see Chapter 22) to minimize the risks of incomplete seating or excessive luting agent space. In some situations, it may be impossible to cast a long-span FPD with ideal retainer dimensions and ideal interabutment dimensions; the challenge lies in obtaining enough interabutment expansion without making the retainers too loose. In such circumstances, a soldered connector may provide better accuracy. The situation is reversed for fabricating frameworks for implant-supported prostheses (see Chapter 13): The fit of the individual units is determined by the implant manufacturer. Only the overall abutment-to-abutment fit is under the control of the technician. However, an accurate, passively fitting implant-supported framework is crucial for avoiding damaging forces. It is not yet clear whether accurate implant-supported frameworks are most effectively made with one-piece castings or as sectioned and soldered or laser-welded units.[42–44]

SOLDERING TECHNIQUE

Armamentarium

- Autopolymerizing acrylic resin
- Zinc oxide–eugenol (ZOE) paste
- Impression plaster
- Mixing bowl
- Spatula
- Small brush
- Waxing instrument
- Sticky wax
- Baseplate wax
- Sprue wax
- Soldering investment
- Glass slab
- Soldering tripod
- Flux
- Solder
- Tongs
- Pickling solution

Step-by-Step Procedure

Occlusal Soldering Index

Intraoral plaster or ZOE is used to make an impression of the occlusal surfaces of the FPD to capture the relative relationship of the individual FPD components and transfer this to the laboratory. This procedure can also be performed in the laboratory if the technician is satisfied that the individual components are seated completely on an accurate definitive cast. An advantage of an occlusal index (Fig. 27.21; see also Fig. 27.3) is that after the soldering procedure has been completed, the FPD can be reseated in the index, and soldering accuracy can be verified (sometimes a small amount of plaster must be removed in the area where the solder has been added, to ensure seating).

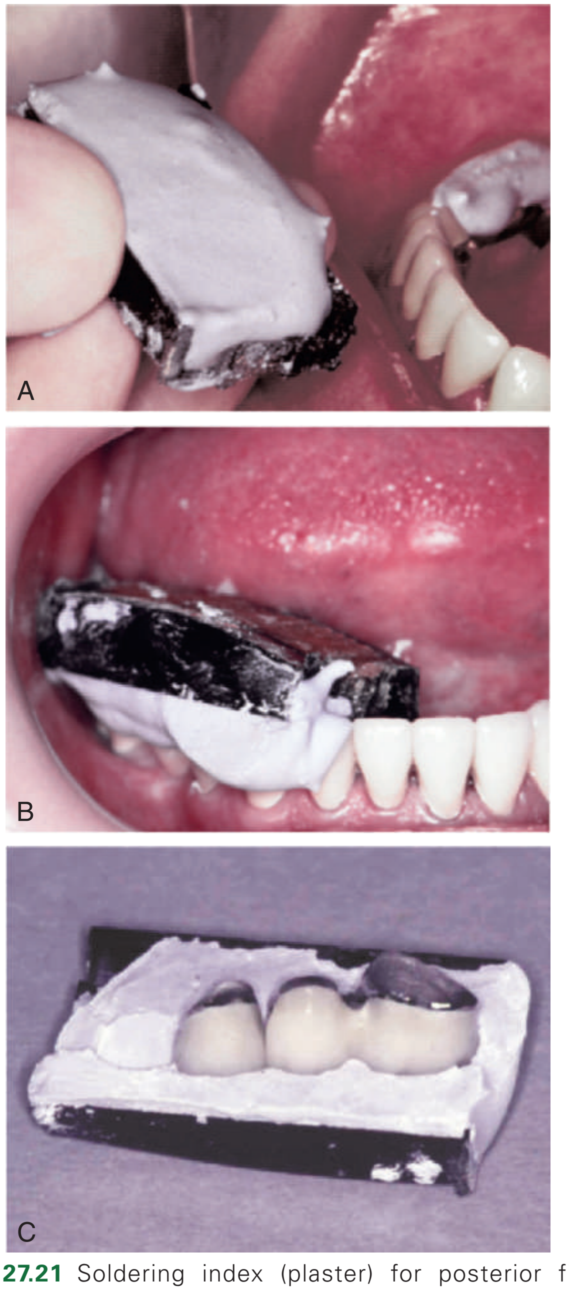

Fig. 27.21 Soldering index (plaster) for posterior fixed partial dentures. (A) A suitable carrier (e.g., baseplate wax) is trimmed to proper shape before a registration is made with impression plaster (B). (C) The plaster occlusal registration.

1. Grind the connector surfaces of the finished castings with a stone or disk to remove surface oxides. Then fully seat the castings on the definitive cast or in the patient's mouth. Postsoldering connectors are best indexed intraorally after the contour and appearance have been perfected. If necessary, the soldering gap can be adjusted at this time (gap distance, 0.25 mm). The castings can be seated intraorally with a small quantity of low-viscosity impression material to ensure that they are not disturbed during the indexing.[45]
2. Make an impression plaster registration in a small tray or on a sheet of baseplate wax for the occlusal index. As an alternative, an index can be made with ZOE paste, a technique that has yielded[46] consistent and accurate recordings. The index should not cover the margins of regular gold retainers because these are to be embedded in the investment to prevent their accidental melting during soldering.
3. Trim the index to fully expose the margins before investing (Fig. 27.22).

Investing

4. Seat each casting into the index, and lute it into place with sticky wax.
5. Have wax flow into the connector area to prevent the investment from entering.

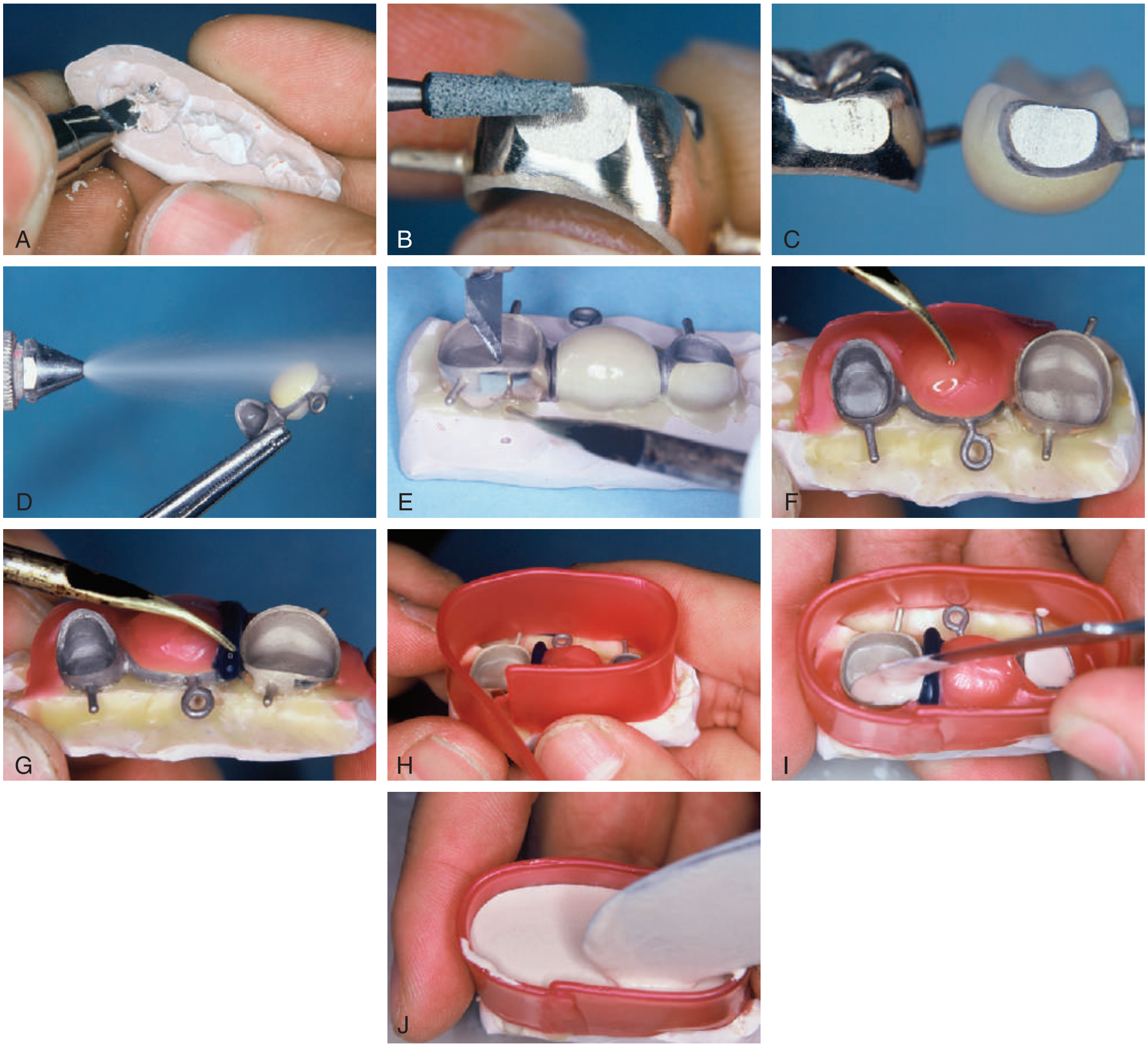

Fig. 27.22 Investing procedure (occlusal index). (A) The index is trimmed to ensure complete seating of the castings. (B and C) The connector area is ground with a noncontaminating stone. (D) The restorations are steam cleaned. (Alternatively, they can be cleaned ultrasonically.) (E) The castings are seated firmly and luted into place with sticky wax. (F) Because glazed porcelain is damaged by contact with the investment, the porcelain is protected with a layer of wax. (G) The wax flows into the connector areas and is adapted below each connector to create an airway. (H) The soldering assembly is boxed. (I and J) When the assembly is filled with soldering investment, great care is taken to ensure that there are no air bubbles in the investment.

6. To create a space that will help the solder spread, adapt sprue wax gingival to the solder joint. Burying the units completely in the investment makes soldering difficult because the unnecessary bulk of the investment prevents rapid heating of the castings.
7. Protect any glazed porcelain from contacting the investment by coating it with wax before investing. To protect regular gold margins from the soldering flame, they should be embedded in the investment; otherwise, they may become overheated and melt. For the same reason, all margins should be embedded in the investment before presoldering.
8. Box the assembly with suitable sheet wax.
9. Mix the investment carefully, and have it flow into the castings without trapping any air. Use only slight vibration so that the castings are not displaced from the index.
10. Allow the invested block to bench set before removing the wax and preheating.

Autopolymerizing Resin Soldering Index

A plaster or ZOE occlusal index is less suitable for the registration of anterior restorations. Because of the thinness of their incisal edges, these units are less stable, and accurate repositioning is more difficult. For this reason, autopolymerizing resin (Fig. 27.23) is recommended, although the resin burns off during the procedure. Therefore, the accuracy of the soldering procedure can be verified only intraorally.

1. Join the completed units together with autopolymerizing resin. The resin will later burn out, leaving no residue that could interfere with the casting.
2. Apply the resin with a bead technique. This minimizes the distortion from polymerization shrinkage. Excessive bulk of resin reduces the accuracy of the technique,[47] but sufficient material must be present to ensure that the components do not break (because they cannot then be accurately reseated in the index). The resin should extend onto the incisal edges of the retainers.
3. When the resin has fully hardened, carefully loosen the prosthesis from the abutments. Then replace it and check whether distortion has occurred. This is done in the same way as the evaluation of a finished FPD. It must be stable with no marginal discrepancies (see Fig. 27.23C). The prosthesis should be invested without delay; otherwise, the resin index will become distorted.[48]

Investing

This process is illustrated in Fig. 27.24.

4. Warm a sheet of wax and push the cervical margins of the restorations through it. Then seal it along the axial wall with a warmed instrument. This protects the porcelain from contact with the soldering investment.

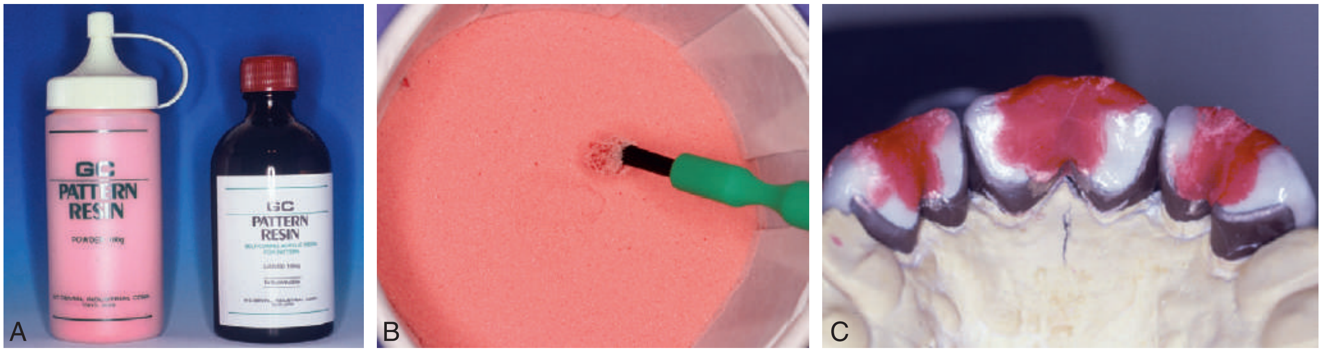

Fig. 27.23 Soldering index (autopolymerizing resin). (A) Armamentarium. (B) A small brush dipped in resin monomer is touched to the polymer powder. This forms a bead. (C) The restorations are thus connected, with resin extending onto the incisal edges of all the retainers.

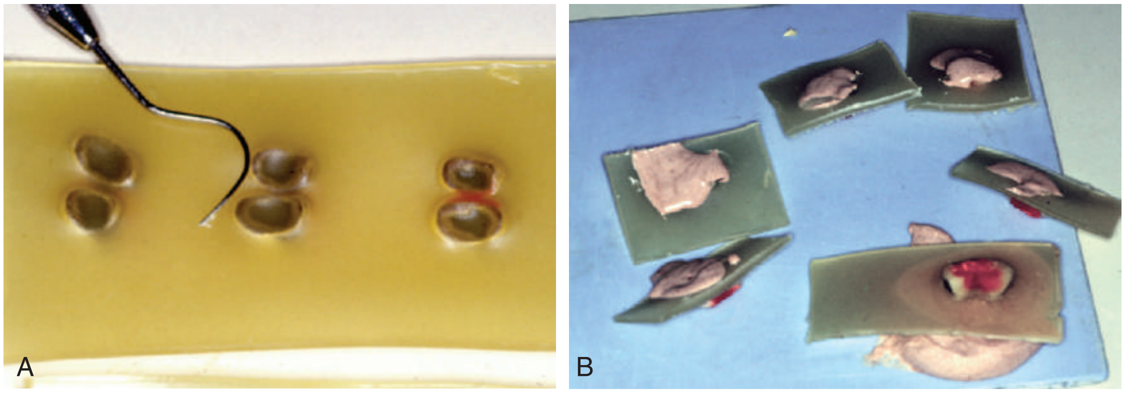

Fig. 27.24 Investing procedure (autopolymerizing resin). (A) The castings are pressed firmly into a sheet of softened wax. Note that the internal walls of the castings are exposed; the wax seals them. (B) Castings are filled with soldering investment and then inverted onto a patty of investment.

5. Fill the castings with soldering investment, and blot excess water from the remaining investment, forming it into a patty on a slab or tile.
6. Seat the restorations on the patty. When a joint is to be oven-soldered, the restoration should be angled forward so that the solder can be placed above the joint before the block is set inside the furnace.

Wax Removal and Preheating

This process is illustrated in Fig. 27.25.

1. If a plaster or ZOE index was used, remove it after the investment has fully set. This separation is most effectively accomplished after the wax is removed with boiling water. The joint space must be free of investment. Flowing of a little flux into the joint space while the soldering block is still warm from wax removal is recommended. This prevents small particles from inadvertently falling into the gap. Be aware that many special soldering investments have low strength, and the assembly is easily broken at this stage.
2. Preheat the investment in a burnout furnace to 650°C (1202°F) for low-heat soldering or 850°C (1562°F) for pre-soldering. Acrylic resin indexes are removed by heating slowly to 300°C (572°F), at which time most of the resin will have burned away.
3. Heat the block to 650°C (1202°F) until all traces of wax and resin have vaporized, and then transfer it to the soldering stand or porcelain furnace.

Torch Soldering (Low Heat)

This process is illustrated in Fig. 27.26.

1. Transfer the assembly to a soldering stand over a Bunsen burner, and place a piece of solder above the gap. Adjust the

Fig. 27.25 Wax removal and preheating. (A and B) Boxing material is removed, and the wax residue is flushed out with boiling water or an organic solvent. (C) The connector area must be free of contaminants. (D) A small amount of soldering flux is applied while the assembly is still warm. (E) The flux is carried into the connector area by capillary action. Then the assembly is placed in the burnout furnace. (F and G) Autopolymerizing resin indexes. These are burned off directly in the furnace after wax elimination. (H) The soldered restorations.

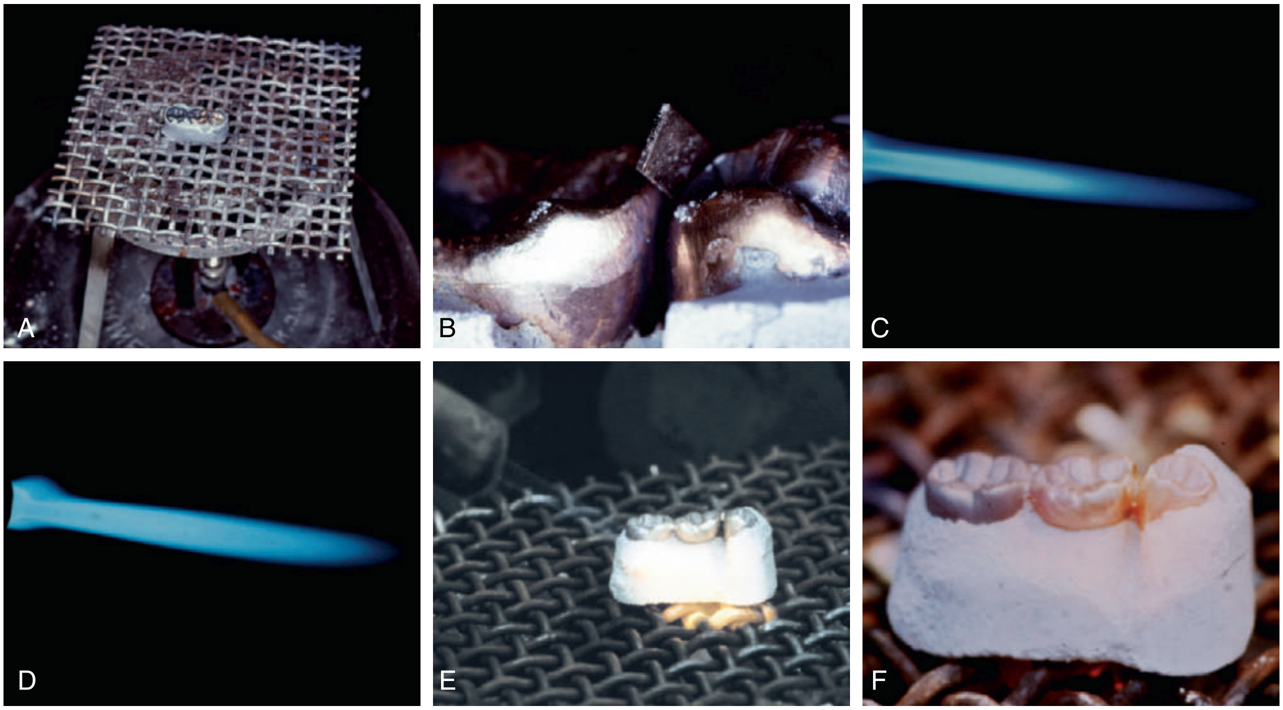

Fig. 27.26 Low-heat torch soldering. (A) The assembly positioned on a wire mesh over a Bunsen burner. (B) A flexed piece of solder is placed into the connector area. (C) A sharply defined flame is preferable for casting procedures. (D) A brush flame is more suitable for soldering. This can be obtained by slight reduction in the amount of air. (E) The assembly is heated evenly until the solder melts. The solder must "spin" in the connector area to form a complete connection (F).

gas-air torch to produce a sharp blue cone (as for casting), and then reduce the air for a softer or less pointed "brush" flame. The reducing zone of the flame is used to heat the investment block. The flame is directed at the lingual surface of the block rather than at the casting.
2. Heat evenly and slowly, moving the tip of the flame constantly. This is particularly important in postsoldering because the porcelain may easily crack. When the metal glows brightly, the solder melts and flows into the joint space.
3. Quickly move the flame to the facial. When the solder "spins" in the joint, remove the flame.
4. Extinguish the flame, and let the soldered prosthesis cool for 4 or 5 minutes before quenching (unless there is porcelain on the restoration, in which case it should cool to room temperature). Earlier quenching may lead to distortion, whereas prolonged bench cooling increases the brittleness of the joint.

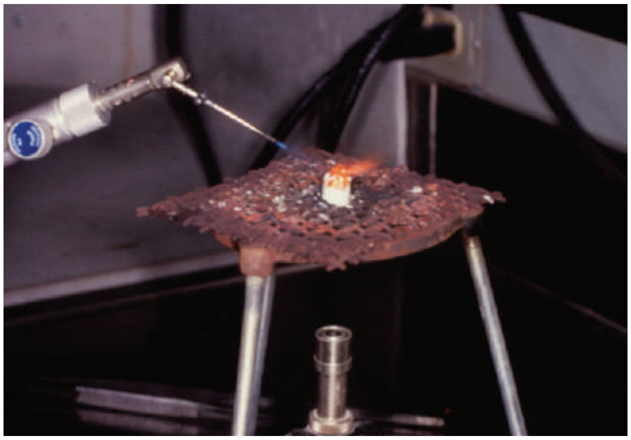

Fig. 27.27 High-heat (before ceramic application) torch soldering with a gas-oxygen torch and a miniature needle tip.

Torch Soldering (High Heat)

This process is illustrated in Fig. 27.27.
1. Wear dark glasses for eye protection (Fig. 27.28). Gas-oxygen torches for high-heat presoldering have a miniature needle tip so that the flame can be pinpointed on the joint space.
2. Place the solder above the gap and concentrate the reducing zone of the flame on the joint space.
3. When the solder melts, draw it into the joint and quickly "chase" it around with the flame (Fig. 27.29). The presolder may have a melting point close to that of the parent metal, and there is danger of melting a thin framework unless the flame is concentrated on the joint space (see Fig. 27.10).

Oven Soldering

This process is illustrated in Fig. 27.30.
1. Prepare a piece of solder by dipping it in liquid flux and melting it in a Bunsen flame to form a ball. The size of the ball is determined by the connector size and the joint gap.

2. Leave a short tail attached to the ball to help position it above the joint space. As an alternative, the solder can be fed into the joint area.
3. Put the assembly in the furnace and increase the temperature to melt the solder. A vacuum is not needed for oven soldering of noble-metal alloys. Air firing is preferred by some technicians because in a vacuum, there is always the chance of drawing entrapped gases to the surface of glazed porcelain, causing localized swelling or bloating.

Fig. 27.28 Eye protection is essential for high-heat soldering and casting of high-fusing alloys.

Evaluation

If the solder fails to flow during torch soldering but forms a ball above the joint area, heating should be discontinued. The solder has oxidized, and further heating will melt the castings. If the solder has flowed properly, the completed joint can be evaluated for size before removal of the investment and, if necessary, reheated while still hot, with additional solder added. Excessive solder must be ground away during the finishing procedure.

If the connector has been designed properly and the solder has been properly positioned, no solder should run onto the occlusal surface or cover the margins. To prevent stray flow, a small amount of antiflux (rouge dissolved in turpentine) can be painted on critical areas before the assembly is heated. After bench cooling for about 5 minutes, the assembly is quenched (postsoldered metal-ceramic prostheses are always allowed to cool to room temperature), and the investment is broken away (Fig. 27.31). The connector is then carefully inspected. If signs of an incomplete joint are evident (i.e., visible porosity in the solder), they are removed by grinding with a fine disk; the units are then reinvested and resoldered.

The joints must be tested for strength (Fig. 27.32). Any connector that can be broken by force of hand will not serve adequately in the mouth. Because broken connectors

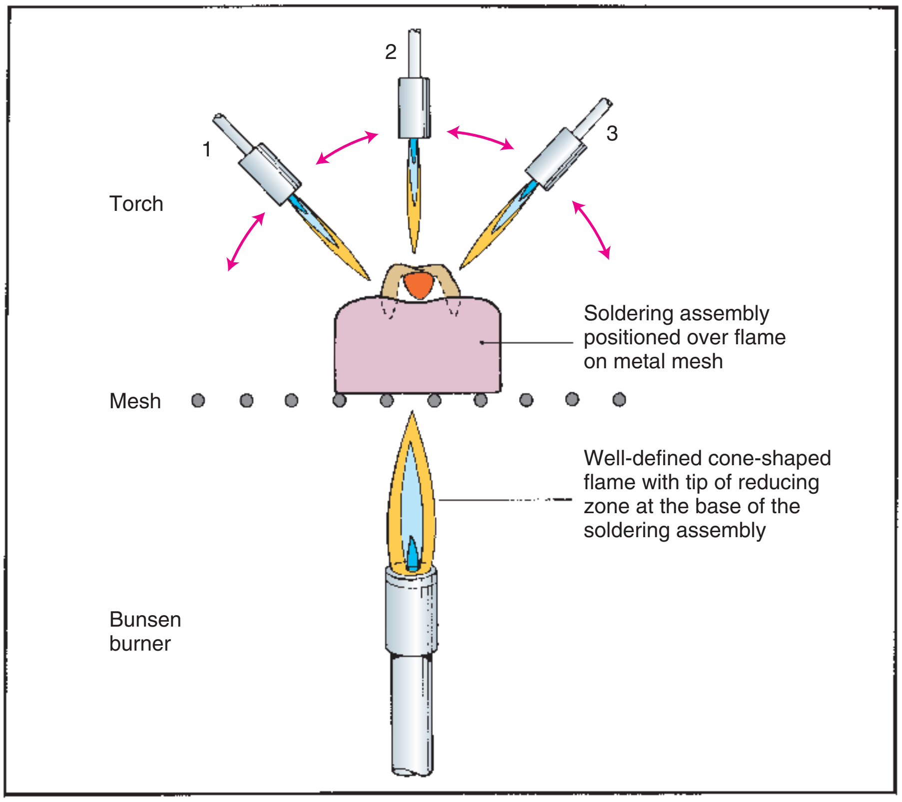

Fig. 27.29 The flame is directed at the connector immediately when the solder melts and is moved around from position *1* to positions *2* and *3*. This ensures that a complete meniscus is formed.

Fig. 27.30 Oven soldering procedure. (A) The invested fixed partial denture (FPD) before soldering. (B) A small amount of flux is added to the clean joint area. (C and D) Solder is added, and the assembly placed in the oven. (E) The soldered FPD. (F) The soldering index is used to assess soldering accuracy. (G) Oven-soldered connector before finishing.

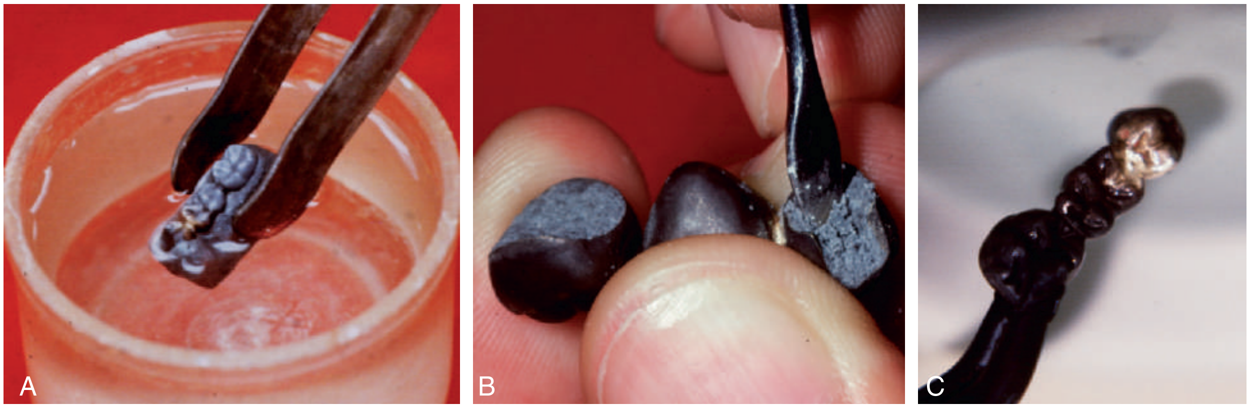

Fig. 27.31 (A) After bench cooling for approximately 5 minutes, the assembly is quenched. (B) The investment is removed from the castings. (C) Surface oxides are dissolved in a pickling solution.

Fig. 27.32 Solder joints should always be tested for strength.

cannot be easily repaired intraorally once the prosthesis has been cemented, the entire restoration usually must be remade.

REVIEW OF TECHNIQUE

Fig. 27.33 summarizes the steps involved in FPD connector fabrication and should be referred to when the material is reviewed.

1. The design of connectors is determined in the wax pattern (see Fig. 27.33A).
2. All soldered connections require clean parallel surfaces. Gap width should be 0.25 mm (see Fig. 27.33B).
3. The units are indexed either from the definitive cast or in the patient's mouth (see Fig. 27.33C).

Fig. 27.33 Technique review. (A) The design of connectors is determined in the wax pattern. (B) All soldered connections require clean parallel surfaces. Gap width should be 0.25 mm. (C) The units are indexed either from the definitive cast or in the patient's mouth. (D) Wax is added to the indexed restorations to shape the soldering assembly. For metal-ceramic restorations, it is added to protect the porcelain. (E) The units are invested, and the investment is allowed to bench set. (F) If a plaster or zinc oxide–eugenol index is used, wax is eliminated with boiling water or an organic solvent, the joint is fluxed, and the assembly is preheated in a burnout furnace. (G) If a resin index has been used, it is placed directly in the burnout furnace. (H) Resin eliminated. The connectors are soldered with a torch or in a porcelain furnace.

4. Wax is added to the indexed restorations to shape the soldering assembly. For metal-ceramic restorations, it is added to protect the porcelain (see Fig. 27.33D).
5. The units are invested, and the investment is allowed to bench set (see Fig. 27.33E).
6. If a plaster or ZOE index is used, wax is eliminated with boiling water or an organic solvent, the joint is fluxed, and the assembly is preheated in a burnout furnace (see Fig. 27.33F).
7. If a resin index has been used, it is placed directly in the burnout furnace (see Fig. 27.33G).
8. The connectors are soldered with a torch or in a porcelain furnace (see Fig. 27.33H).

SUMMARY

Connectors join individual retainers and pontics. Rigid or nonrigid connectors can be used. Connector size, shape, and position influence the success of an FPD. The use of soldered connectors can simplify the fabrication of larger FPDs, which may be cast separately in groups of one or two units and assembled after their individual fit has been verified. The technical procedures involved in soldering are not difficult. If the joint surfaces have been correctly designed and soldering gap width has been carefully controlled, the procedures are routine. All debris must be removed from the connector area because it interferes with surface wetting.

Conventional soldering involves the assembly of type II, III, or IV gold castings. Presoldering is the assembly of metal-ceramic substructures before porcelain application. Postsoldering is the assembly of metal-ceramic units after porcelain application. Heat sources used for soldering procedures include gas-air torches, gas-oxygen torches, furnaces, and laser units.

If the basic principles are understood and the technique has been mastered, these procedures are entirely reliable.

STUDY QUESTIONS

1. Contrast soldering, brazing, and welding.
2. Discuss how biologic, mechanical, and esthetic considerations affect connector size and position for each of the following classes of teeth: incisors, premolars, and molars.
3. When and why would a nonrigid connector be used? A loop connector?
4. Discuss fineness and carat. What is their importance in dental soldering?
5. How do soldering investments differ from conventional casting investments? Why?
6. What is flux? Antiflux? How do they work? Give several examples of each.
7. What are the fundamental differences among conventional soldering, postsoldering, and presoldering? When contrasting the last two techniques, identify the advantages and limitations associated with their use.
8. Describe the step-by-step procedures for two techniques to make a soldering index for a fixed partial denture. What are the respective advantages and limitations?

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28

Finishing the Metal Restoration

A metal restoration is not ready for evaluation and cementation merely because it has been stripped of its investment. The unpolished surface is relatively rough, and a series of finishing procedures is needed to produce highly polished axial surfaces. Such surfaces limit the accumulation[1,2] and retention[3] of plaque and facilitate maintenance of the health of the supporting periodontal tissues. The sprue needs to be removed, and the area of its attachment must be recontoured. Any nodules or other minor irregularities remaining on the cast surface must be eliminated.

Metal finishing for metal-ceramic restorations is similar to that for metal crowns. The discussion in this chapter applies to both restoration types. In practice, the final polishing of metal-ceramic restorations is not performed until after characterization and glazing (see Chapter 29). Titanium restorations require special polishing armamentarium and techniques.[4]

OBJECTIVES AND PROCEDURES

The objectives and procedures for finishing are different for each part of the crown. The following discussion is sequentially divided into corresponding phases; each is identified as a zone (Fig. 28.1).

Zone 1: Internal Margin

Objective

To minimize dissolution of the luting agent, a 1-mm-wide band of metal immediately adjacent to the margin must be closely adapted to the tooth surface.[5] A discrepancy within this zone can significantly reduce a restoration's longevity. Good adaptation is obtained by careful reflowing of the wax pattern (Fig. 28.2). With careful standardization of technique, the dental technician can achieve predictable and consistent results.

Procedure

If a defect occurs in the marginal area, the restoration must be remade. This may necessitate an additional patient visit to make a new impression. Defects can be prevented or minimized by paying particular attention to reflowing the margins of the wax pattern and through careful investing (see Chapter 22).

Even small nodules can prevent a casting from seating completely. Careful examination under ample magnification helps identify such interferences. Small nodules, if far enough away from the margin itself, can be removed under a 10x binocular microscope with cautious use of small rotary instruments (e.g., a No. ½ round bur). However, great care is needed to avoid damage to the margin and costly remakes.

Zone 2: Internal Surface (Intaglio)

Objective

No contact should exist between the die and the internal surface (intaglio) of the casting. A uniform space of 25 to 40 μm is necessary for the luting agent to spread evenly. Any contacts must be identified and relieved by careful selective adjustment of the internal surface.

Procedure

Under normal circumstances, a casting's internal surface does not require finishing. It should, however, be examined for nodules (Fig. 28.3) and must be completed *before* the restoration is seated on the die. Nodules can be removed with a small round tungsten carbide bur, which can be time-consuming because it may need to be repeated several times. If the internal surface needs to be adjusted more than occasionally, the investing procedure should be reexamined for flaws.

Even a very small nodule can result in a significant increase of the marginal gap width (Fig. 28.4). A binocular microscope is especially helpful in identifying nodules. High-quality loupes can also be used. Great care should be exercised when a casting is seated on its die. Any significant force will abrade or chip the die so that the casting will seat on the die but will not seat fully on the prepared tooth. Overlooking this at the cementation appointment will result in a restoration with open margins and a poor prognosis. If a casting does not seat, a nodule may have been overlooked and may have scratched the die, or a little stone may have been picked up in the process. Close examination of the internal surface of the casting or the axial walls of the die (Fig. 28.5) will reveal this. Corrective action is often relatively simple, and the casting may be acceptable. Care must be taken not to seat a faulty casting repeatedly, thereby abrading the die. After a die has been abraded by a casting, it should not be used for rewaxing a restoration. If rewaxing is necessary, a new die is required.

When a nodule is removed from the internal aspect of a casting, it is recommended that a slightly greater amount of alloy in the area. Once the casting has been adjusted, determining the exact location of the nodule is no longer possible. Therefore, the nodule should be removed entirely in one step rather than through sequential relief of the internal surface (Fig. 28.6).

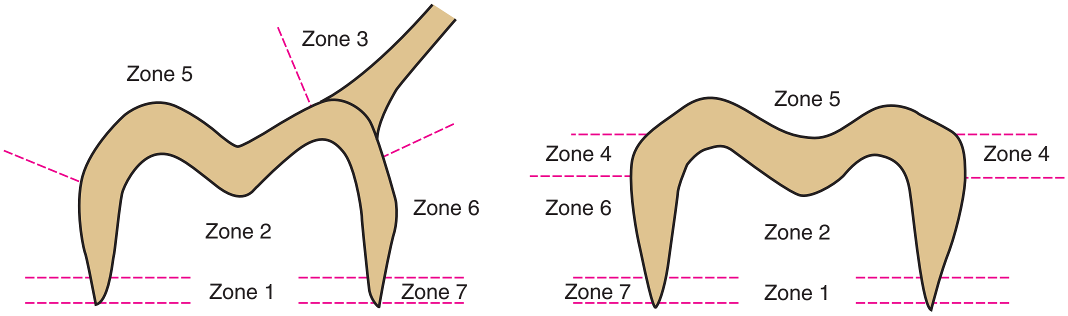

Fig. 28.1 Recommended sequence for finishing of a cast restoration. All procedures for a zone should be completed before the next zone is started. *Zone 1* is the internal margin; *Zone 2*, the internal surface; *Zone 3*, the sprue; *Zone 4*, the proximal contacts; *Zone 5*, the occlusal surface; *Zone 6*, the axial walls; and *Zone 7*, the external margins.

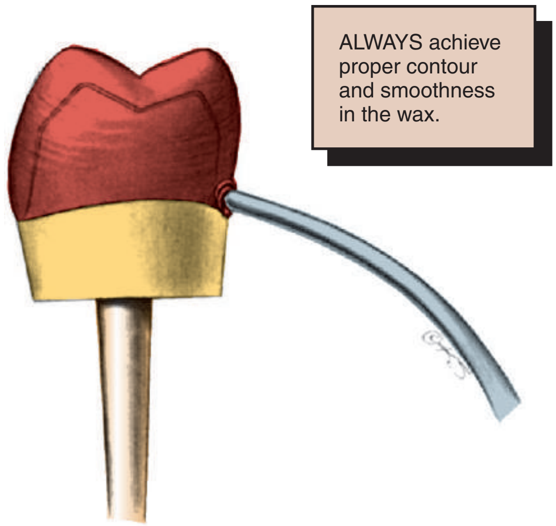

Fig. 28.2 Reflowing of the wax pattern. The objective is to create a well-adapted 1-mm zone to prevent cement dissolution. Proper reflowing before investing is essential.

Fig. 28.3 Nodules on this casting have resulted from improper investing. To enable complete seating of the casting, even small ones such as these must be removed entirely.

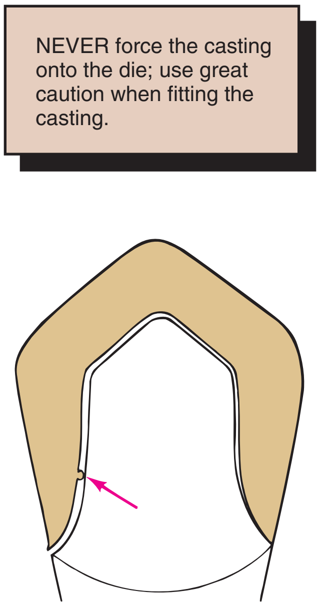

Fig. 28.4 A relatively small nodule *(arrow)* results in a substantial marginal gap width.

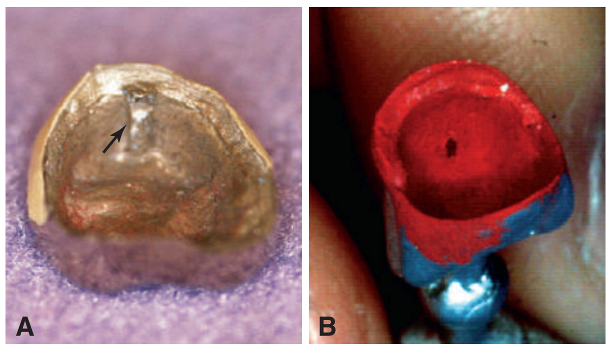

Fig. 28.5 (A) Internal surface of a casting. Note the stone *(arrow)* adhering where the die has been abraded by the casting. (B) A suitable marking agent (e.g., rouge and turpentine) can be used to detect areas that must be relieved to allow complete seating.

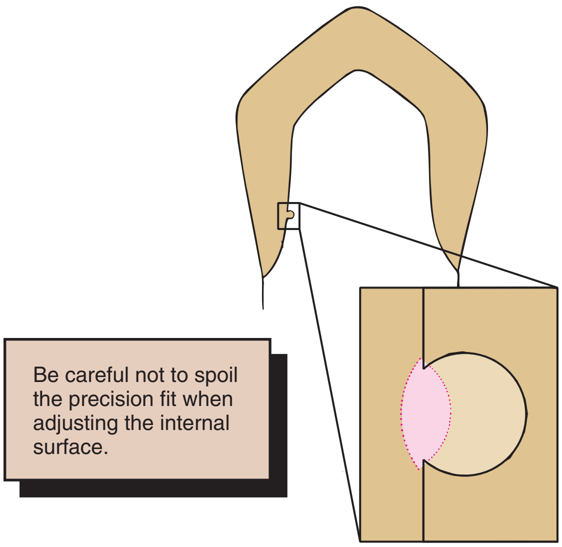

Fig. 28.6 When a nodule is removed, removing slightly more than the defect ensures complete seating of the restoration.

Indiscriminately removing material from the internal aspect of any casting is not an acceptable alternative. This results in excessive loss of retention and resistance form, and the restoration must be remade.

Marking agents. Several agents are commercially available to facilitate the identification of the seating interference between the casting and the die. These include water-soluble (e.g., Liqua-Mark, American Dental Supply, Inc., Allentown, PA) and solvent-based dyes (e.g., AccuFilmII, Parkell, Inc., Edgewood, NY). Powdered sprays (e.g., Occlude, Pascal Company, Inc., Bellevue, WA) have been shown to build up into an excessively thick film and are best avoided when seating crowns on dies.[6] A suspension of rouge in turpentine or an elastomeric detection paste (e.g., Fit Checker, GC America, Inc., Alsip, IL) can also be used as an alternative.[7] These agents should be applied as a thin film to the internal surface of the casting. High magnification of the casting after seating reveals initial contact for grinding (Fig. 28.7). Regardless of the method used, the internal surface of the casting should always be thoroughly cleaned before the luting procedure (see Chapter 30).

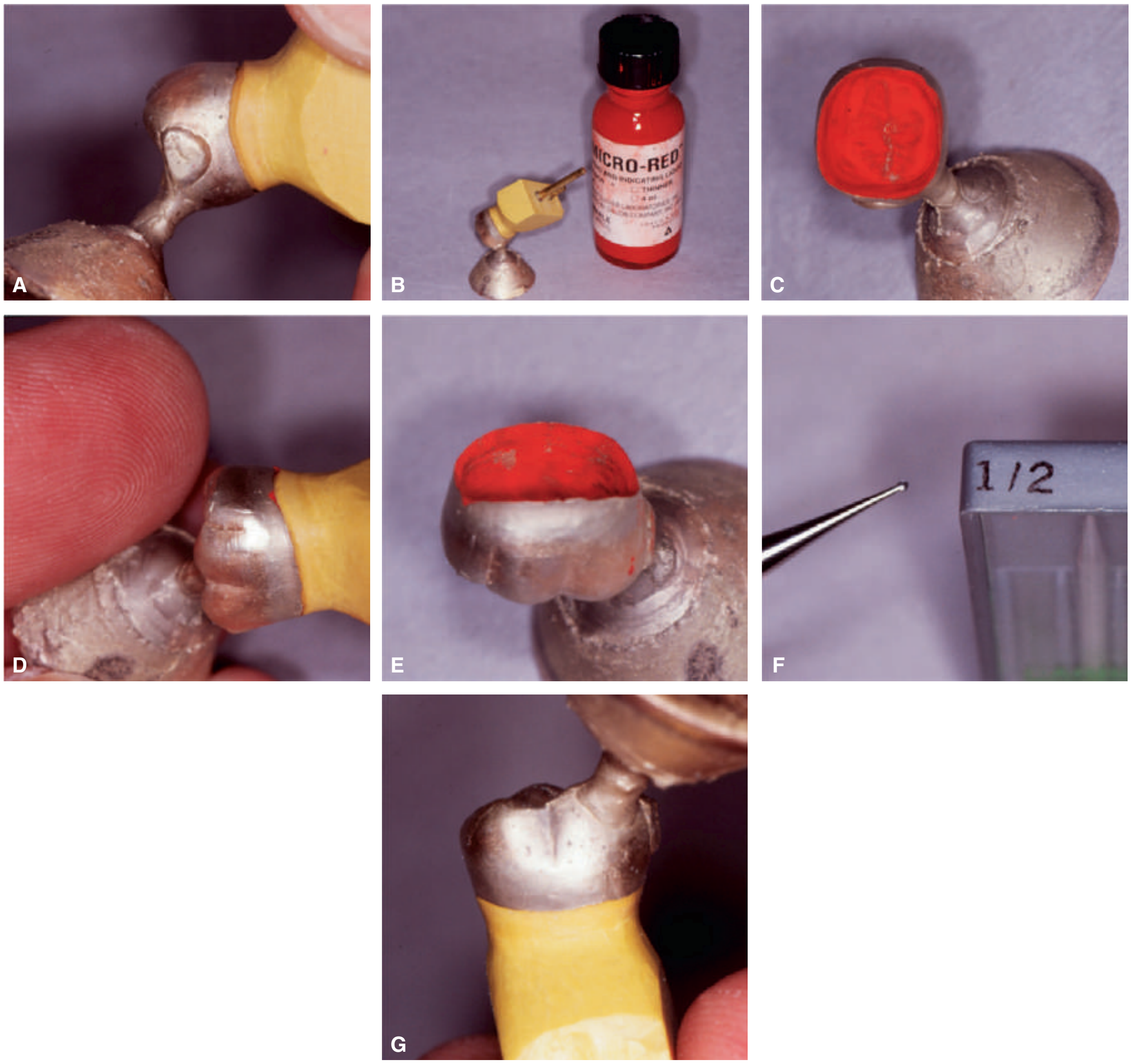

Fig. 28.7 Liquid marking agents can be helpful if the internal surface of a casting has a nodule. (A) Incomplete seating. (B) Liquid marking agent. (C) A thin coat is applied to the internal surface and air-dried. (D) The casting is gently returned to the die. (E) The area of interference is identified. (F) Nodules are best removed with a small round bur. (G) Seated casting.

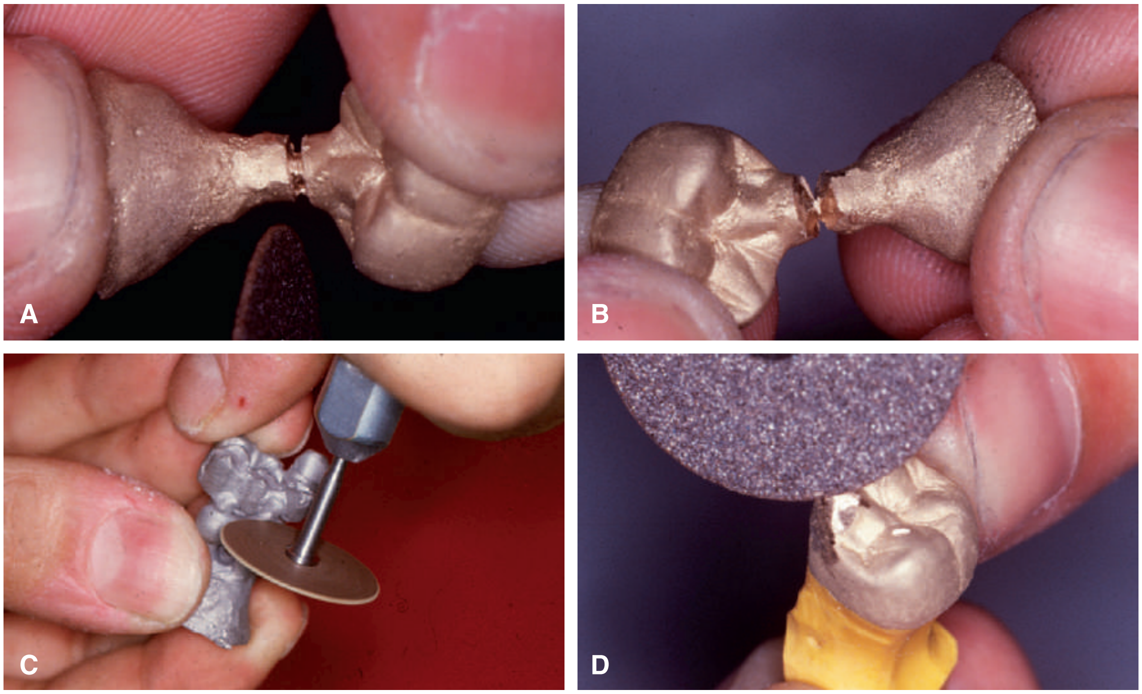

Fig. 28.8 The most effective way to remove the attachment area (A) is to cut around the sprue and then twist it off (B). (C) With multiple castings made simultaneously, access is more difficult. When it is necessary to sever a sprue completely, care must be taken not to damage the margin inadvertently. (D) Disks and stones are used for gross recontouring.

Zone 1: The Sprue

Objective

To reestablish proper coronal structure and function, the sprue must be sectioned, and the casting must be recontoured in the area of its attachment.

Procedure

Once the fit of the casting has been verified on the die, and it is acceptable, the sprue is sectioned, and the area of its attachment to the casting (Fig. 28.8) is reshaped.

A carborundum separating disk is used to cut through the sprue. Cutting should be performed circumferentially, with a small area maintained in the center of the sprue. To break this last connection, it is twisted and separated from the casting. Wire cutters are not recommended because they may lead to distortion of the casting. Any excess in the area of the sprue attachment is removed with the disk, and the area is refined with stones and abrasive paper disks.

Zone 4: Proximal Contacts

Objective

The proximal contact areas are adjusted in the laboratory so that they will be correct (or slightly too tight) when the casting is evaluated in the patient's mouth.

Procedure

Special care is needed to prevent the finishing procedures from producing an overreduced and, consequently, inadequate proximal contact. Although this can be corrected with solder (see Chapter 29), it is a time-consuming and unnecessary procedure.

Fig. 28.9 Rather than risk a deficient proximal contact at evaluation, the technician may reduce the cast slightly by scraping the adjacent teeth with a blade.

A slightly excessive contact, however, may be corrected easily during clinical evaluation. The proximal contacts on the stone cast can be minimally relieved by careful scraping with a scalpel (Fig. 28.9). The casting is then adjusted until it just seats. When adjacent castings are made, they should not be simultaneously adjusted to seat on the definitive cast. Under these circumstances, the proximal contacts should be left slightly too tight in the dental laboratory. Such multiple castings are clinically evaluated sequentially and on an individual basis. Adjustments are made for each casting independently.

When proximal contacts are adjusted, placing a thin articulating film (Mylar) between adjacent castings or between the casting and the adjacent tooth is helpful (Fig. 28.10). Doing this allows the areas where binding contact occurs to be adjusted through selective adjustment where markings result. When a

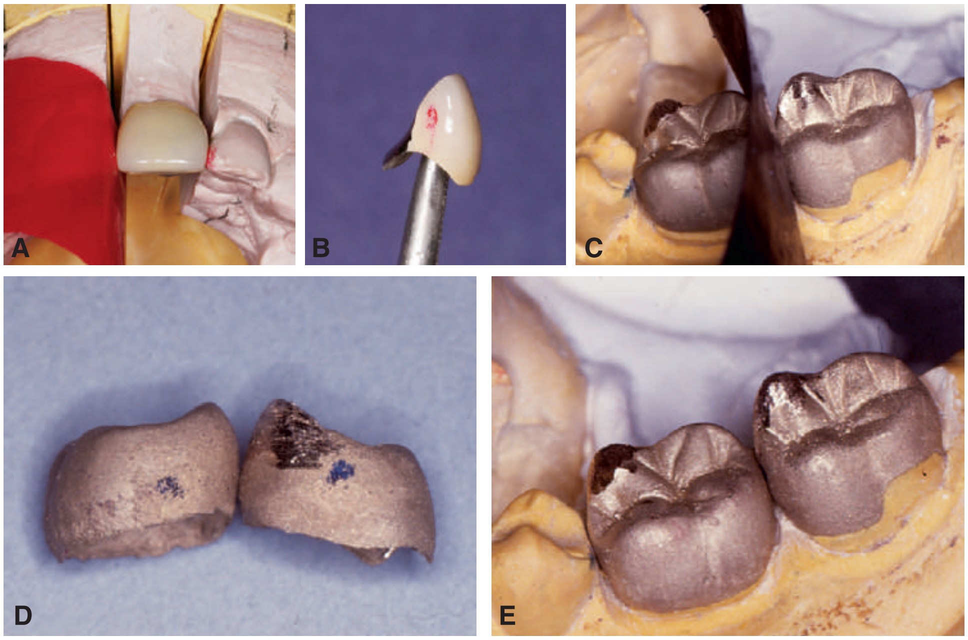

Fig. 28.10 (A) Thin articulating film interposed between a metal-ceramic restoration and the adjacent tooth. (B) The area of contact that prevents complete seating is readily apparent. (C–E) Articulating film is used to detect the location of an excessive proximal contact on cast metal.

contact is still slightly tight, rubber wheels are recommended lest too much metal is removed. It can be challenging to obtain a visible mark on such metal. Creating a matte surface with air abrasion will result in a more visible mark.

Connectors

When a partial fixed dental prosthesis is being finished, the connectors require special attention. Unless they are properly contoured and highly polished, periodontal health is invariably adversely affected, even in the presence of the most meticulous oral hygiene. Mesiodistally, a properly finished connector has a parabolic configuration (Fig. 28.11). Rotary instruments such as rubber wheels, which allow access to the cervical aspect of the connector for finishing while not jeopardizing the margin, are essential in these situations. In cases of root proximity between adjacent teeth, this can be quite challenging. After preliminary finishing with rubber wheels, a piece of twine impregnated with polishing compound can be used to achieve the final polish to the cervical aspect of the connector (Fig. 28.12).

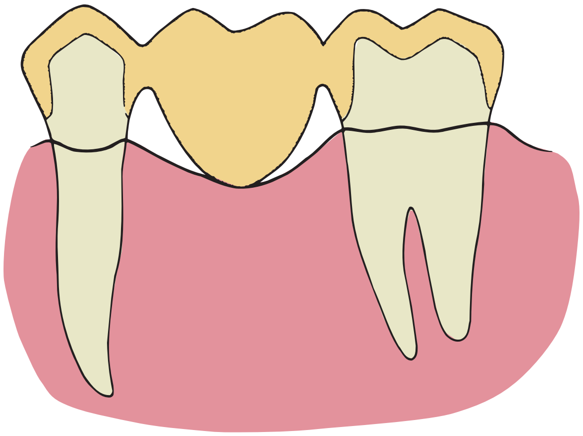

Fig. 28.11 Cross-sectional illustration of properly finished connectors.

Zone 5: Occlusal Surface

Objective

Occlusal contacts are reestablished in static and dynamic relationships to the opposing arch. Obtaining accurate and stable contacts does not require highly polished metal occlusal surfaces; a satin finish is acceptable. Occlusal form must ensure positional stability and satisfy all functional requirements (see Chapter 4).

Procedure

The occlusal contacts are checked with thin articulating film (Mylar; Fig. 28.13) to ensure that they match the design in the waxing stage. If they do not, the occlusion must be adjusted. Wax is subject to elastic recovery. If an occlusal contact is heavy in wax, it springs back slightly when the articulator is opened and produces an occlusal prematurity in the casting (Fig. 28.14). If tiny contact points are established carefully during the waxing phase, significant occlusal adjustment should not be routinely necessary.

Occlusal adjustments can be performed with flame-shaped finishing burs or diamonds (Fig. 28.15). A large stone creates unwanted concavities in the occlusal surface. The correct technique for occlusal adjustment is to redevelop the anatomy of the entire ridge or cusp rather than grinding only the point of interference. Simultaneously, any nodules can be removed, and grooves can be defined with a finishing bur or a small round bur.

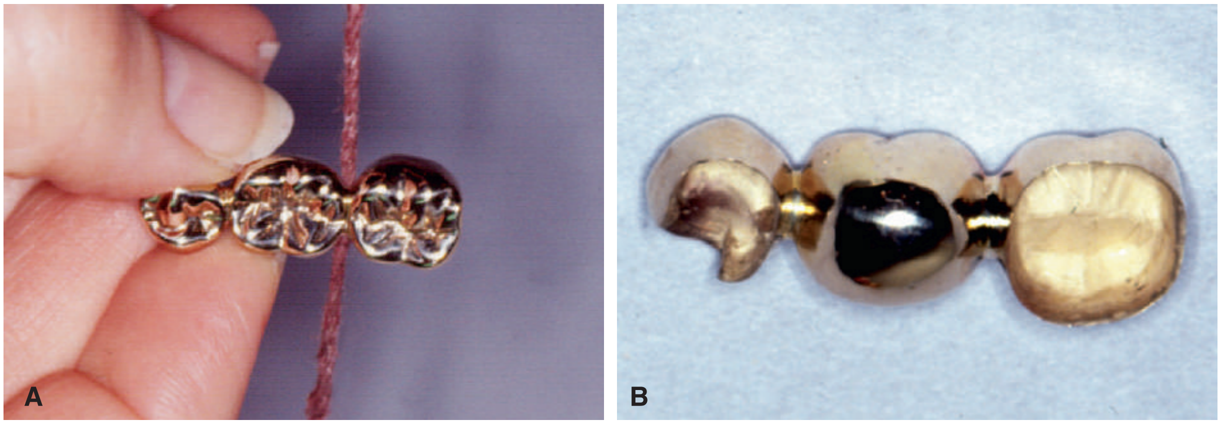

Fig. 28.12 Polishing connector areas. (A and B) Twine impregnated with polishing compound is an efficient way to polish this hard-to-reach area.

Fig. 28.13 After complete seating is verified, the initial point of contact is marked.

Fig. 28.14 (A and B) Occlusal prematurities are generally the result of excessively heavy contact on the wax pattern.

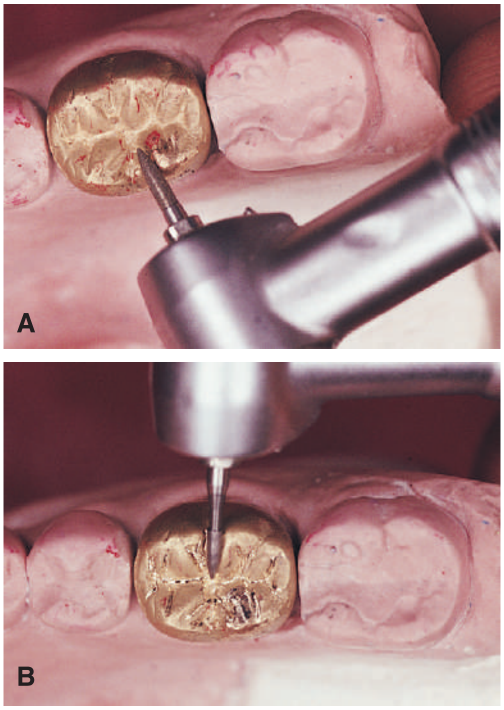

Fig. 28.15 (A) Occlusal adjustment is readily accomplished with a pointed diamond or carbide bur. (B) The grooves and fissures are concurrently refined.

Before starting any adjustment, the practitioner should use a thickness gauge on the metal. If only minimum clearance was established at the tooth preparation stage, indiscriminate adjustment leads to inadequate casting thickness (Fig. 28.16) and possible perforation. Although soldering such a hole in a casting is possible, the occurrence of this complication usually indicates an earlier error that must be corrected (e.g., inadequate clearance necessitates additional reduction of the tooth preparation).

After the occlusal contacts have been refined, they must not be altered by extensive polishing. A high polish may be essential for plaque control on axial surfaces (zones 6 and 7), but its

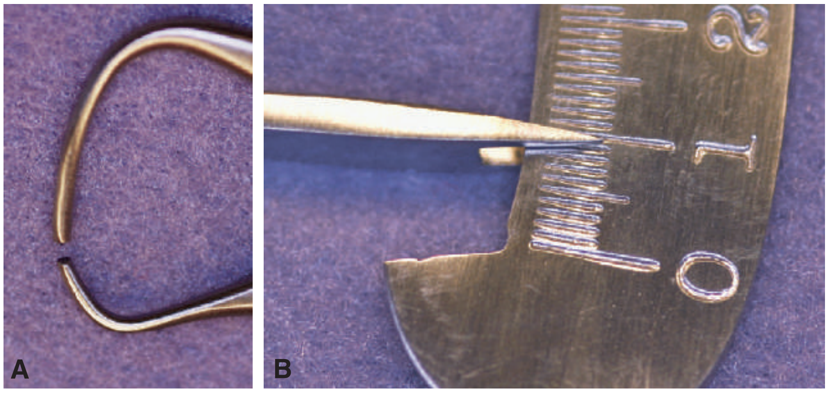

Fig. 28.16 As occlusal adjustments are made, (A) the residual thickness is continually monitored with an appropriately designed thickness gauge. (B) For structural durability, metal thickness of less than 1.0 mm is inadequate and results from insufficient occlusal reduction.

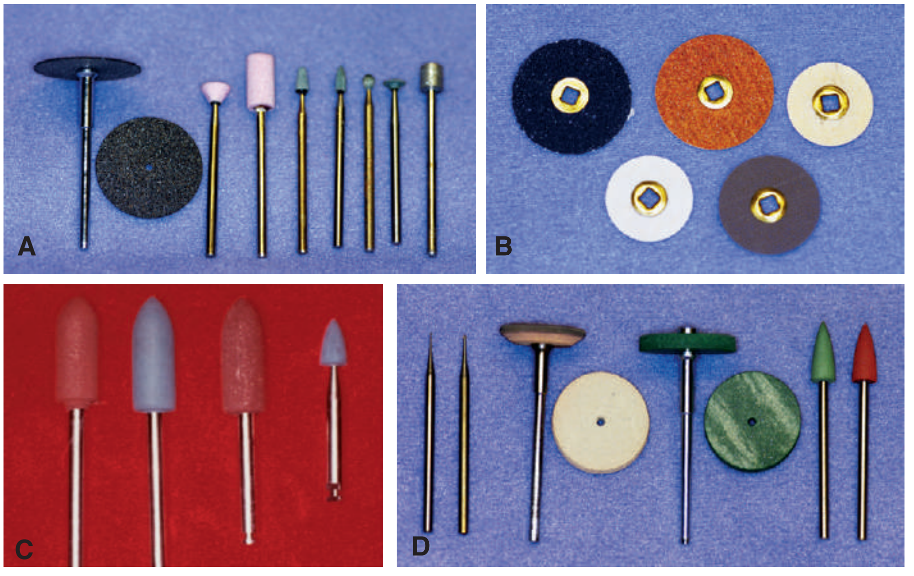

Fig. 28.17 Abrasives for finishing. A sequence of progressively finer grades is used to attain the desired surface. Carborundum disks and stones of varying degrees of coarseness (A) are typically used first; these are followed by garnet paper and abrasive paper disks (B), rubber points and white Arkansas stones (C), and rubber wheels and points, along with small carbide burs for removing nodules (D).

benefit on the occlusal surface of metal castings is questionable. An accurate occlusion so painstakingly established in wax can be rapidly destroyed by overzealousness to make a casting look "shiny."

If the wax pattern has been carefully finished, a smooth casting results, and removing surface oxides with a soft wire brush wheel is sufficient. The surface can then be polished with rouge on a soft brush wheel (which removes only 5 µm from the surface of the casting[8]; see Fig. 28.19).

Some authorities[9] recommend producing a matte finish on the occlusal surfaces to aid in the initial identification of wear facets during function, which show up as shiny marks on an otherwise dull surface. This type of finish is usually achieved with an airborne-particle abrasion unit and 25- to 50-µm Al_2O_3 (alumina) particles. However, a 5-second blast with 50-µm alumina at 0.5 MPa (73 psi) pressure has been shown to remove about 20 µm of metal from the abraded surfaces[10]; therefore, the margins should be protected.[11] An exposure of about 1 second usually produces a smooth satin finish. If this cannot be accomplished, the finishing procedures before this step are likely deficient, and further refinement is necessary.

Zone 6: Axial Walls

Objective

When axial wall finishing is completed, the walls should be smoothly contoured and highly polished, enabling the patient to perform optimum plaque control.

Procedure

Surface defects are removed by grinding with abrasive particles bound into a grinding stone or rubber wheel, on a paper disk, or applied as an abrasive paste (Fig. 28.17). Each particle acts as a cutting tool on the metal surface.

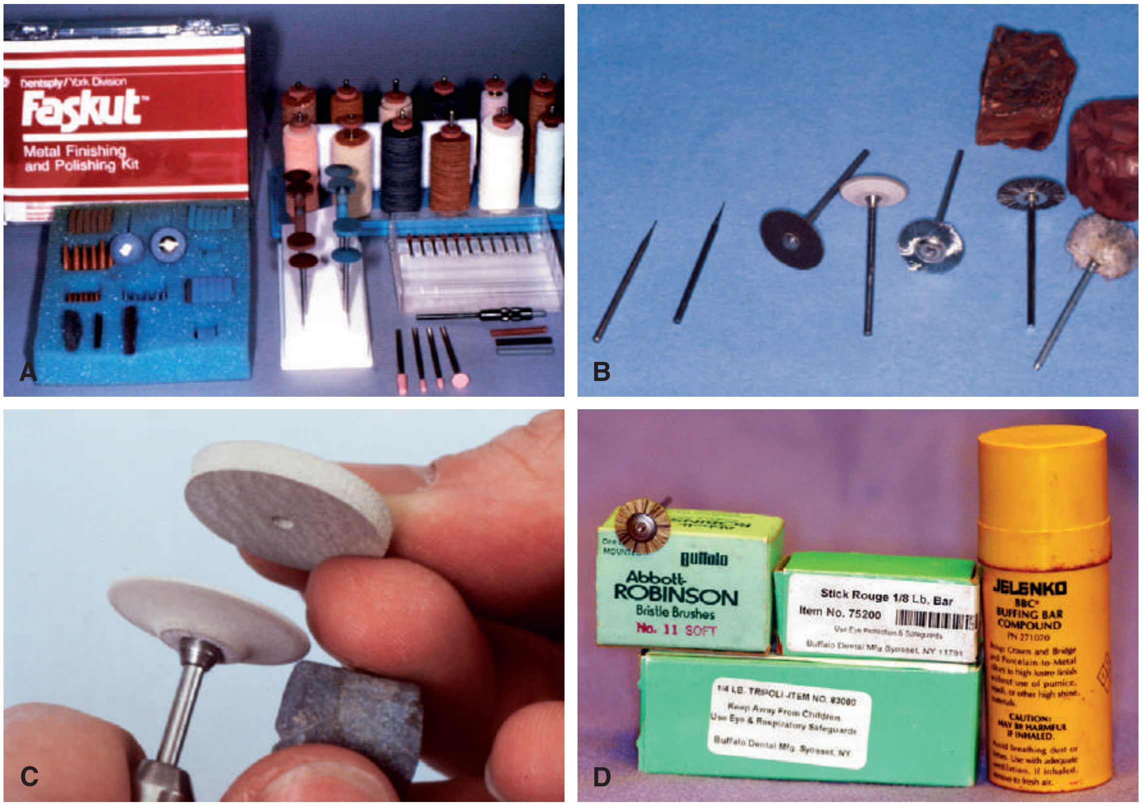

Fig. 28.18 Finishing armamentarium. (A) Assorted abrasives, abrasive paper disks, rubber points, and polishing wheels. (B) Instruments used include small carbides (for removing nodules) and a steel wire brush (for occlusal surface smoothing) to buffing wheels and compounds. (C) A coarse wheel is used to true and thin the edge of a rubber wheel. (D) Buffing compounds applied on a felt wheel or bristle brush.

The most efficient method of polishing[12] is to use a sequence of progressively finer abrasives (Fig. 28.18), each removing the scratches remaining after use of the previous grade. Time is wasted if the progression to a finer grade abrasive is too rapid because the coarser grits remove material much more efficiently.

Light pressure is applied when abrasives are used, and the disks and wheels are moved continuously over the surface rather than held stationary in any single location. Otherwise, the surface of the casting is ground into a series of facets that will preclude achieving a deep luster and ultimately can impede plaque control. When all surface irregularities have been removed, and the progression through the series of abrasives has left a finish with only minute scratches, the axial surfaces of the restoration are polished with the polishing compounds of choice. Tripoli polishing compound consists of naturally occurring silica and finely weathered chert from schistose rocks and is used on a polishing brush at high rotational speeds with intermittent pressure to achieve a smooth pre-polished surface. This is followed by using jeweler's rouge, a mixture of ferric oxide and tallow, which serves as a binder. The use of these will readily lead to the development of a deep luster.

Jeweler's rouge rapidly produces a high polish on a well-prepared surface of a dense casting (Fig. 28.19k). This is carried on a wheel or brush, with heavier pressures and higher rotational speeds than were used in finishing (see Fig. 28.19).

Alternative polishing compounds contain carborundum chips which break up into smaller pieces as polishing progresses, allowing pre-polishing and final polishing to be done with a single material. The efficacy of polishing compounds is a function of the physical properties of the metal being finished.

Zone 7: External Margins

Objective

Margin finishing is crucial for a cast restoration's longevity and therefore merits special attention. The objective of all cast restoration finishing is a highly polished metal surface without ledges or steps as the transition is made from restoration to unprepared tooth. Failure to accomplish this leads to compromised plaque control.

Procedure

Where access allows, cavosurface margins should be finished directly on the tooth (see Fig. 29.27). Unfortunately, the areas where access for finishing is restricted (i.e., proximally or subgingivally) are precisely where plaque control presents the most problems. Therefore, only the least crucial areas can be finished intraorally. An advantage of partial-coverage restorations over complete crowns is that they allow better access for finishing margins and subsequent plaque control.

Fig. 28.19 Finishing and polishing. (A) Initially a wire brush is used on the occlusal surfaces. (B) A fine-grit abrasive paper disk is applied to remove pits and irregularities from the axial walls. Note that the margin is not touched at this time. (C and D) Rubber points and small carbides are used for selective finishing of the occlusal structure. (E) A rubber wheel is then used on the axial walls. (F) Castings, after polishing with buffing compound, immediately before clinical evaluation. (G) When the fit has been verified clinically, the margins are polished. (H and I) The completed castings immediately before cementation. (J) Scanning electron micrograph of a gold alloy in the "as-cast" state. (K) The same casting after finishing and polishing with a series of abrasives, culminating in rouge. (J and K, Courtesy Dr. J.L. Sandrik.)

The parts of the margin that cannot be finished on the tooth are finished on the die (Fig. 28.20). Care must be taken not to remove more metal than is strictly necessary. Excessive finishing creates problems similar to those caused by incomplete polishing. This raises the issue of how much material can be removed from the surface of a casting without compromising the ultimate fit and emergence profile of the finished restoration.

A stone die from an elastomeric impression is approximately 25-µm wider than the tooth because of polymerization and thermal shrinkage of the impression material and expansion

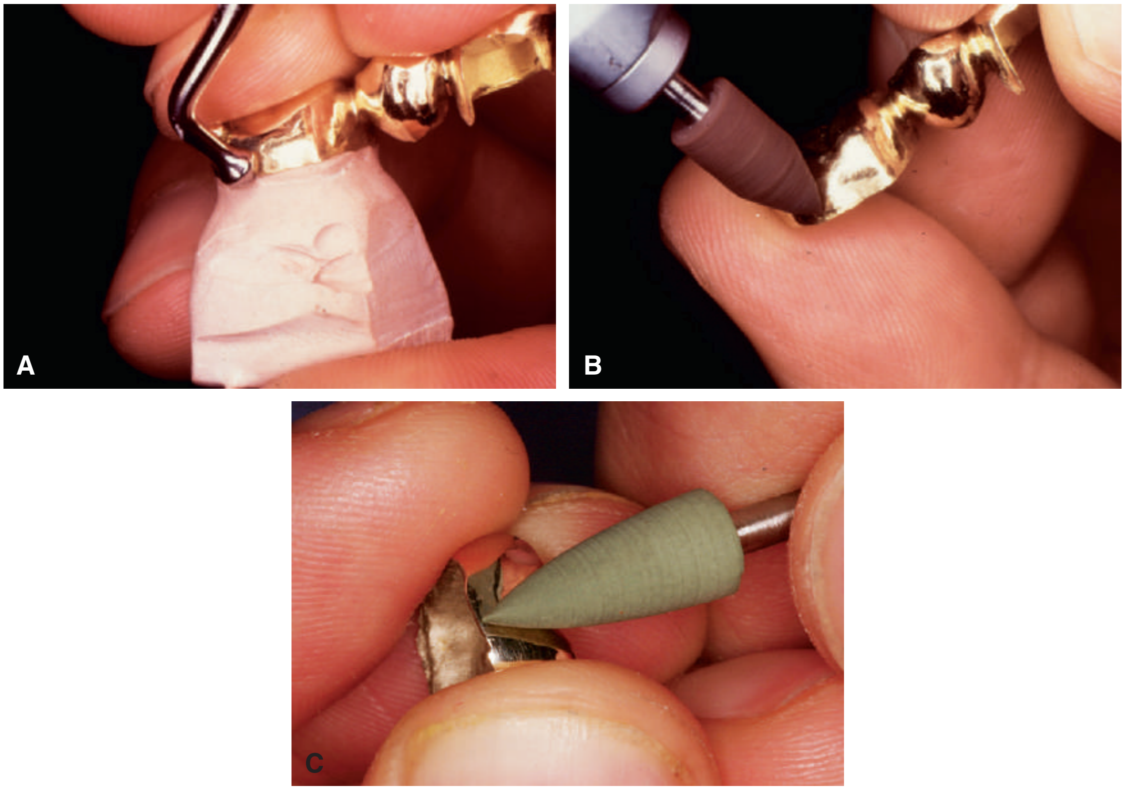

Fig. 28.20 When subgingival margins do not allow access, final finishing is performed on the die. During final polishing, the margin is carefully supported with a finger. (A) Carefully rubbing a smooth instrument along the length of the margin (burnishing). (B) Gently brushing a fine-grit stone over the surface to remove casting roughness. (C) Using a soft rubber wheel or point.

of the gypsum.[13] In theory, therefore, if 12.5 μm is removed during finishing, the casting will be flush with the tooth surface. Although these values cannot be measured on a day-to-day basis in a dental office, they illustrate the tolerances of and restrictions imposed by the materials that are currently in use.

The edge of the margin must not be distorted during finishing, although carefully rubbing a smooth instrument along the length of the margin (burnishing; see Fig. 28.20A) may improve the margin,[14,15] but only when softer alloys are used.[16] Unfortunately, burnishing does not make a poorly fitting margin acceptable.

To perform finishing, a fine-grit stone should be brushed gently over the surface to remove casting roughness (see Fig. 28.20B). This is followed by brushing with a soft rubber wheel or point (see Fig. 28.20C) and finally by rouge on a brush. The margin should be supported with a finger during final polishing.

When the casting is smooth on all critical surfaces, any remaining polishing compound can be removed with a soft toothbrush, by ultrasonic cleaning in an appropriate solution, or by steam cleaning.

REVIEW OF TECHNIQUE

Fig. 28.21 presents the steps involved in finishing a restoration and should be consulted when techniques are reviewed.

1. The internal margin is inspected to confirm that the casting accurately reproduces the prepared tooth and is intimately adapted to the prepared surfaces adjacent to the margin (see Fig. 28.21A).
2. The internal surface is inspected under magnification and adjusted as necessary with small stones and tungsten carbide burs. Adjustments are restricted to areas where binding contacts occur (see Fig. 28.21B).
3. The casting should seat completely without force and without noticeable rocking or instability (see Fig. 28.21C).
4. The sprue is removed (see Fig. 28.21D).
5. The area of its attachment is reshaped (see Fig. 28.21E).
6. The proximal contact areas are identified (see Fig. 28.21F).
7. On the cast, proximal contacts can be left slightly tight before the clinical evaluation appointment (see Fig. 28.21G).
8. The occlusal surfaces are evaluated and adjusted. No centric or excursive interferences should remain (see Fig. 28.21H).
9. The axial surfaces are finished and polished (see Fig. 28.21I). Finishing the cervical aspect of axial walls on metal-ceramic restorations is postponed until after final glazing and characterization. In addition, if a soldering procedure is anticipated, the marginal area is left unfinished until the soldering has been completed and the fit of the assembled prosthesis is acceptable.
10. The polished restoration is cleaned. A steam cleaner or ultrasonic cleaner (with the appropriate solutions) can be used (see Fig. 28.21J). The cleaned castings are seated on the definitive cast.

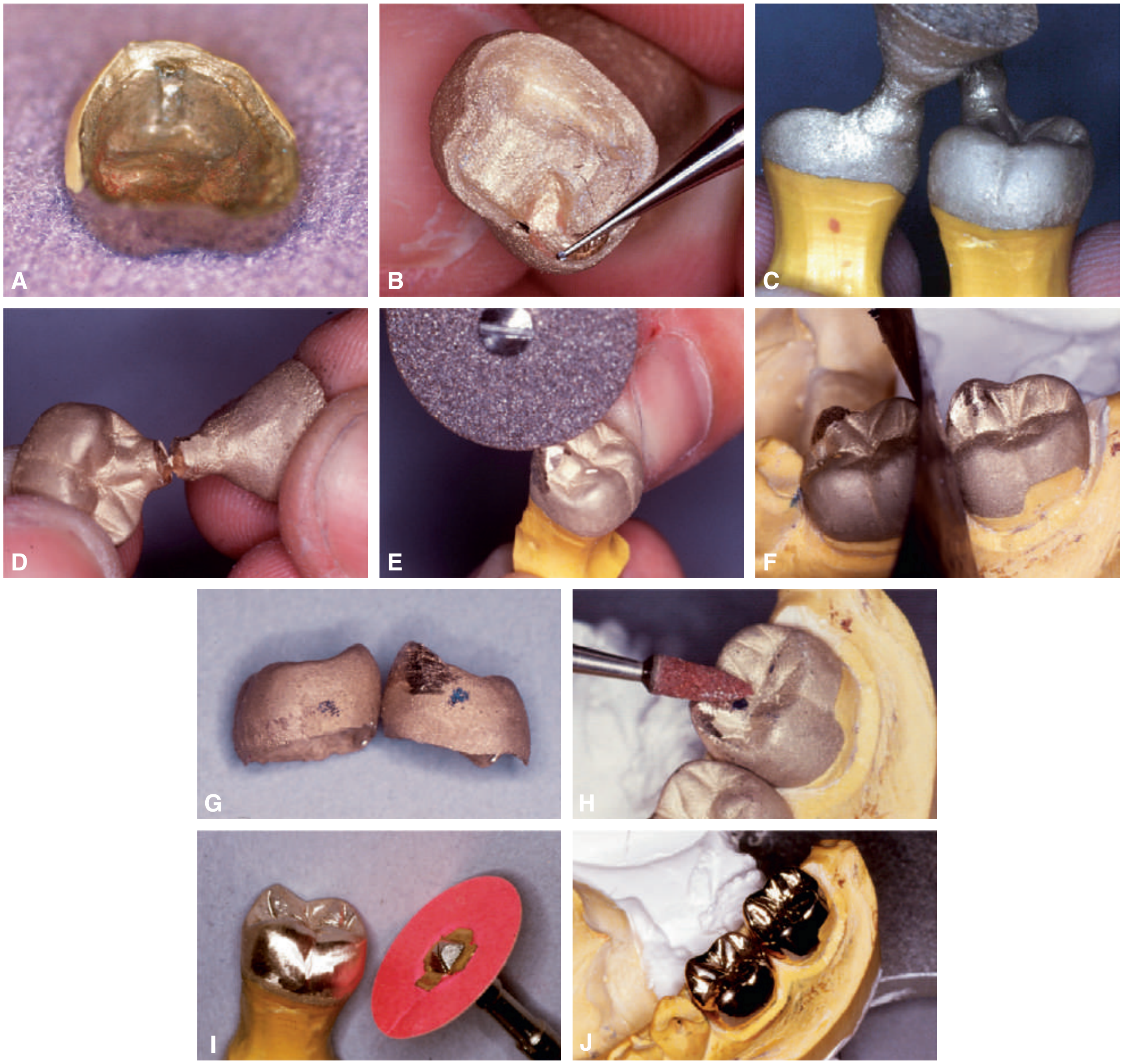

Fig. 28.21 Technique review. (A) The internal margin is inspected to confirm that the casting accurately reproduces the prepared tooth and is intimately adapted to the prepared surfaces adjacent to the margin. (B) The internal surface is inspected under magnification and adjusted as necessary with small stones and carbide burs. (C) The casting should seat completely without force and noticeable rocking or instability. (D) The sprue is removed. (E) The area of its attachment is reshaped. (F) The proximal contact areas are identified. (G) On the cast, proximal contacts can be left slightly tight before the clinical evaluation appointment. (H) The occlusal surfaces are evaluated and adjusted. (I) The axial surfaces are finished and polished. (J) The polished restoration is cleaned.

STUDY QUESTIONS

1. What is the purpose of finishing and polishing the margin of a cast restoration? The occlusal surface? The proximal contact area?
2. What is the recommended procedure for severing a sprue?
3. What is the recommended procedure for removing a nodule?
4. What is the recommended procedure for shaping and finishing a connector for a partial fixed dental prosthesis?
5. Discuss the uses and limitations of air-particle abrasion in finishing cast restorations (gold and metal-ceramic).

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29

Evaluation, Characterization, and Glazing

QUALITY ASSESSMENT PART 1: EXTRAORAL ASSESSMENT

The first quality assessment is critical evaluation of the restoration once it is returned from the dental laboratory. A laboratory prescription (see Chapter 16) is a legal document. It is important to confirm that what was prescribed is what is received. In addition, the quality of the prosthesis must be assessed well before the patient appointment for intraoral evaluation. Not only does such evaluation give the dentist a sense of its quality, but it also provides an opportunity to anticipate how the prosthesis will be seated. For instance, when multiple crowns are involved, there may be an ideal or necessary sequence for the individual crowns to be placed to accommodate individual paths of placement dictated by their proximal contacts. Before the patient appointment, the marginal fit, axial contours, size and location of proximal contacts, and occlusion are evaluated. If the prosthesis does not meet the dentist's clinical standards or when the prescription was not followed, the laboratory should be contacted and the prosthesis possibly returned. Requesting a laboratory to remake a prosthesis is a serious request, and the relationship between the dentist and laboratory must have well-defined individual goals and responsibilities (see Chapter 16). For example, the laboratory cannot make an ideal crown margin from a definitive impression with a void on a finish line. There are many clinical errors that can accumulate and result in unacceptable laboratory work that are not the laboratory's responsibility. A definitive cast gives the dentist an opportunity to evaluate their own work outside of the patient's mouth. Ongoing critical self-assessment of one's own tooth preparations and tissue management will inevitably improve one's clinical skills.

Once the dental laboratory technician has accepted a dentist's work authorization, it is his or her responsibility to make a prosthesis that fits the definitive cast. It is not the dental laboratory technician's responsibility to make a prosthesis to fit the patient's mouth. Consequently, the definitive cast becomes the moderator between the dentist and dental laboratory technician, and so its accuracy is vital (Fig. 29.1).

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology can fabricate definitive restorations without the traditional stone casts. Although stone casts are still the standard in trueness, casts can be accurately fabricated digitally and evaluated virtually or manufactured through stereolithographic three-dimensional (3D) printing (Fig. 29.2).[1,2] Even though multiple techniques exist to make accurate "casts," it is more important for the professional to know how to perform routine methods for quality assessment of prostheses than it is to master the fabrication techniques themselves. To acquire this skill, dental professionals need to devote significant time and effort participating in the fabrication process of digital prostheses. In an evaluation of the quality of zirconium dioxide frameworks produced by five different laboratories from five different countries, using the same standardized CAD-CAM chain of production, significant variability existed in framework quality. Clinically significant differences in quality existed in margin fit and connector and pontic design, and even postprocessing traces were detected.[3] Without a standardized method for quality assessment, determining the cause of a clinically unacceptable restoration is far more challenging, and errors that are missed at this stage have a high risk of being repeated.

Stone Die Casts

Much research has gone into the accuracy of stone casts to be able to reproduce an exact duplicate of a patient (Fig. 29.3).[4–8] Consequently, stone casts have had a long and successful history in dentistry.

Advantages

- Accurate for both partial and complete dental arches
- Crown margins can be closely inspected on a die
- High-quality reproduction of surface texture
- When die spacer is used, it can aid in the correction of a tight-fitting intaglio surface of a definitive crown that does not fully seat in a patient.
- No monthly or annual fees to maintain the equipment
- Good for creating monolithic and bilayered restorations

Disadvantages

- Sectioned dies can exhibit die instability
- Stone dies can abrade
- Extraoral evaluation of tooth preparations are delayed until casts are fabricated

Fig. 29.1 (A) Evaluation of definitive prostheses on stone casts. Here, the prostheses are evaluated for fit and occlusion, along with the proportions and contours of the teeth. Any errors detected should be reported to the dental laboratory technician and returned for corrections. (B) The prostheses fit and occlusion intraorally should be identical to that on the casts. (C) Dentofacial assessment. Confirmation that the tooth position is identical to that in the original plan. Only after the dentist approves the prostheses should the patient do their own esthetic evaluation before cementation.

Fig. 29.2 Example of a digital die. The finish lines have been marked by the dentist, and the image provides an immediate self-assessment of the tooth preparations.

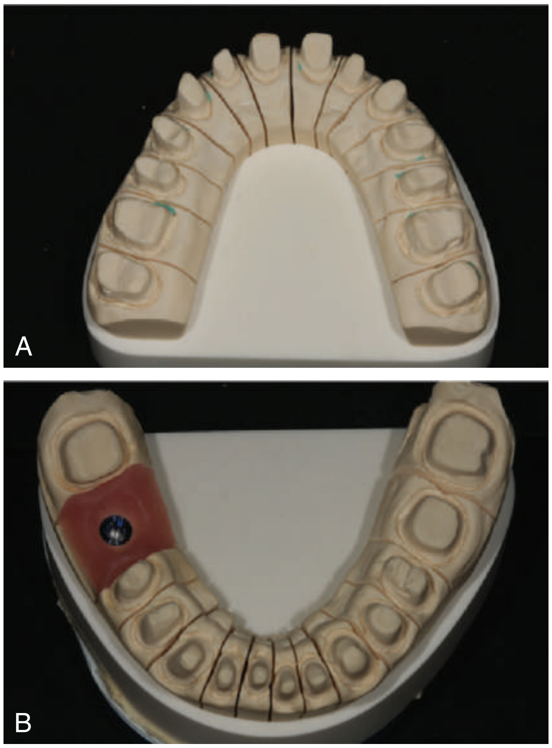

Fig. 29.3 (A and B) Maxillary and mandibular stone die casts. (Photographs courtesy Harald Heindl, CDT.)

- Time consuming
- Technique sensitive with a steep learning curve
- Color is not communicated to the laboratory with stone casts
- Expense of shipping the case between the dentist and laboratory

Solutions

- Die instability will affect the proximal contacts. To address this problem and have perfect proximal contacts, create a solid cast (Fig. 29.4). Pouring an additional cast from the same impression that is not sectioned for dies gives a true representation of the patient in regard to proximal and occlusal contact. To seat a crown on a solid cast, the gingival tissues on the cast must be trimmed away. In situations where the definitive crown has good proximal contacts on the die cast, still evaluate and adjust them on the solid cast if needed.
- Use of a die spacer permits visual evaluation if the die was abraded. When the die spacer is partially missing, the initial seating of the definitive crown may have been rushed. It is possible to push a crown on to a die and forcefully make it fit because of abrasion of the stone. If a die is badly abraded, a new die can be poured from the same impression to reevaluate the fit of the crown margin to the finish lines of the preparation. If it is determined that the definitive crown does not fit, the intaglio areas can be adjusted in the areas where the die spacer was abraded off.
- Clinical photos are useful to communicate tooth color and shade to the dental laboratory.

Digital Die Casts

Dr. Francois Duret introduced the first optical impression into the field of dentistry.[9] Since then, digital dentistry has expanded exponentially.

Advantages

- Accurate for partial casts
- Immediate extraoral "on-screen" evaluation of tooth preparation
- Time efficient
- A magnified view of the tooth preparation can be viewed to greatly increase visual acuity
- Proposed material thicknesses can be superimposed over tooth preparations to aid dentists in critical self-assessment of their tooth preparations.
- Some programs use artificial intelligence to detect finish lines
- Tooth color and shade can be measured and communicated to the dental laboratory
- The "die" does not abrade

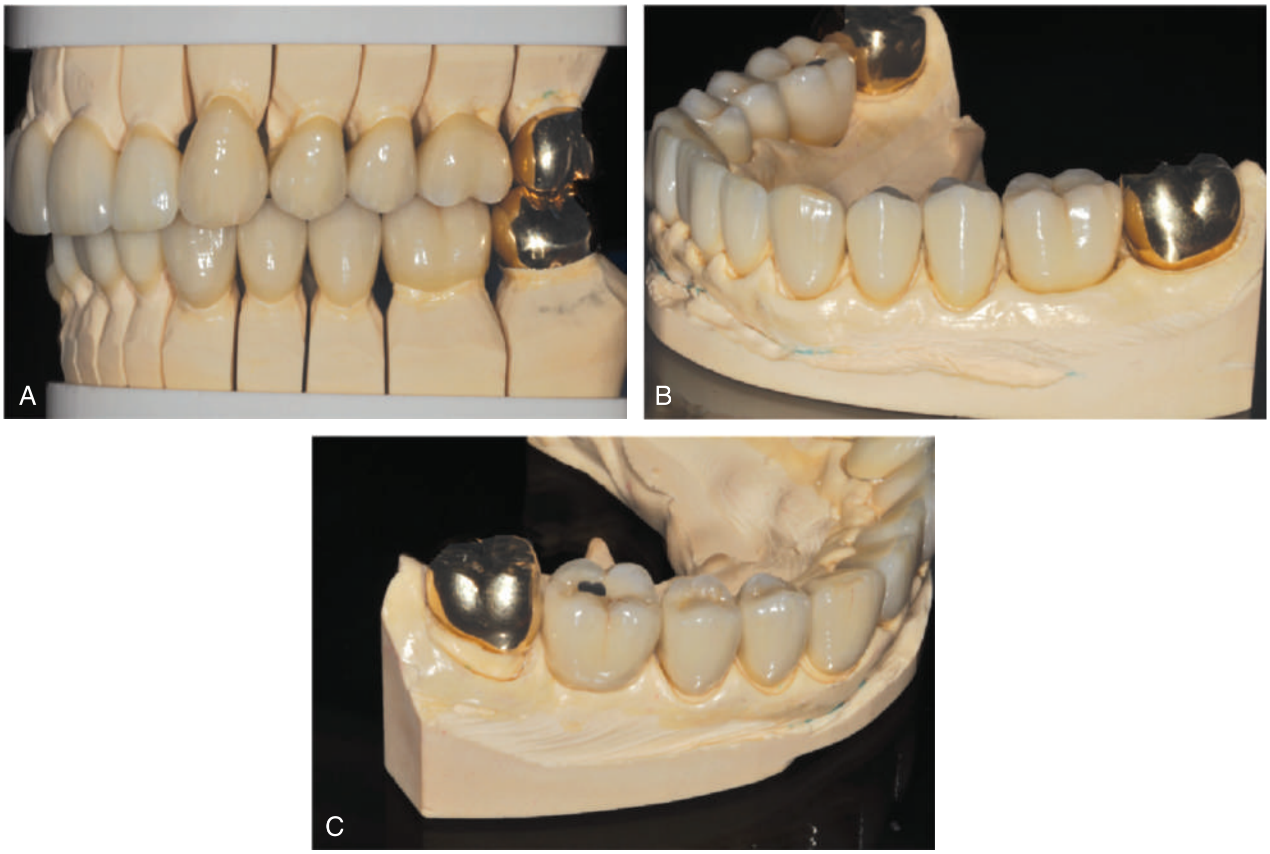

Fig. 29.4 (A) Evaluation of definitive crowns on articulated die casts. (B) Evaluation of proximal contacts on solid cast. The crowns are fully seated with good proximal contacts. (C) Example of a tight proximal contact between the two molar restorations. Because of the tight proximal contact, the gold crown cannot completely seat.

- Sectioned dies do not create instability in the digital cast
- Intuitive to learn for new dentists
- Currently, a digital cast and die system only allows creating monolithic restorations

Disadvantages

- Not as accurate for complete dental arches when compared with a correctly fabricated stone cast[2]
- The definitive crown does not have a die to evaluate marginal fit
- Inability to evaluate and test proximal and occlusal contacts
- Monthly or annual fees are required by most computer systems for maintenance, software program updates and file storage.
- Without an analog cast, a bilayered restorations cannot be fabricated.

Solutions

- Because there is no die on which to evaluate the definitive crown before intraoral evaluation, it is critical the optical scan is evaluated as if it were a stone cast. The tooth preparation is viewed on a computer screen under high magnification. If any sharp line angles or irregularities on the finish line are detected, such areas should be reprepared and rescanned. Once the dentist is satisfied with the tooth preparation, it is highly recommended that the finish line is delineated by the dentist. Marking the finish line is another means of aiding the laboratory to create a clinically acceptable crown (see Fig. 29.2). Next, it is recommended to use the computer program to evaluate the path of insertion chairside. If the software program indicates the presence of any undercuts in the tooth preparation, it is recommended that the preparation is modified even if it might be possible for the technician to block such out and proceed with crown fabrication. This is particularly important because there is no analog die: the preparation needs to be as perfect as possible, and with today's scanning capabilities, immediate extraoral self-assessment is possible with minimal loss of chair time.
- Independent of the type of cast, a dental laboratory technician and a dentist's criteria for ideal crown design may be different. The digital workflow creates a great opportunity to increase and improve communication. At any step in the digital design process, screen shots can be shared with the dentist for confirmation and approval before the laboratory proceeds with the next step. In-office fabrication of the definitive restoration makes such checks easier to perform. If a dedicated outside laboratory is used, a mutual calibration phase is normally necessary, followed by periodic feedback. Shared images can effectively communicate size and location of proximal contacts, occlusal anatomy, emergence profile, and fixed partial denture (FPD) connector size (Fig. 29.5).
- Some systems permit clinical evaluation of the partially sintered ceramic restoration so that proximal contacts, fit, stability, and occlusion can be confirmed before final in-office firing (Fig. 29.6). If the restoration is deficient, appropriate corrections are made and a new restoration is milled. If it is not possible to detect any underlying problem with the tooth preparation, the scan, or the crown design, one must verify that the CAD-CAM system has been recently calibrated.
- Accuracy is not dependent upon only routine calibrations but also the make, model, and software program version of the CAD-CAM system itself. Not all systems are equal, and as with so many things in fixed prosthodontics, dentists need to spend the necessary time to remain aware of the most recent advances with associated advantages and disadvantages.

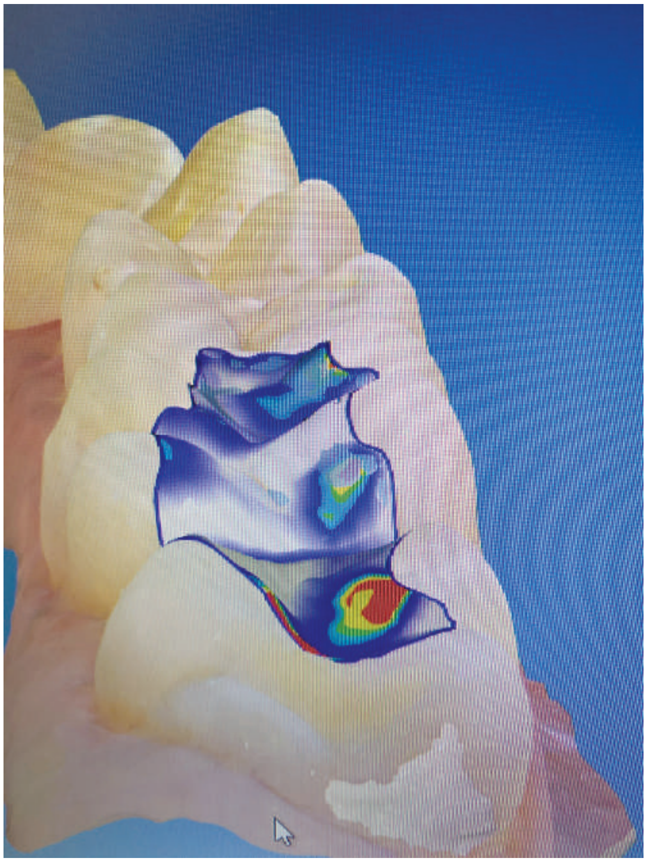

Fig. 29.5 During a digital crown design, the design could not be kept away from a margin. Note *red color* on occlusal margin of the second molar indicating a heavy occlusal contact. The dental laboratory technician texted the dentist this photograph before the ceramic inlays were milled.

3D-Printed Casts

Advantages

- Permits prosthesis evaluation as on a stone cast
- More abrasion resistant compared to a stone cast
- A solid cast can be fabricated along with a cast with removable dies to more easily evaluate multiple proximal contacts
- Permits fabrication and evaluation of bilayered restorations

Fig. 29.6 (A) Milled lithium disilicate inlay restorations in the "blue" precrystalized phase. (B) Confirmation of proximal contacts and fit of lithium disilicate inlays in the "blue" phase. (C) Bonded lithium disilicate inlay restorations.

Disadvantages

- Printed casts cost more than stone casts
- The quality of the printed cast is dependent on the quality of both the optical scanner and the 3D printer.
- In general, the surface texture of the teeth is not as good as with a properly fabricated stone cast

Ceramic Restoration

To inspect ceramic restorations in a meaningful manner, it is important to have a thorough understanding of the available fabrication methods. For instance, with pressed ceramics, it is possible to trap air pockets inside the ceramic (Fig. 29.7). Such voids weaken the ceramic and should be resolved when detected. In regard to milled ceramics, the issue with voids is eliminated but it is possible to have the intaglio surface overmilled, resulting in too large of a cement space and leading to restoration instability. However, before a new milled restoration is made, it needs to be determined if the overmilling was caused by an inappropriate tooth preparation with line angles that are excessively sharp or if such was caused by a setting in the computer software program.

Hand-layered ceramics and veneering ceramics also need to be dense and free of voids (Fig. 29.8). Correct use of sable porcelain brushes can sculpt high-quality, dense restorations without voids (Fig. 29.9).

Dental laboratories should have a dedicated, dust-free room for layering ceramics. Dental model trimmers, lathes, and other common laboratory equipment create airborne particles that can become trapped within a layered ceramic restoration causing structural and esthetic flaws.

Metal-Ceramic and Metal Restorations

Cast alloy restorations should be dense and free of porosity (Fig. 29.10). Excessive porosities within FPD connectors will structurally weaken a framework precisely in the location where they are subjected to high stresses. Porosities within cast dental alloys typically occur from improper wax pattern placement and sprue design within a casting ring (see Chapter 22). Dental alloys shrink upon cooling, and as a result every casting will have porosity. However, with correct sprue design and placement of the wax pattern in the casting ring, the porosity will occur within the button of the casting and not in the restoration

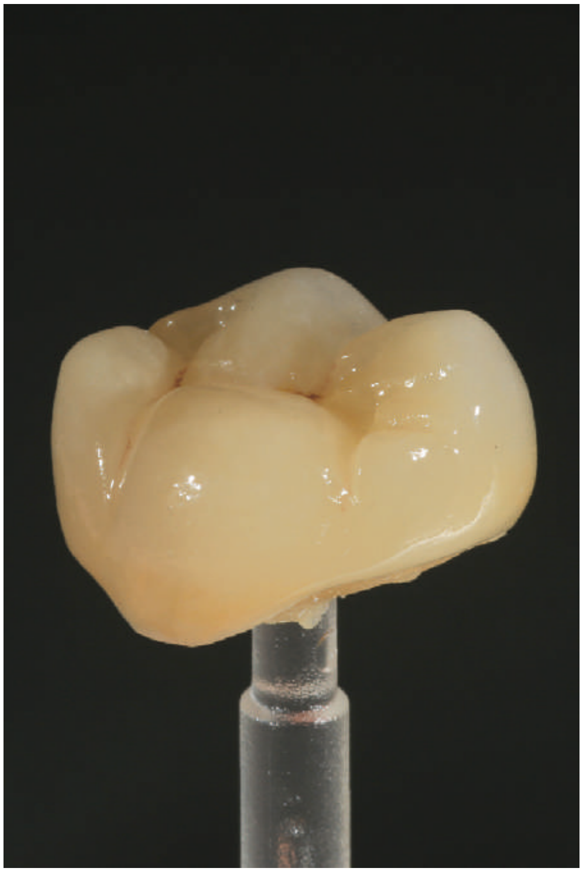

Fig. 29.7 Extra oral evaluation of a ceramic crown. The ceramic was heat pressed. No voids or imperfections are noted.

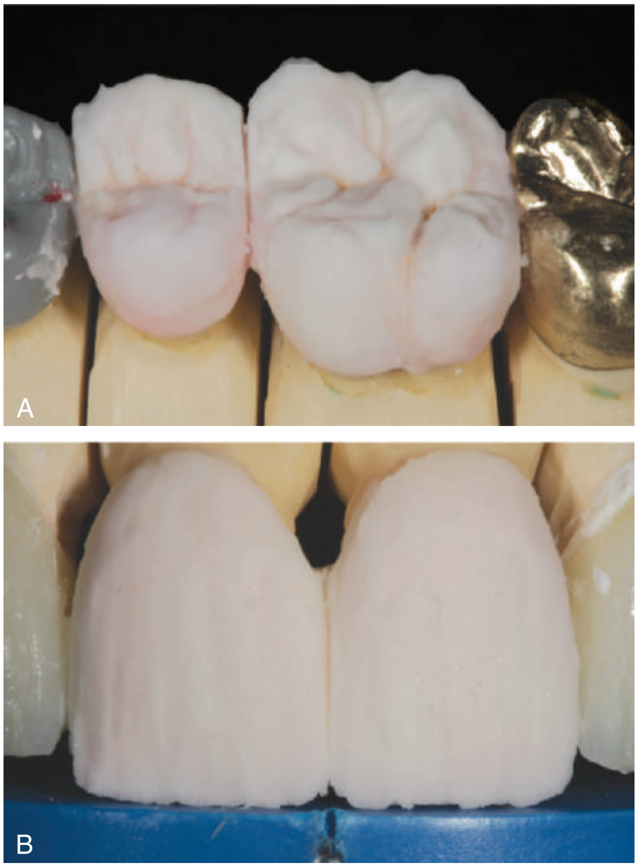

Fig. 29.8 (A and B) Hand-layered feldspathic porcelain. (Photographs courtesy Harald Heindl, CDT.)

Fig. 29.9 Sable brush sculpting proximal contact and line angle of a crown. (Photograph courtesy Harald Heindl, CDT.)

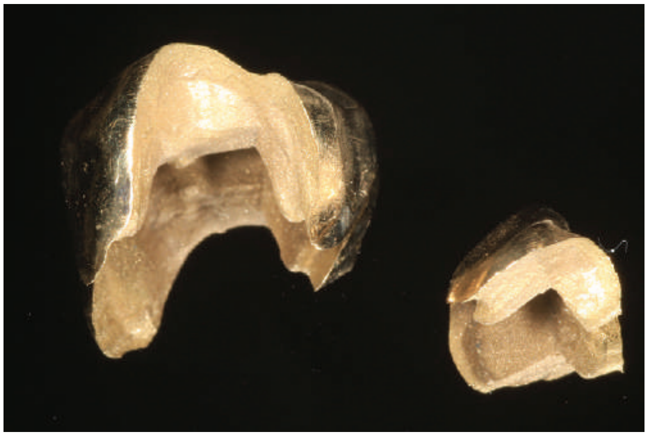

Fig. 29.10 Dense cast gold inlays free of porosity.

itself. The first section of a dental casting to cool will pull molten alloy from the last place of cooling.[10] The shrinking action of the cooling alloy pulls molten alloy from the area of the casting located in the heat center of the casting ring to create a dense casting (Fig. 29.11).

Once the extraoral evaluation is completed, the prosthesis is cleaned either ultrasonically in a bag with alcohol or with a steam cleaner to remove any residual polishing compound and is then disinfected with chlorhexidine.

QUALITY ASSESSMENT PART 2: INTRAORAL ASSESSMENT

The second part of quality assessment is to evaluate the prosthesis in the patient's mouth. If all previous steps have been correctly completed, the fit to the hard tissues should be identical to those replicated on the cast. However, subgingival margins will not be assessed as easily as on a cast with a trimmed die (Fig. 29.12). Intraorally, definitive restorations

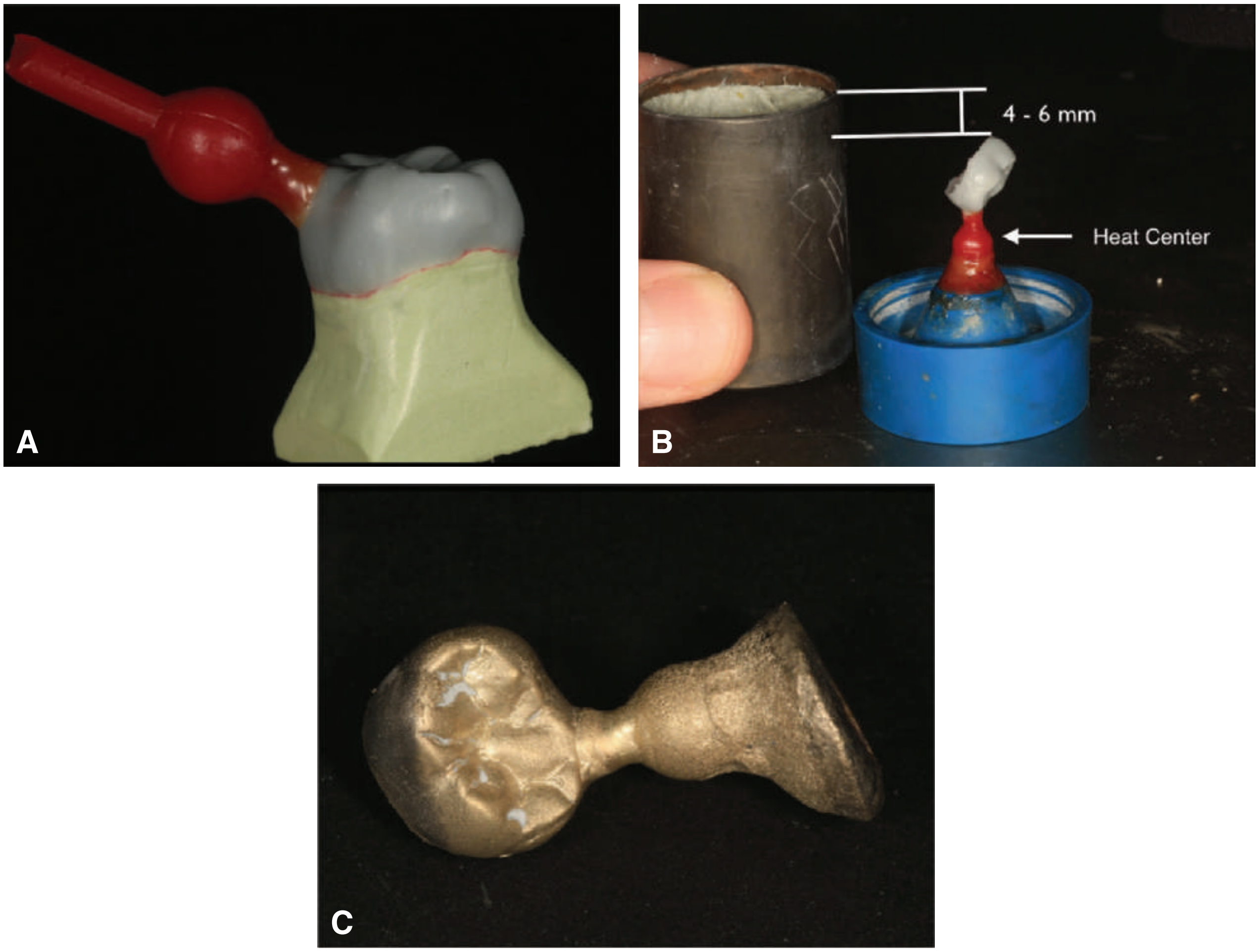

Fig. 29.11 (A) A wax sprue is placed on a large area of the wax pattern and pointed to the smallest area of the crown. In the current example, the smallest area is the lingual margin. (B) Positioning the wax pattern in the casting ring so that a thin margin is close to an edge of the casting ring to cool first. For investment strength, 4 to 6mm is required. The sphere of the sprue former is positioned in the center of the ring so that it will cool last. (C) Devested gold casting. Note the porosity is in the button area and not in the crown.

have a specific sequence of areas to check at the evaluation appointment to confirm ideal prosthetic fit. The very first part of a crown to evaluate is the proximal contacts, followed by margin integrity, stability, internal fit, and last, the occlusion. Proximal contacts have to be ideal for a restoration to completely seat. If left too tight, they will prevent a restoration from completely seating, resulting in open margins and high occlusal contacts. Once the fit has been confirmed, the dentist's quality assessment goes beyond and assesses hygienic and esthetic contours with the periodontium, color, surface texture, and integration with the face. Only after the prosthesis has gone through a thorough assessment and found to meet all requirements, is the patient asked to do their own assessment and give approval for cementation. Such is best accomplished with the patient sitting up, rather than being supine, with a large handheld mirror held at an appropriate distance of approximately 18 to 24 inches, simulating normal conversational distancing between individuals. Extraoral evaluation by the patient can easily lead to difficulties with patient acceptance (Fig. 29.13).

Interim Restoration and Luting Agent

There are many techniques to remove interim restorations. A hand instrument such as a large discoid cleoid or spoon excavator placed under a margin can gently pry and lift and interim restoration in a tilting manner while applying minimal force to the tooth (Fig. 29.14). Alternatively, a hemostat positioned on the buccal and lingual surfaces can be rocked gently in a buccolingual direction to break the seal of the interim luting agent. Care must be taken to not apply a lateral bending force to delicate teeth that have been prepared for complete crowns lest tooth fracture results. A Backhaus towel clamp is handy to remove soft tin alloy crowns. With their sharp beaks, the instrument pierces the crown on the buccal and lingual surface, and then the crown is lifted off the tooth in a vertical path. Special band removers (Fig. 29.15) may also be used. Most of the interim luting agent will adhere to the intaglio surface of the interim restoration when it is removed from the mouth. Any remaining cement should be loosened from the prepared tooth surface with an explorer, followed by scrubbing the preparation with chlorhexidine to clean the tooth structure

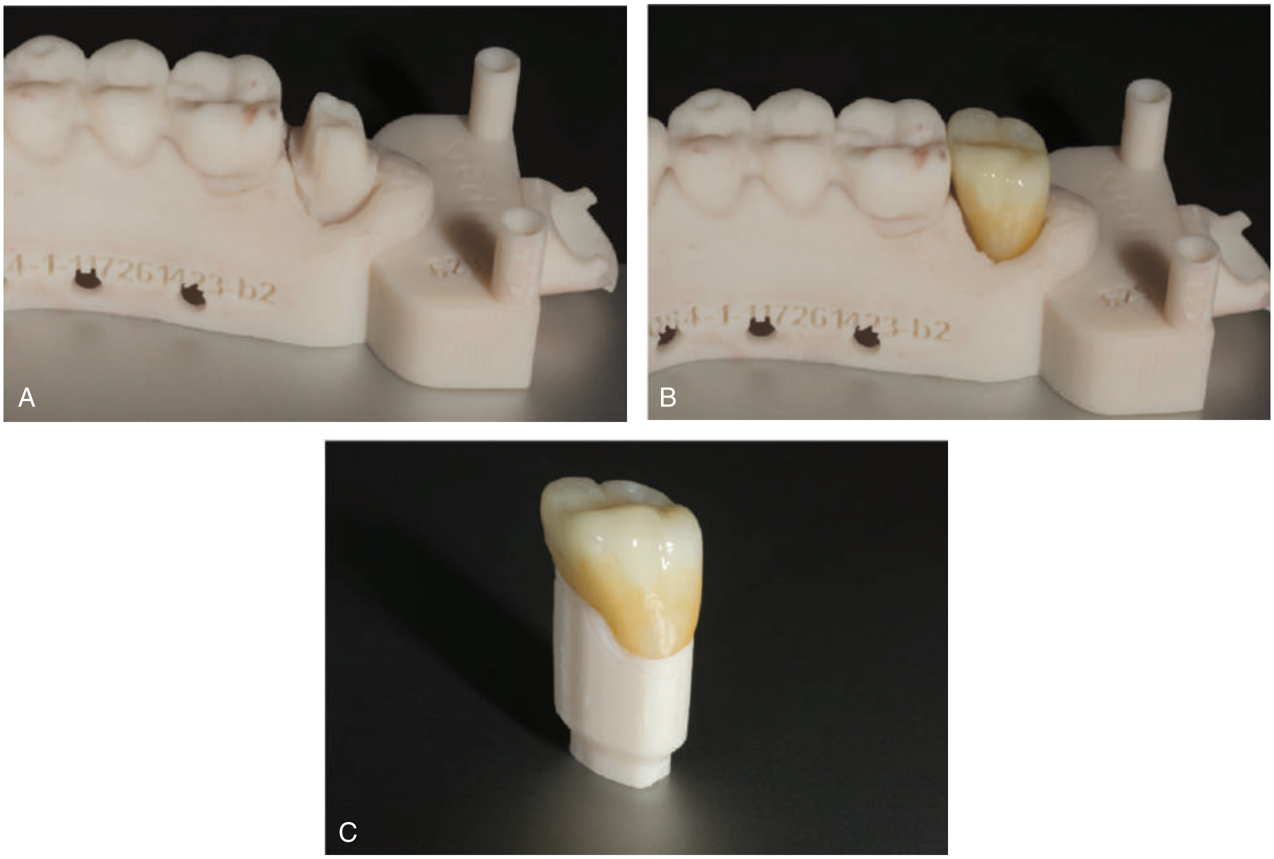

Fig. 29.12 (A) Printed die cast for a crown with a deep subgingival finish line. (B) Evaluation of monolithic zirconia crown on printed die cast. (C) Close inspection of a deep subgingival lingual margin confirms a high quality in margin fit.

(Fig. 29.16). If the interim restorations were "spot bonded," the small area of tooth structure where the restorations were bonded must be prepared slightly with a dental bur. If this step is rushed, a small amount of residual bonded composite can remain undetected on the tooth preparation. When subsequently evaluating a ceramic restoration on the abutment, even a very small piece of composite can prevent a ceramic restoration from completely seating and simultaneously create a high risk of ceramic fracture. Although the spot-bonded composite must be completely removed from the preparation, polishing the whole preparation after the restorations is fabricated is undesirable because it may alter crown stability or alter the configuration of a finish line. In some bonding protocols, dentin may be treated with air particle abrasion before bonding. The preparations are rinsed with water and air spray, and after drying, the area is inspected. All residual luting material must be removed because even a very small particle of interim cement can prevent a restoration from seating completely and compromise an adhesive cementation protocol.

Evaluation Sequence

Following a logical sequence during the evaluation procedures is important if mistakes are to be avoided. The recommended sequence is as follows:

1. Proximal contacts
2. Marginal integrity
3. Stability
4. Occlusion
5. Dentofacial analysis (if applicable)
6. Contours
7. Color
8. Characterization and glazing

The proximal contacts are evaluated first because excessively tight contact prevents the restoration from seating, causing a marginal discrepancy. If a restoration does not seat completely, assessing stability or adjusting the occlusion is premature.

Proximal Contacts

The location, size, and tightness of a restoration's proximal contacts should resemble those of the natural teeth. Typically, textbooks refer to contacts that allow unwaxed floss to "snap" through "relatively easily." Although this is not a very scientific definition, the use of floss is a convenient method for comparing the tightness of the proximal contacts with other contacts between adjacent teeth in the arch. However, a snapping action of dental floss only indicated that the space between the teeth is smaller than the thickness of the floss. A snap does not indicate true contact between the teeth. If the floss does not pass, the contact is excessively tight; if it goes through too easily, food impaction may result (Fig. 29.17). The use of shim stock (thin Mylar film) is a more reliable indicator of proximal contact than floss. A passive contact allows the Mylar film to be pulled from the interproximal with some slight resistance. If the strip tears, the contact is too tight (Fig. 29.18). The ideal

Fig. 29.13 Patient unfortunately was allowed to evaluate their prosthesis on the bench. Patients have not had formal training to assess prostheses extraorally and may develop a bias before seeing their new teeth intraorally. It is advised to let patients do their assessment after the dentist has completed and approved the prosthesis through the two-part assessment.

Fig. 29.14 Spoon excavator is positioned on an interim restoration margin. The instrument is used to lift the margin in an occlusal direction. Care must be taken to not damage a tooth preparation finish line.

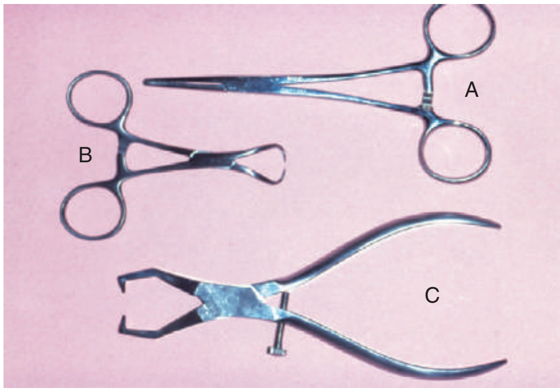

Fig. 29.15 Hemostat (A), Backhaus towel clamp forceps (B), and Baade-type band remover (C).

Fig. 29.16 The tooth preparation is cleaned with chlorhexidine dispensed from a dental syringe with a brush on the end.

Fig. 29.17 Deficient mesial contact, which could allow food to become impacted.

contact allows for positional stability of the abutments and adjacent teeth, as well as straightforward maintenance of the supporting structures. Most patients give reliable information as to a tight proximal contact when asked whether they "feel as though they have a seed between their teeth," provided that a local anesthetic has not been administered. A deficient contact is easily overlooked but invariably results in discomfort as food becomes impacted.

Excessive Tightness

Ceramic restorations. A tight proximal contact in unglazed or unpolished ceramic is easily adjusted with a porcelain adjustment wheel. The area of contact (Fig. 29.19) can be identified with thin marking tape.

Fig. 29.18 Shim stock is positioned in a proximal contact to evaluate the contact between two crowns. The shim stock should offer a slight tug back action when attempting to remove from the contact.

Fig. 29.19 The location of tight porcelain contacts can be identified with thin marking tape.

After glazing, a slight change in the contact may be observed because of the pyroplastic surface flow that occurs during firing. If adjustment of a glazed restoration is needed, it should be repolished with diamond-impregnated silicone wheels and points, pumice, or diamond-polishing paste.

Metal restorations. If a tight contact prevents the seating of a metal restoration, adjustments are readily made with a rubber wheel. The matte finish produced helps to identify where binding occurs because a shiny spot (Fig. 29.20) appears where adjustment is necessary.

When a contact is too tight, the restoration is removed from the patient's mouth, adjusted, and then reevaluated intraorally. The dentist must remember to allow a small degree of excessive tightness for polishing. When both proximal contacts of a crown are excessively tight, the dentist should make adjustments on an alternating basis, verifying whether additional material needs to be removed before proceeding with further adjustments.

Deficiency

Ceramic restorations. Deficient ceramic proximal contacts can be addressed in a number of ways. Monolithic ceramic restorations with deficient proximal contacts can be treated with a veneer of ceramic to close the contact, but the restoration of course is no longer monolithic. To retain the benefit of a monolithic restoration, one must go back to the design phase of the CAD-CAM crown, increase the contact strength, and mill a new one. Stepping back to the design phase of crown fabrication gives the laboratory excellent feedback for calibration so future crowns may have better proximal contacts.

Fig. 29.20 Identifying the location of a tight proximal contact. The metal is given a matte finish by grinding with a rubber wheel. A shiny mark *(arrow)* is formed where the contact is excessive.

With a bilayered ceramic restoration, a cast with removable dies or solid cast is helpful so that a specific amount of veneering ceramic may be layered and fired to the proximal contact. Although such porcelain can also be added without an available cast, subsequent clinical adjustment may require additional chair time. It must be noted that the strength of the veneering ceramic is dependent on its core. If veneering ceramic is not supported, the risk of porcelain chipping is increased. If a large deficiency exists and a gross amount of veneering ceramic would need to be added, it may be more prudent to fabricate a new bilayered restoration that does provide appropriate support for the weaker veneering material.

Bilayered ceramic or metal-ceramic restorations offer an additional opportunity to evaluate the crowns clinically before they receive final firing and glazing. This is known as a bisque clinical evaluation. At the bisque stage, this is time consuming, but adding additional porcelain is not a problem. However, if a restoration has been completely finished, glazed, and characterized at the time the deficient contact is discovered, a lower fusing "add-on" or correction porcelain can be used to solve the problem (Fig. 29.21).

These correction porcelains are a mixture of body porcelain and overglaze with additional modifiers to produce a maturation temperature as low as 850°C (1562°F). Minor corrections can thus be made with little risk of dimensional change in any other part of the restoration. Major corrections should be made by means of an additional firing with the conventional body and incisal powders, although there are limits to the number of times a restoration can be fired if devitrification is to be avoided (see Fig. 24.34B).

Metal restorations. A gold casting with a deficient proximal contact can usually be corrected by soldering (Fig. 29.22). The procedure is simple and can be performed in the dental office in a matter of minutes. However, soldering a proximal contact should not be routinely necessary. After soldering, the restoration requires pickling and repolishing.

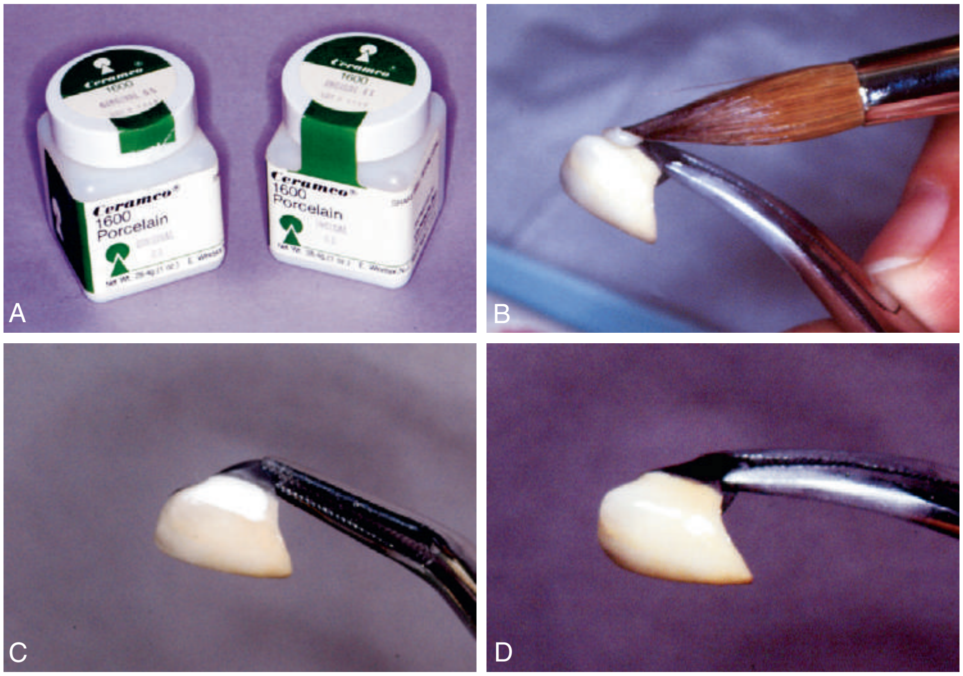

Fig. 29.21 Correction of a defective proximal contour with porcelain. (A) A low-fusing add-on porcelain is used. (B) Applying the porcelain. (C) Corrected proximal contours. (D) Fired restoration.

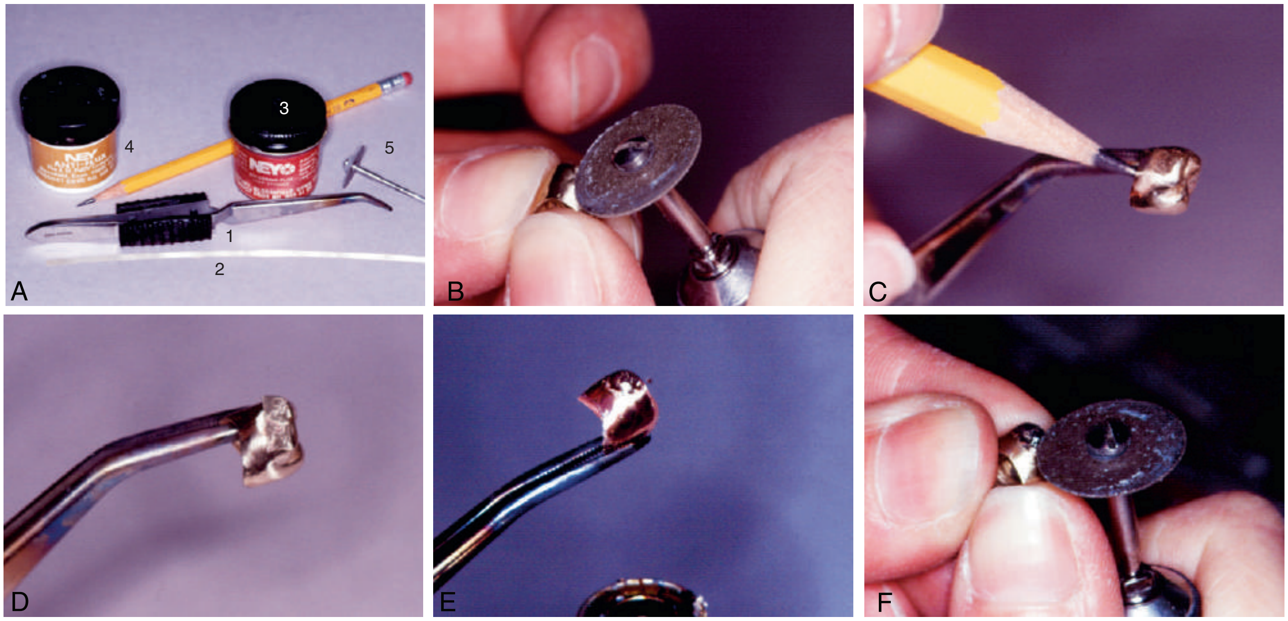

Fig. 29.22 Adding a proximal contact with gold solder. (A) Armamentarium. *1*, Soldering tweezers. *2*, Gold solder. *3*, Paste flux. *4*, Antiflux. *5*, Finishing disk. (B) The deficient proximal surface is roughened. (C) Antiflux (graphite or rouge/turpentine) is added to the margin. (D) A segment of solder is positioned with paste flux. (E) The solder is heated over a Bunsen burner flame until just when it melts. (F) Proximal contact is readjusted.

Armamentarium. The equipment needed is shown in Fig. 29.22A.

- Soldering tweezers
- Gold solder
- Paste flux
- Bunsen burner
- Antiflux
- Polishing armamentarium

Step-by-step procedure

1. Roughen the deficient area with a disk (see Fig. 29.22B).
2. Protect the margin of the casting with a graphite pencil (or another suitable antiflux; see Fig. 29.22C).
3. Coat a small piece of solder with flux, and position it on the previously roughened surface (see Fig. 29.22D).
4. Hold the casting with the soldering tweezers in a properly adjusted flame of the Bunsen burner to position the solder

at the height of the reducing portion of the flame (see Fig. 29.22E, see also Fig. 27.18).

5. Observe the solder carefully as it heats up. As the solder starts to fuse, it spreads rapidly. With a little practice, the casting can be tipped to help the solder flow in the desired direction. The casting is then immediately removed from the flame.
6. Pickle the casting and adjust the proximal contours with disks (see Fig. 29.22F) before repolishing and cleaning.

Margin Integrity

The completed restoration should go into place without binding of its internal aspect against the occlusal surface or the axial walls of the tooth preparation; in other words, the best adaptation should be at the margins. If the indirect procedure is handled properly, there should be no noticeable difference between the fit of a restoration on the die and the intraoral fit.

Several techniques have been used to detect where a casting binds against an occlusal or axial wall, including disclosing waxes, painting the inside of the restoration with a suspension of rouge in turpentine or acetic acid, airborne-particle abrasion to form a matte finish surface, powdered sprays, water-soluble marking agents (Fig. 29.23), and special elastomeric detection pastes (Fig. 29.24). However, none has proven to be entirely satisfactory. Most techniques are rather messy and time consuming and should not be needed on a routine basis.

Powdered sprays (originally designed to facilitate seating of frameworks of removable dental prostheses) can build into a layer of excessive thickness on the restoration's internal surface, interfering with seating the crown.[11] Elastomeric paste (Fig. 29.25) has some advantages. The material is similar to a silicone impression material and is obtained as a two-paste system. Its viscosity is similar to that of the definitive luting agents, and so it can be used not only to identify unwanted internal contacts but also to assess adequate marginal fit. The degree of clinically acceptable marginal opening (i.e., the discrepancy unlikely to have an adverse effect on the prognosis) is hard to define. Margin integrity has been the subject of many laboratory and clinical evaluations. To minimize dissolution of the luting agent, the thickness of the cement film at the margins should be kept minimal. Through careful technique, a marginal gap width of less than 30 µm can be obtained consistently.[12,13] Once the fit has been confirmed, the elastomeric paste is also useful to temporarily retain crowns during a clinical pick-up impression (discussed later in the chapter).

Assessment

Fig. 29.26 illustrates the possibilities that may be encountered in verifying margin integrity. The presence of a small overhang or ledge (see Fig. 29.26A and B) does not necessarily mean that the

Fig. 29.23 Water-soluble marking agent.

Fig. 29.24 Elastomeric detection paste was placed in the intaglio surfaces of ceramic fixed partial denture retainers as well as between the pontics and gingiva to evaluate fit and space.

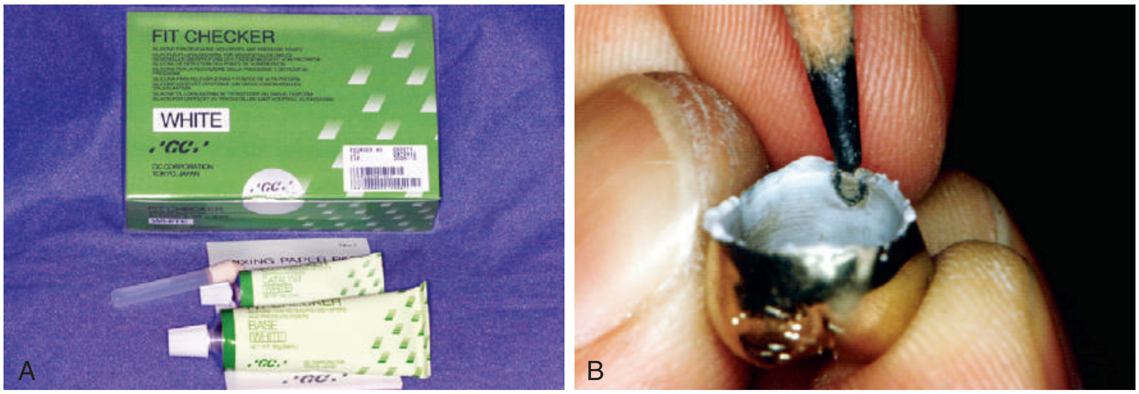

Fig. 29.25 (A) Elastomeric detection paste, recommended for evaluating the internal surface of a restoration. (B) The interference is seen as a perforation in the film of silicone material, which can be marked with a colored pencil. The residual film of silicone should be thoroughly removed before the restoration is cemented. (B, Courtesy Dr. J.H. Bailey.)

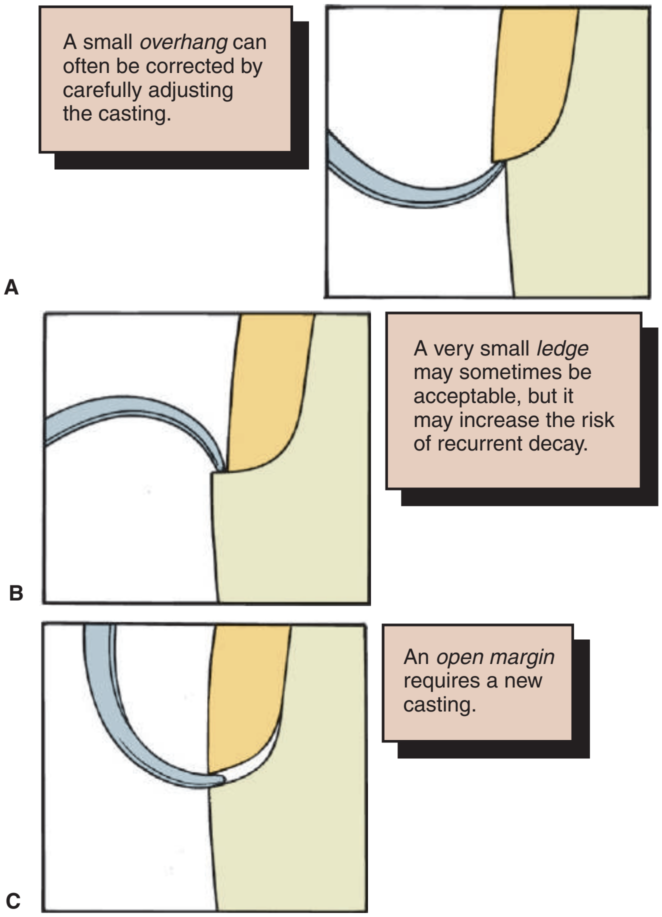

Fig. 29.26 Assessing margin integrity with an explorer. (A) An overhang. (B) A ledge. (C) An open margin.

restoration must be remade. It may merely require additional finishing where accessibility allows.

A sharp explorer moved from restoration to tooth and from tooth to restoration can be used in evaluating the marginal adaptation. If resistance is encountered in both directions, a gap or open margin exists, and its cause must be determined. If the gap is the result of an excessive proximal contact or of residual interim luting agent that prevents the casting from being seated, the situation is easily remedied. However, an obviously inaccurate restoration should be quickly rejected. Trying to "make it fit" is wasted effort, and making a new impression is a better use of time.

Finishing

In general, margin finishing is performed extraorally and confirmed intraorally, and after cementation, some intraoral polishing is done on the restorative-tooth interface. If a thick margin is causing an overhang in a horizontal plane to the finish line, it might be feasible to be finished on enamel, but extreme care must be taken when finishing margins on dentin. Subgingival or interproximal margins are not easily accessible for correcting imperfections intraorally. Cementum is easily lost, and freshly exposed dentinal tubules that are not restored may cause dental sensitivity. It is advised to make corrections extraorally, preferably at the fabrication stage in the laboratory. Because clinical examination of subgingival margins is not always straightforward, a precementation digital radiograph may be justified to confirm that what is seen on the dental die is the same as in the mouth. Dentists may be tempted to use digital radiographs more routinely when fabricating restorations digitally without dental dies. However, routine precementation radiographs to assess margin quality will increase a patient's radiation exposure; therefore a dentist must apply the as low as reasonably achievable (ALARA) principles.[14] It has been demonstrated that dentists cannot solely rely on digital radiographs to assess margin fit without an intraoral assessment.[15] The same research also showed that metal-ceramic crowns were significantly more likely to be falsely evaluated as acceptable when actually an open margin is present (gap space of >80 μm),[15] whereas lithium disilicate and fluorapatite crowns were significantly more likely to be falsely determined as unacceptable when actually they were clinically acceptable (≤ 80 μm).[15]

Supragingival cast gold margins on enamel may be finished with the restoration seated on the tooth. White stones and cuttle disks rotating from restoration to tooth structure should result in a suitably finished margin (Fig. 29.27), which, if the restoration is properly adapted, is virtually undetectable with the tip of a sharp explorer.[16]

It has been reported that accessible margins of cast-metal restorations can also be burnished during the cementation procedure before initial setting of the cement.[17] However, the less accessible proximal margins can neither be readily evaluated nor easily finished intraorally. For routine clinical practice, it is important to note that other studies[18,19] have shown that correcting a poorly fitting cast restoration with finishing procedures is not possible.

Stability

Restorations retained on geometrically shaped tooth preparations providing mechanical retention should next be assessed for stability on the prepared tooth. Definitive restorations should not rock or rotate when force is applied. Any degree of instability is likely to cause failure during function. If instability is caused by a small positive nodule, this can usually be corrected; however, if it is caused by distortion, a new definitive impression is necessary.

Many bonded ceramic restorations cannot be evaluated for "stability" or occlusion until they have been bonded. For bonded ceramic restorations, the ability to reproduce the same position of the restoration when seating and reseating it on the tooth is important (Fig. 29.28). If the restoration does not seat in the same position during each attempt, it may not get bonded in the intended position once loaded with an adhesive luting agent. As a result of a position discrepancy after bonding, the definitive restoration has to be cut off, the tooth reprepared, and a new restoration made. Without a reliable and reproducible seat that produces stability for bonding, there is a high risk for a time-consuming remake.

Occlusion

After the restoration has been seated and the margin integrity and stability are acceptable, the occlusal contact with the opposing teeth is carefully checked. The criteria for these

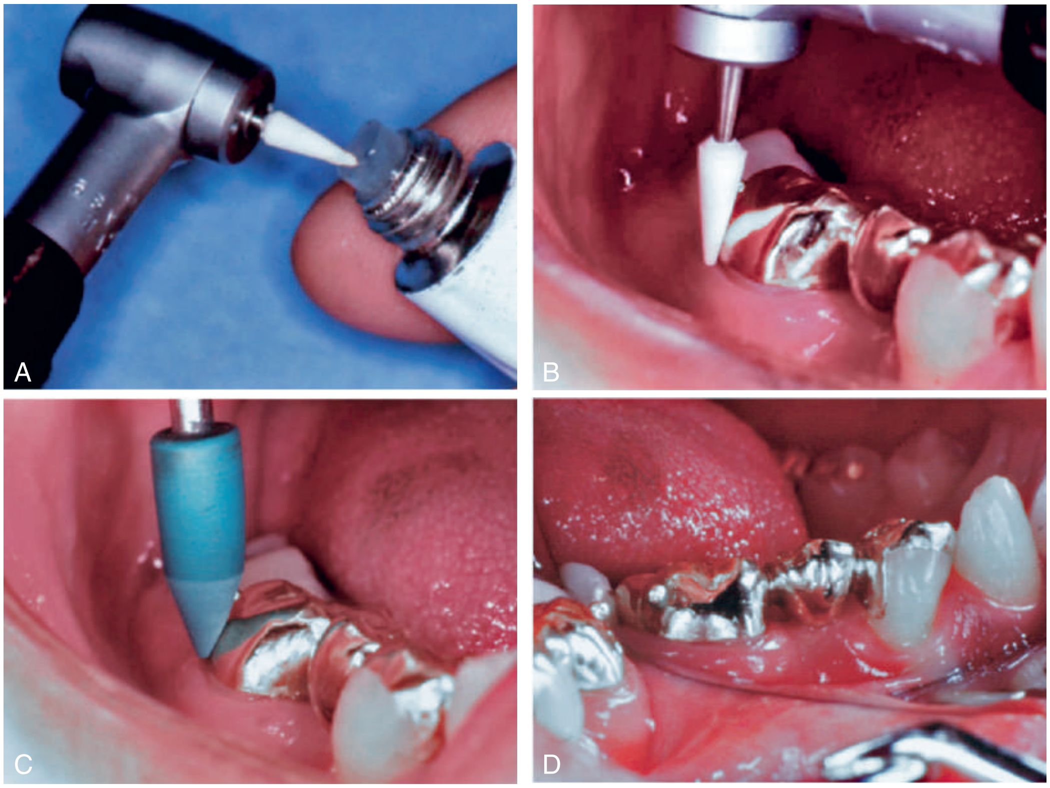

Fig. 29.27 Supragingival margins allow access for finishing the restoration directly on the tooth. (A and B) Fine-grit white stone lubricated with petroleum jelly. (C) Rubber point. (D) Completed restoration.

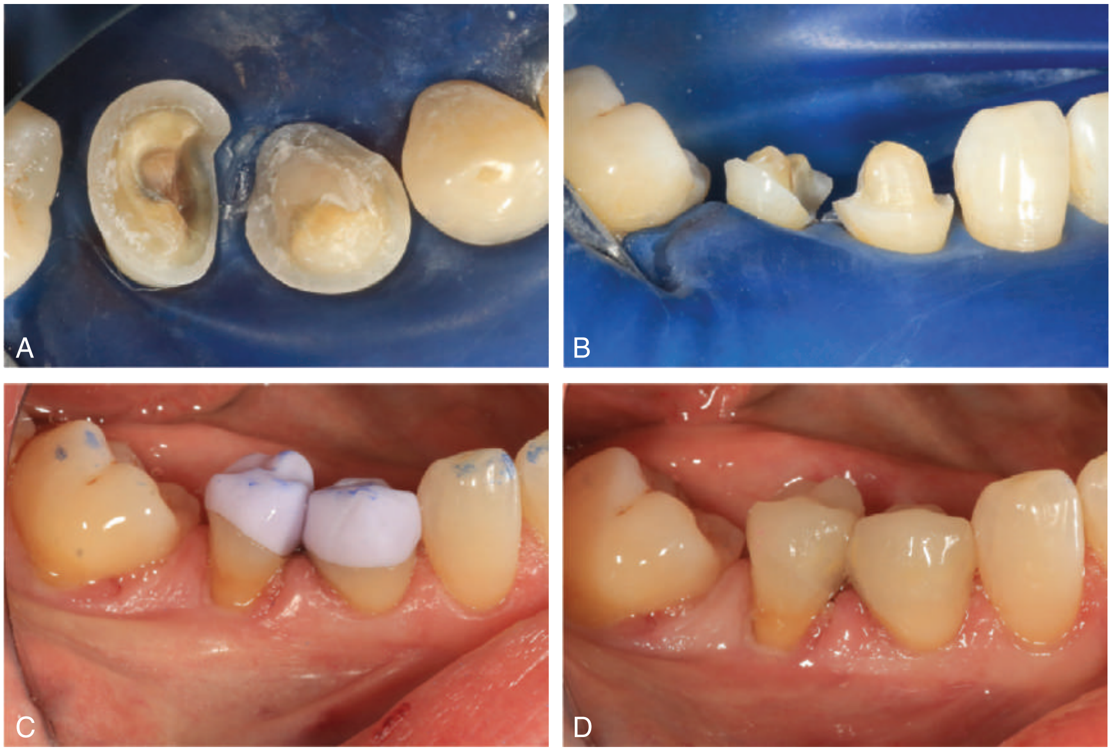

Fig. 29.28 (A and B) Occlusal and buccal view of tooth preparations without classic mechanical retentive geometric shapes. Because of the quantity and quality of circumferential enamel after occlusal reduction, the cervical tooth structure was preserved to maximize abutment durability. (C) Occlusion and fit of lithium disilicate restorations were assessed at the "blue" phase. The restorations do not have classic stability to resist occlusal contacts without bonding that was detected by an opening at the tooth restoration interface on the second premolar. However, they do have stability with a definitive reproducible seat that is important for the bonding protocol. (D) Insertion of lithium disilicate restorations after glazing.

relationships, both static and dynamic, are discussed in Chapter 4. Any undesirable lateral interfering contacts, as well as maximal intercuspation or centric interferences, must be identified (Fig. 29.29). Ceramic restorations that depend on adhesion may not have the stability to fully evaluate the occlusal contacts and function during mandibular excursive movements. For many bonded ceramic restorations, the occlusion is finalized only after cementation. Adjustment of eccentric contacts is often needed if the restoration was made from a closed-mouth impression.

Evaluation and Adjustment

Armamentarium

- Hemostats
- Miller forceps
- Marking ribbon or tape
- Petroleum jelly
- Thin Mylar shim stock
- Diamond rotary instruments
- White stones
- Ceramic polishing points, cups, wheels

Only restorations in supraocclusion can be adjusted chairside. Restorations without occlusal contacts need to be returned to the dental laboratory technician for correction or remake.

Step-by-step procedure. This process is shown in Fig. 29.30.

1. Before seating the restoration, assess the contact relationship between maxillary and mandibular teeth. The most convenient way to do this is to cut a narrow strip of Mylar shim stock, hold it in hemostats or forceps, and have the patient open and close the jaws with the strip between opposing teeth. A tug felt on the strip indicates occlusal contact (Fig. 29.31). Ideally, contact should be as evenly distributed as possible, but it is not uncommon to find one or more areas of relatively light contact between opposing teeth. As a reference for evaluation of the restoration, use the patient's occlusal contact that holds the shim stock.

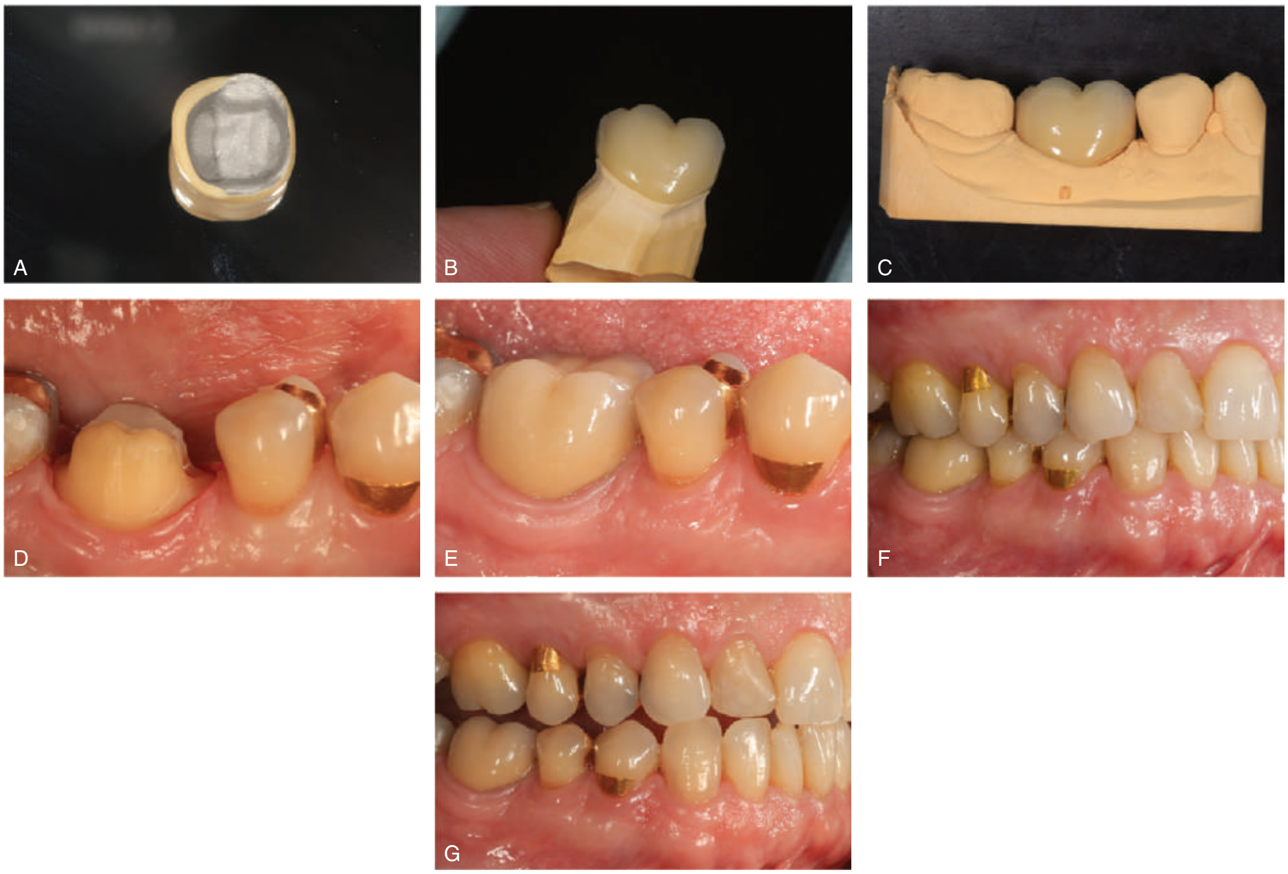

Fig. 29.29 A clinical example of the steps for a dentist to fully assess a metal-ceramic crown to confirm clinical acceptability before getting a patient's approval for cementation. (A) Extraoral evaluation of a metal-ceramic crown. A dense casting and veneer are noted. (B) The margins and fit are closely inspected on the die. (C) Confirmation of proximal contacts on a solid cast. (D) Since the quality of the single crown was up to clinical standards, an appointment was made for the patient, the interim restoration was removed, and the preparation was cleaned of all residual debris. (E) Proximal contacts were first confirmed. After the proximal contacts were finalized with porcelain polishing wheels, the fidelity between the finish line and margin was confirmed to be the same as the stone die. (F) Once the fit was confirmed, the occlusion was assessed in maximal intercuspation. (G) Once the static occlusion was confirmed with shim stock and articulating film, the mandibular movements were assessed. Because the patient had canine guidance, all lateral interferences were eliminated. If adjustments were made to the ceramic, it should be polished with dedicated porcelain polishing cups and points. After the occlusion has been confirmed, the contours, color, and characterization are evaluated. Once the dentist approves the restoration, both extraorally and intraorally, then the patient can assess the new restoration intraorally.

Fig. 29.30 Evaluating and adjusting the occlusion. (A) Refinement on the articulator before evaluation. (B) Testing the occlusal relationship with shim stock and marking with tape. Typically, some adjustment is needed, especially in more complex treatments, but this should not be extensive unless an error has been made. (C) After adjustment, the occlusal contacts should always be verified with shim stock because ribbon markings can be misinterpreted.

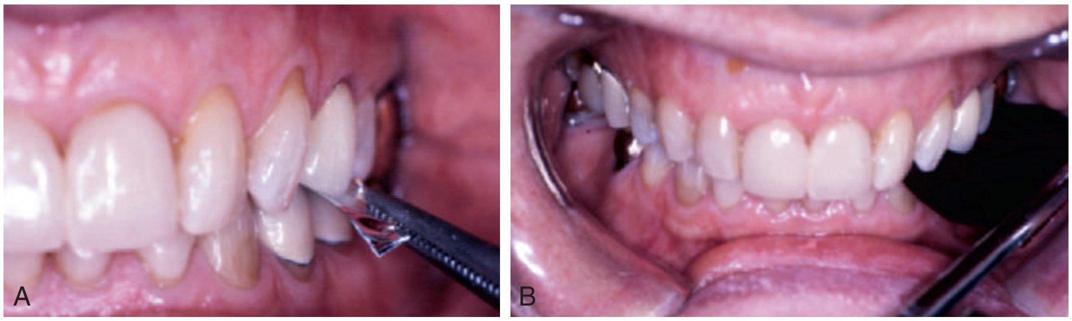

Fig. 29.31 (A) Use shim stock (Mylar) to identify presence or absence of occlusal contacts. (B) Use articulating tape to identify the location of occlusal contact.

2. Seat the restoration, have the patient close the jaws, and reassess the contacts. The new restoration should hold the shim stock and yet not alter the existing tooth relationships. If a discrepancy is detected, a decision must be made whether this can be adjusted intraorally or whether a remount procedure is necessary.
3. The pigments from articulating paper are hydrophobic. As a result, the pigment does not transfer well to wet occlusal surfaces. Dry the teeth with 2 × 2 cotton to remove saliva to increase the effectiveness of the pigments in transferring to the crown and marking occlusal contacts.
4. Mark any interferences that are detected in the static position for maximal intercuspation. Have the patient close the jaws on articulating film. Glazed ceramic restorations do not mark well with articulating film. To accommodate the short coming, apply a thin layer of petroleum jelly (Vaseline) to the film. The petroleum jelly acts as an emulsifier to create spheres of pigment that readily transfer and explode upon occlusion resulting in a readable mark. If one is having problems with multiple false occlusal marks because of tall cusp tips, the following technique has been found to be of use. With scissors, partially cut multiple strips along the long

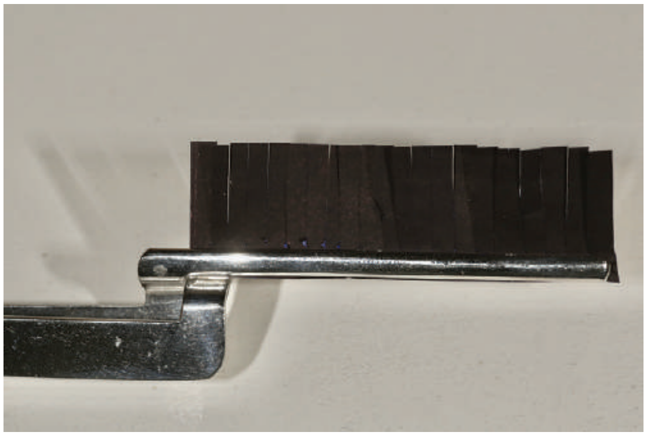

Fig. 29.32 Articulating paper modified with multiple cuts along its long edge. The newly created thin strips of articulating paper easily bend over cusp tips with less risk of creating false occlusal contacts.

edge of the articulating paper (Fig. 29.32). It has been found that the multiple thin strips will more readily flex over cusp tips without leaving false markings when compared with unmodified articulating paper.[20]

5. Adjust the marked maximal intercuspation interferences with the diamond rotary instrument or white stone for ceramic restorations and high-speed carbide burs for metal restorations. Always check the thickness of the restoration with calipers before an adjustment is made. On occasion, adjusting an opposing cusp rather than cementing a restoration that is too thin may be the preferred method, although performing such adjustment at the tooth preparation stage is recommended. Explaining the procedure and its rationale to the patient before grinding an opposing tooth is essential. Options, such as increasing occlusal clearance by repreparing the tooth, should be presented to the patient before the procedure continues.
6. Be careful not to misinterpret occlusal markings. Note that a true interocclusal contact leaves a circular mark (like a point of a ball point pen), but a false contact leaves a smudge. When assessing the occlusion of a single restoration, a clear center may be found within the occlusal markings like a bull's-eye. These circular patterns with a clean center are indications of hyperocclusal contacts for the single restoration and must be adjusted until the contact gets smaller and without a clean center. In contrast to the insertion of a single crown, when a complete arch of crowns is being evaluated for occlusion, the contacts with the bull's-eye effect are desirable as long as they distributed equally and bilaterally on each crown across the dental arch. Marking ribbon or tape is useful for helping to determine the location of a maximal intercuspation interference. However, shim stock is a more reliable indicator than ribbon or tape for confirming the presence or absence of an occlusal contact and should be used to evaluate the result.
7. Only once the static occlusal contacts have been idealized in either maximal intercuspation or centric occlusion should the dynamic occlusal evaluation for mandibular movements be assessed. Use two colors of ribbon for the different types of movement. Excursive movements and interferences are first marked in one color (e.g., green). Then a different color (e.g., red) is inserted for maximal intercuspation or centric contacts. Any excursive interferences (in this example, green marks not covered by red) are adjusted with the diamond or white stone.

Once the occlusion for monolithic lithium disilicate or zirconia restorations has been idealized, the modified surfaces must be polished with a dedicated ceramic polishing kit. Polishing a surface is simply taking large scratches to smaller scratches and so must be followed up by a careful and thorough polishing protocol to prevent the surface from being rough and abrasive. An appropriate finishing protocol for lithium disilicate and zirconia ceramics is presented in Figs. 29.33 and 29.34. Note the differences in the final polishing sequence. In general, polished ceramic occlusal contacts are less abrasive than glazed ceramic occlusal contact and do not have to be returned to the laboratory after occlusal adjustment when polished correctly. For ceramic restorations that are sent back to the laboratory for color modification or glazing, minor adjustments and polishing may still be needed after glazing because of the pyroplastic flow of the porcelain.[21] Fig. 29.29 is a clinical example of each step in the process for the quality assessment of a complete crown before cementation.

An alternative technique for metal restorations requires the use of an airborne-particle abrasion unit with aluminum oxide (Fig. 29.35). A matte finish is obtained on the occlusal surfaces of the casting in question, and the patient is asked to close the jaws. Where shiny marks appear, an adjustment is made. However, this technique has the following disadvantages:

1. Differentiating between centric and excursive contacts is not possible.
2. The technique is more time consuming.
3. It is applicable only to cast-metal occlusal surfaces.

Remount

If clinical evaluation reveals a need for significant occlusal adjustment of multiple restorations, a remount procedure[22] may be indicated. When extensive restorative dentistry is undertaken, the remount serves to convey the relationships of the restorations and teeth to the dental laboratory (Fig. 29.36). Detailed adjustments can then be made in an organized manner. Any inaccuracy (e.g., slight tooth movement, previous mounting discrepancies, or small dimensional change inherent with the indirect process) can be compensated for with relative ease, which thus reduces the amount of chair time needed for intraoral precementation adjustment.

Intraoral occlusal refinement is limited because of visibility and access difficulties. Laboratory adjustments offer far superior access and visibility and the opportunity to properly evaluate lingual contact relationships.

The remount procedure consists of making an impression of the seated restorations in the patient's mouth, with an occlusal index in place. The index is made with reinforced resin or impression plaster and provides the opportunity to accurately reposition the castings back into the impression after it has been

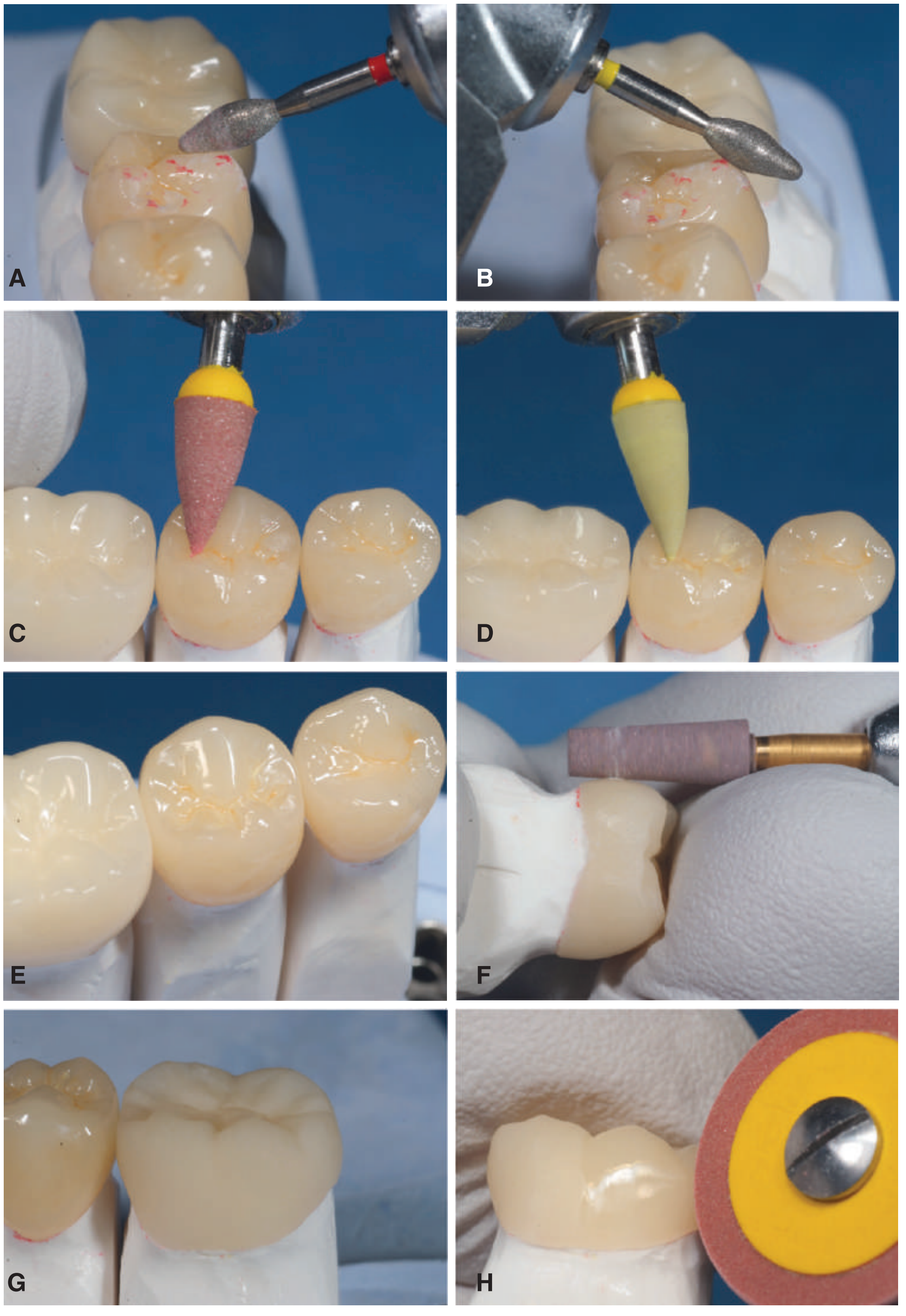

Fig. 29.33 Finishing protocol for lithium disilicate ceramics. (A) Intraoral occlusal adjustment of LD2 with red-band fine Dialite finishing diamond 8369DF. (B) Intraoral occlusal adjustment of LD2 with yellow-band extra-fine Dialite finishing diamond 369DEF. (C) Intraoral polishing of LD2 with intraoral red medium polishing Dialite LD point W16MLD. (D) Intraoral fine polishing of LD2 with intraoral yellow fine polishing Dialite LD point W16FLD. (E) Completely polished LD2 crown with no stain or glaze. (F) Grinding off positioning sprue with LD Grinder LD13M, which minimizes heat generation. (G) Devested IPS e.max Press LD crown. Because occlusion can be precisely waxed, there is no need to grind-in anatomy. Only polishing is necessary. (H) Dialite LD red medium polishing wheel R17MLD for establishing shine on lithium disilicate (note right side polished and left side untreated airborne-particle abraded surface).

Fig. 29.33 Cont'd (I) Dialite LD red medium thin polishing disk L20MLD for polishing grooves. (J) Dialite LD red medium polishing point H2MLD for crafting a shine in the occlusal grooves. (K) Dialite LD yellow fine polishing wheel R17FLD for establishing high shine and luster on lithium disilicate (note right side with finish polish). (L) Dialite LD yellow fine thin polish disk L20FLD for polishing grooves. (M) Dialite LD yellow fine polishing point H2FLD for creating a shine in the occlusal grooves. (N) Completed lithium disilicate crown only polished with Dialite LD kit and no stain or glaze. (O) Comparison of LD stain and glazed premolar crowns, Dialite LD kit polished LD first molar crown and Dialite ZR polished ZrO_2 second molar crown (lingual view). (P) Comparison of first premolar stained and glazed, second premolar, and first molar polished only. Dialite ZR polished ZrO_2 second molar crown (buccal view). (Courtesy Dr J.A. Sorensen.)

Fig. 29.34 Finishing protocol for zirconia ceramics. (A) Adjustment of occlusion on anatomic contour ZrO_2 crown using football-shaped red-band Dialite finishing diamond 8369DF. (B) Grinding in anatomy of ZrO_2 crown using football-shaped red-band Dialite finishing diamond 8369DF. (C) Primary and secondary anatomy ground in anatomic contour ZrO_2 crown. (D) Small round red-band Dialite finishing diamond 8801LDF grinding in grooves and refining secondary anatomy in ZrO_2. (E) Gross contouring of complete ZrO_2 crown with green coarse LD Grinder LD13C. (F) Refining adjustment of complete ZrO_2 crown with pink medium LD Grinder LD13M. (G) Dialite ZR green medium polishing wheel R17MZR for establishing shine on ZrO_2 (note right side with high polish even with Medium Fine polishing only). (H) Dialite ZR green medium polishing point H2MZR for crafting a shine in the occlusal grooves. (I) Dialite ZR orange fine polishing point H2FZR for high shine in the occlusal grooves. (J) Dialite ZR orange fine thin polishing disk L20FZR for high shine in grooves. (K) Completed polished anatomic contour ZrO_2 crown.

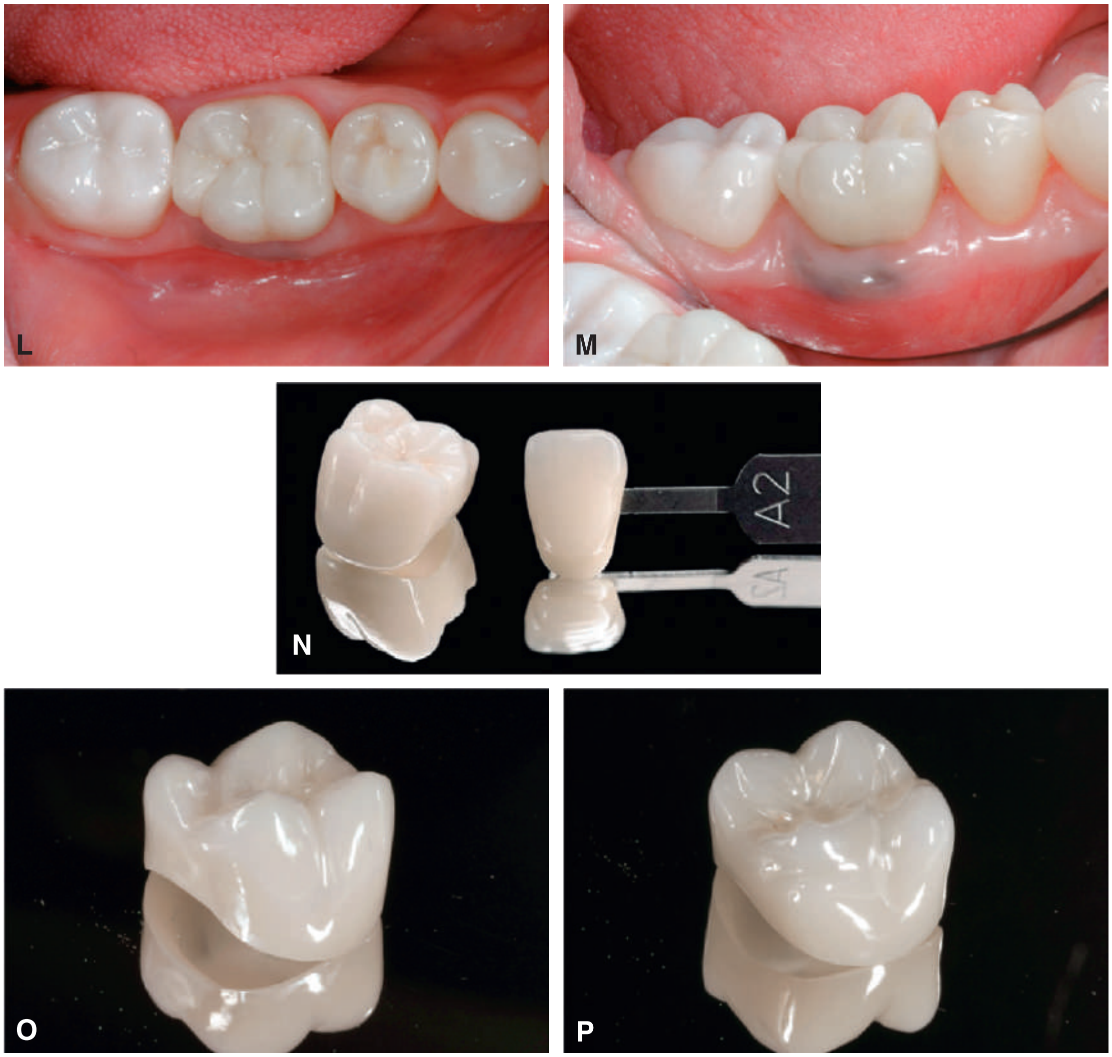

Fig. 29.34 Cont'd (L) Completed anatomic contour ZrO_2 crown mandibular second molar and lithium disilicate crowns mandibular first molar and mandibular second premolar with durable high shine and luster (occlusal view). (M) Completed anatomic contour ZrO_2 crown mandibular second molar and lithium disilicate crowns mandibular first molar and mandibular second premolar with durable high shine and luster (buccal view). (N) The Lava Plus All-Zirconia Monolithic system achieves esthetic results that match the VITA Shade Guide. (O) Lava Plus monolithic translucent ZrO_2 crown differentially colored with incisal and dentin internally, then polished with Dialite ZR system (buccal view). (P) Lava Plus monolithic translucent ZrO_2 crown polished with Dialite ZR system (palatal view). (Courtesy Dr J.A. Sorensen.)

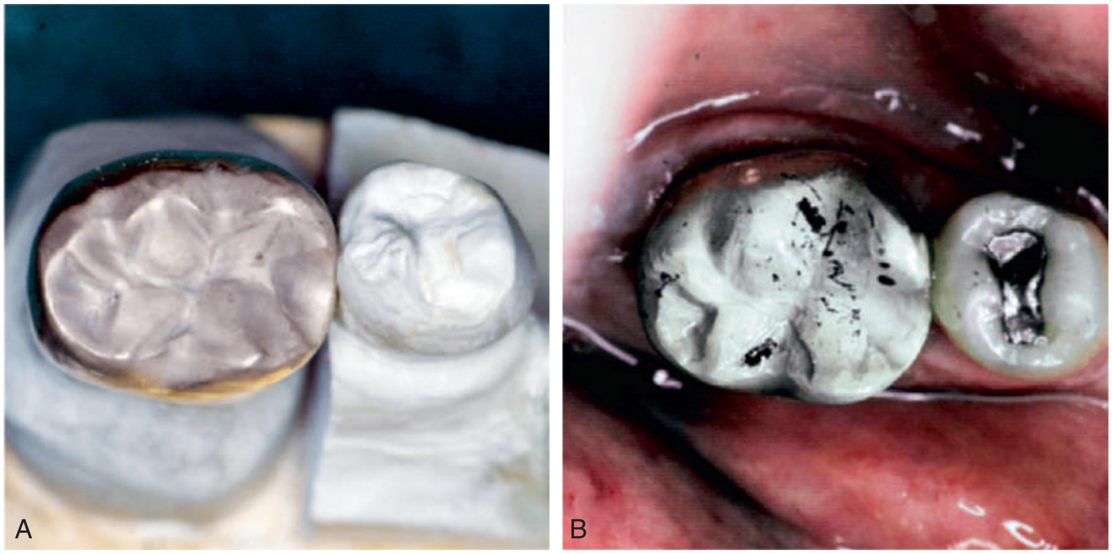

Fig. 29.35 Occlusal prematurities can be identified by giving the casting a matte finish with an airborne-particle abrasion unit. (A and B) The prematurities appear as shiny areas. (Courtesy Dr. M.T. Padilla.)

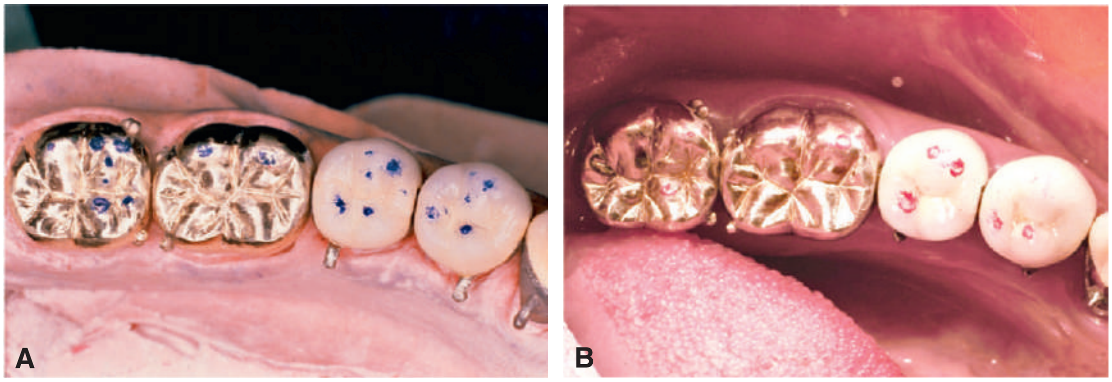

Fig. 29.36 (A and B) Occlusal relationships transmitted to the laboratory should be accurate when a careful technique has been followed. Any discrepancies are often better corrected by a remount procedure in the laboratory.

removed from the patient's mouth. A new definitive cast can then be fabricated. To facilitate removal of the castings from the newly fabricated definitive cast, resin is usually poured into the castings, after which the rest of the impression is poured in conventional type IV stone (Fig. 29.37). The cast can then be articulated with a conventional facebow transfer and occlusal registration techniques (see Chapter 2).

Armamentarium. The equipment needed is shown in Fig. 29.38.

- Impression trays
- Polyvinyl siloxane
- Rubber bowl and spatula
- Elastomeric fit checking paste or interim luting agent
- Petrolatum
- Photopolymerizing resin
- Stiff wire (e.g., coat hanger wire)
- Zinc oxide–eugenol (ZOE) occlusal registration paste
- Inlay wax or light-bodied polyvinyl siloxane
- Facebow transfer equipment
- Centric relation recording

Step-by-step procedure. This process is shown in Fig. 29.39.

1. Use photopolymerizing resin (e.g., custom tray resin) to make an occlusal index of the restorations on the definitive cast. The index will ensure that the restorations are accurately positioned on the remount cast. Reinforce the index with stiff wire. The index should not extend beyond the occlusal table of the restored teeth, and its thickness should be less than 5 mm. It should fit the cast passively.
2. Adjust the occlusal surface of the index until only shallow indentations of the cusp tips remain.
3. Seat the restorations on the prepared teeth (see Fig. 29.39B). To prevent dislodgment, use a small amount of elastomeric fit checking paste or interim luting agent mixed with petrolatum. Elastomeric fit checking pastes are less time consuming to clean off of teeth and restorations than an interim luting agent. FPDs that have yet to be assembled can be stabilized with autopolymerizing resin applied by the brush-bead technique (see Fig. 27.34).
4. After the fit of the index has been verified, cover the surfaces of the restorations with a thin coating of petrolatum,

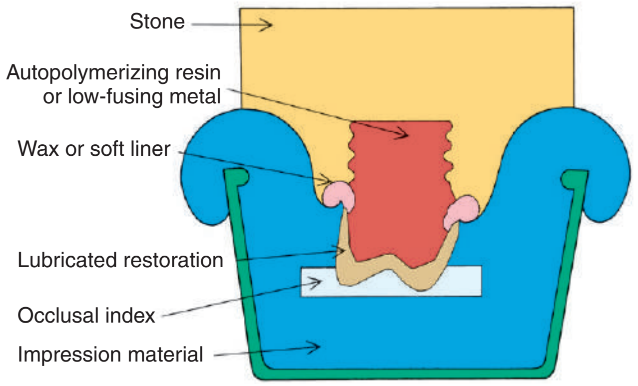

Fig. 29.37 Cross-sectional schematic of the remount procedure.

Fig. 29.38 Armamentarium for a remount procedure: (A) Impression trays; (B) Irreversible hydrocolloid; (C) Rubber bowl and spatula; (D) Interim luting agent; (E) Petrolatum; (F) Photopolymerizing resin; (G) Stiff wire (e.g., coat hanger wire); (H) Zinc oxide–eugenol occlusal registration paste; and (I) Inlay wax or light-bodied reversible hydrocolloid.

and apply ZOE registration paste to the occlusal surface of the index. Then seat it in the patient's mouth. As an alternative, impression plaster can be used (see Fig. 29.39C).

5. Make an orientation impression over the index and the restorations with an elastomeric impression material in a stock tray, ensuring that the index is not displaced (see Fig. 29.39D).
6. Make a conventional opposing impression if no restorations were made for that arch. If restorations have been made for both arches, repeat the procedure described for the opposing arch.
7. After an interocclusal record has been obtained, remove the restorations from the mouth, replace the interim restorations, and schedule a remount appointment for the patient.
8. Clean the internal surface of the restorations of all residual elastomeric paste or cement and debris, reseat the restoration in the index, and apply a thin coating of petrolatum to the intaglio of the crowns.
9. Cover any exposed margins of the restorations with wax or soft lining resin. As an alternative, polyvinyl siloxane impression material can be applied around them with a syringe. Note: Crowns with long retentive axial walls can be partially filled with polyvinyl siloxane to facilitate their subsequent removal.
10. Fill the internal surface of the castings with autopolymerizing resin, adding retention (see Fig. 29.39E). Although type IV stone can be used, difficulty may be encountered retrieving the restorations from the model because of the setting expansion of the stone. If stone is to be used, the castings must be lubricated carefully, and special care must be taken to prevent fracture when they are removed.
11. Complete the maxillary cast (see Fig. 29.39F).
12. Use the newly obtained centric relation record at the occlusal vertical dimension and articulate the cast (see Fig. 29.39G).
13. Save the index to verify accuracy after the remount cast is poured.

This completes the remount procedure. The restorations can now be reassessed and adjusted in the dental laboratory. Although a remount procedure is not routinely needed, it may be advantageous when extensive treatment is undertaken to reduce the amount of chair time required for occlusal adjustment.

Ceramic Restorations

During evaluation of ceramic restorations, certain additional steps are necessary to satisfy esthetic, biologic, and the restoration-tooth interface requirements. Achieving an esthetic result depends on the contour of the restoration, surface characterization, and color match. With highly translucent ceramics, the color of the underlying tooth structure is vital to the definitive color of the restoration. Water or evaluation paste must be used to optically connect the tooth to the restoration. During the color assessment, an optically connected ceramic restoration gives the most accurate prediction of color before final bonding. If the tooth-restoration interface is left dry, the color assessment will be misleading.

Fixed Partial Dentures

Bilayered FPDs often require an additional appointment for assessment: a coping or framework evaluation stage, followed by reevaluation after the esthetic veneer has been applied. At the framework evaluation appointment, the dentist assesses the margin integrity, stability, occlusion, and substructure design. Especially important at this appointment is the assessment of the veneering area: specifically, the framework must deliver adequate support so that a uniform thickness of veneer can be created. Uniform veneer thicknesses have been traditionally done with an anatomic contour waxing and then cutback for FPDs and for single crowns (Fig. 29.40). A more contemporary method can be done through a CAD-CAM cutback (Fig. 29.41). When the veneering ceramic is not properly supported, there is a high risk of porcelain chipping. In addition, when the veneering ceramic possesses different thicknesses, there is a negative esthetic affect in uneven area of translucencies and opacities. Furthermore, the location of the core-ceramic junction in relation to the location of the occlusal contacts should also be assessed. Over time occlusal contacts on a core-ceramic junction creates undesirable results. Inevitably, the two materials will wear at different rates and porcelain chipping results. As a result of differential wear over time, core-ceramic junctions should be designed away from the occlusal table.

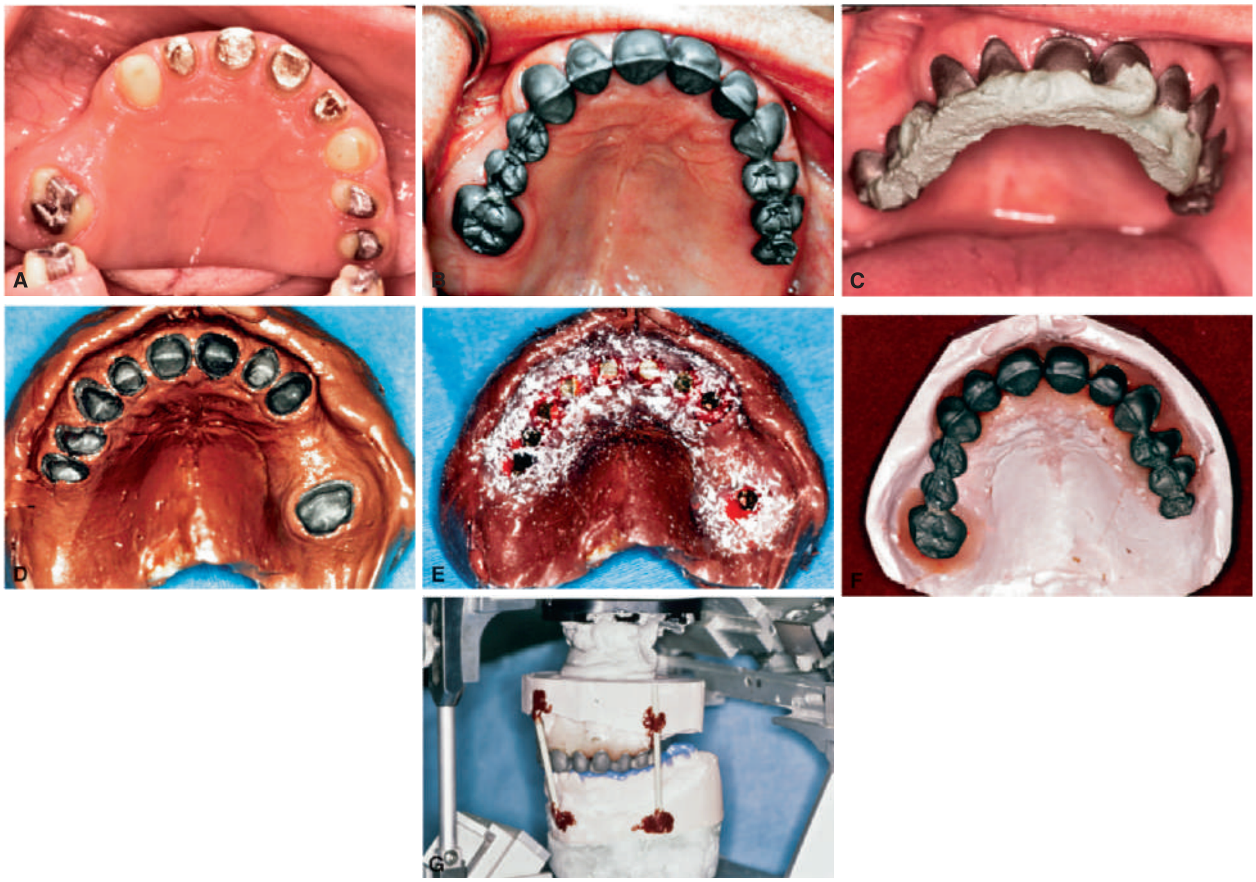

Fig. 29.39 Remount technique. (A) A maxillary arch is prepared for metal-ceramic crowns and fixed dental prostheses. (B) The metal framework is evaluated clinically; a remount procedure is needed. (C), Impression plaster can be used to register the location of each unit. (D), The registration is picked up with an elastomeric material. (E) Restorations are lubricated, and soft lining resin is painted around them. Their internal surfaces are filled with hard resin. Acrylic resin chips provide retention for the soft resin. Small wood screws are inserted into the hard acrylic resin, which are also for retention. The remainder of the cast is poured (F) and articulated (G) in the usual way. (Courtesy Dr. J.H. Bailey.)

Fig. 29.40 A putty matrix was created off of an anatomic contour waxing. A uniform amount of wax was removed from the anatomic contour waxing. The wax cutbacks were cast create copings for bilayered restorations. The putty matrix is repositioned over the opaque cast copings to evaluate space for the veneering ceramic. Ceramic veneers that are not supported with a uniform core are at risk of chipping. (Photograph courtesy Harald Heindl, CDT.)

For bilayered and monolithic FPDs, the tissue contact area of pontics must be convex (Figs. 29.42 and 29.43). Any concavity or flanges in the tissue contact area of a pontic will not be hygienic. Dental floss must be able to establish a "C" shape contact to the pontic to clean the area (Fig. 29.44). Tissue contact and connector dimensions must be assessed carefully; adaptation must be passive, to prevent tissue irritation. Primarily because of the inevitable inaccuracies that result from the many steps in the indirect technique and the high degree of precision required for a successful FPD, restorations almost inevitably require some chairside adjustment before cementation.

Dentofacial Analysis

On anterior teeth, confirm the proper position of the maxillary incisal edge with the lips in repose. Establishing the maxillary incisal edge was the first step in the dentofacial analysis for a facially generated tooth position (Chapter 2). This is a key step in achieving natural looking, age-appropriate teeth that have good esthetics, phonetics, and function.

A solid cast of a well-adjusted interim restoration (made from a diagnostic waxing or from digital smile design) along with

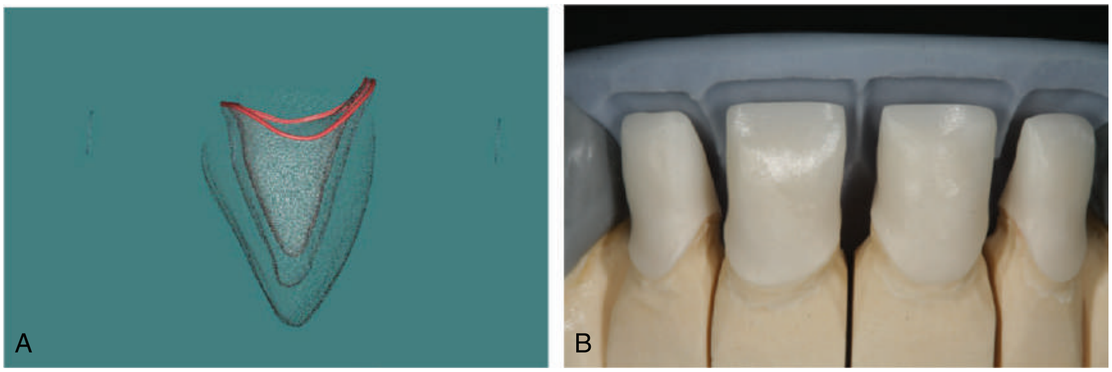

Fig. 29.41 (A) Digital cutback for a bilayered ceramic restoration. On the computer screen, the preparation, zirconia coping, and anatomic contour waxing are superimposed on each other. (Image courtesy Harald Heindl, CDT.) (B) Zirconia cores evaluated on the die cast along with a putty matrix of the anatomic contour waxing. The veneering space is confirmed to be uniform and adequate to support the hand applied porcelain. (Photograph courtesy Harald Heindl, CDT.)

Fig. 29.42 Example of a convex pontic design for an implant supported fixed partial denture. The pontic design must facilitate a patient's home care and not have a convex contour or worse a flange. The convex pontic interface gingiva is important for natural teeth as well as dental implants.

Fig. 29.44 Clinical example of teaching a patient how to thread floss under a new implant supported fixed partial denture.

Fig. 29.43 Adjusting the interproximal area.

photographs are vital to relay information to the technician so that tooth position is seamless from the diagnostic waxing, to the interim restorations, to the definitive restorations (Fig. 29.45).

When the dentofacial analysis is not followed to completion, excessive adjustment of long teeth will result in removal of the translucent incisal porcelain. In contrast, if the maxillary incisal edge is too apical, the crowns can be veneered if the core or framework will support the extra addition. However, neither solution is esthetically or structurally ideal and will often compromise the end result.

When assessing the incisal edge, it is important for the observer to always view from the same angle. To calibrate the angle of view, the author again recommends the observer to always view the teeth from a position that is on the same parallel plane as the anterior occlusal plane (Chapter 2). When an occlusal plane is viewed from a superior point of view, the maxillary incisal edge will have a curve similar to the curvature of the lower lip during a smile. When the occlusal plane is viewed from an inferior vantage point, the maxillary incisal edge will appear to have a reversed curve to the lower lip during a smile. Esthetic recommendation in the literature is for the incisal edges of the maxillary anterior teeth to follow the curvature of the lower lip when the patient smiles.[23] However, this recommendation is from a superior vantage point and difficult to calibrate throughout treatment because of the variability in smiles one individual possesses.

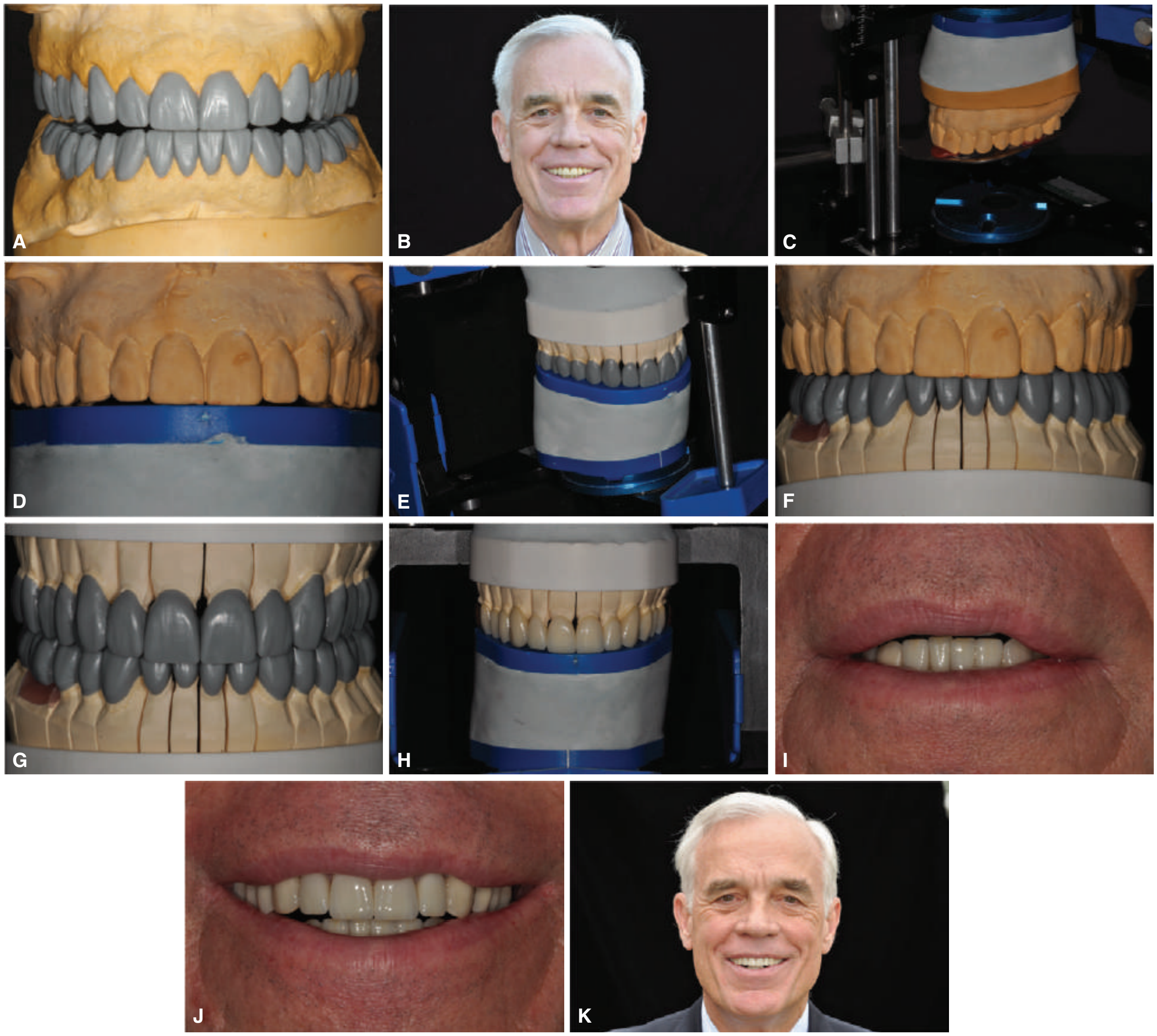

Fig. 29.45 (A) Diagnostic waxing for a comprehensive oral reconstruction. (B) The diagnostic waxing was copied to the interim restorations for an esthetic and functional evaluation. (C) After approval of both the esthetics and function casts were created and articulated onto a semi-adjustable articulator with an average axis facebow. (D) Once the cast was articulated from the interim restorations, a plate was placed on the occlusal plane and fixed with mounting stone to lock in the maxillary incisal edge and occlusal plane. (E) Anatomic contour waxing were fabricated on the die cast to copy the interim restorations. (F) Mandibular anatomic contour waxing were then fabricated on the die casts that opposed the interim cast. (G) The occlusion was finalized with the maxillary and mandibular anatomic contour waxing. (H) Definitive restorations are confirmed to follow the same occlusal plane established with the interim restorations. (I) Repose facial expression confirms the maxillary and mandibular incisal edge position of the definitive restorations. (J) Smile facial expression is useful to assess the esthetic position of the occlusal plane. (K) Frontal view of a full face in a sociable smile is important to evaluate the facially generated tooth position that was first proposed in the diagnostic waxing, confirmed with the interim restorations and carried to completion in the definitive restorations.

Assess the dental midline. The dental midline was determined before the therapy began at the diagnostic phase of treatment. Whether the dental midline was established to be coincidental with the facial midline, mandibular midline, or neither, it needs to be verified that in the definitive restorations it is located in accordance with what was decided at the time of the original treatment plan. Gross errors in the dental midline position can lead to costly remakes of ceramic restorations.

Once the incisal edge position has been evaluated to achieve the desired esthetic result, verify its position for speech characteristics by engaging the patient in a conversation. Have the patient enunciate the consonants. *F* sounds are particularly helpful because they are made with the incisal edge of the maxillary central incisors touching the junction of the moist and dry surfaces of the vermilion border of the lower lip ("wet-dry line").[24]

Fig. 29.46 Evaluation of gross asymmetry between two maxillary central incisors is straightforward because of our binocular vision.

Fig. 29.47 The two lateral incisors have different rotations. Observers have to shift their gaze when evaluating the two rotations, making them more difficult to assess than the two maxillary central incisors.

Fig. 29.48 Definitive ceramic crown on central incisor is a challenging restoration because of humans' binocular vision. Asymmetries between the central incisors are quickly detected. To give the illusion of symmetric proportions, a small root effect was placed on the distofacial aspect of the ceramic crown.

Contouring

With the way the human eyes are positioned in the skull, their respective fields of view partially overlap. Known as binocular vision, an observer is able to evaluate the two maxillary central incisors simulations without any eye movement. Because of binocular vision, the central incisors must be symmetric to each other. Any small variation between the two central incisors is easily detected, even by lay people, and considered abnormal (Fig. 29.46). By contrast, lateral incisors cannot be viewed simultaneously. The observer has to look at one tooth and then shift their gaze to the contralateral tooth (Fig. 29.47). As a result of having to shift from one field of view to another, subtle variations in position and contour between the two lateral incisors are harder to detect. Mild asymmetries distributed across the dental arch have a potential to create an esthetic balance and deliver a natural appearance (Fig. 29.48).

Tooth proportions are also closely related to contours. To maintain contour symmetry, many times a dental ceramist will have to use optical illusions to create symmetry. One technique is to develop root effects to optimize tooth proportions and contours. When root effects are incorporated into a ceramic restoration, it is advisable to not make them longer than 2 mm because otherwise they become too obvious (see Fig. 29.48).

Armamentarium. The equipment needed is shown in Fig. 29.49.

- Flexible diamond disk
- Porcelain grinding wheel
- Ceramic-bound stones
- Diamonds

When a restoration evaluated in the bisque stage is to be contoured, it should be moistened first with water or saliva. The moist surface reflects light in the same manner as eventually the glazed restoration will.

Step-by-step procedure

1. Check the proximal contact relationship, marginal fit, stability, and occlusion of the restoration (adjust as necessary).
2. Verify the contour of the gingival third and make any necessary adjustments to the emergence profile. Open gingival embrasures create cervical black triangles that are esthetically unattractive. From the tip of the papilla to the osseous crest, research has established a measurement of 4 to 5 mm of periodontal soft tissue will fill in a gingival embrasure.[25,26] The tissue thickness can be measured before a tooth is prepared for a specific patient. The measurement is taken after the tooth has been anesthetized. Once the periodontium is anesthetized, insert a periodontal probe into the sulcus next to the proximal contact to record the periodontal pocket depth. Knowledge of the sulcus depth is important so that a subgingival margin does not extend apically past the pocket depth. Now that the sulcus depth is known, the dentist records the soft tissue thickness at the papilla. With firm pressure, press the periodontal probe apically through the periodontal attachment until it contacts the alveolar crestal bone. With the periodontal probe tip resting on the crestal bone, the height of the papilla can be measured. As an example, the patient measured 4 mm from osseous crest

Fig. 29.49 Armamentarium for porcelain adjustment. (A) Pink aluminum oxide stones *(left)*. Thin diamond disk *(center)*. Green silicon carbide stones *(right)*. (B) Shofu Porcelain Adjustment Kit with white aluminum oxide stones *(left)* and silicon carbide impregnated polishers *(right)*. (C) Brasseler Porcelain Adjustment Kit with diamond impregnated rubber polishers in three grits. *Blue*, Course; *gray*, fine; *pink*, medium.

Fig. 29.50 (A) Extraoral conformation that the ceramist placed the proximal contact in the correct vertical distance to the proximal finish line to achieve complete papillae fill between the crown without constriction of the periodontal tissues. (B) Intraoral evaluation to assess the integration of crown contours and proximal contacts to that of the healthy gingiva.

to summit of a papilla and in the same area has a 3-mm periodontal sulcus; a crown finish line could be atraumatically placed 1 mm within the sulcus without causing any recession or impingement of the periodontal attachment. If a gingival black triangle is to be avoided, the ceramist would then need to be instructed to start the proximal contact 3 mm incisal of the finish line to get complete papilla fill of between the crowns (Fig. 29.50).

3. In contrast, excessive bulk in this area is another common error, and axial overcontouring is often associated with periodontal inflammation (Fig. 29.51). When adjustment of a metal-ceramic restoration is needed, the porcelain and metal should not be ground simultaneously because small metal particles may be transferred to the porcelain, causing discoloration and a black spotty appearance after glazing. If grinding both porcelain and metal simultaneously is absolutely necessary, the direction of grinding should parallel the metal-ceramic junction (Fig. 29.52). A thin, flexible disk provides good access to reduce any overcontoured interproximal area (see Fig. 29.43).
4. Ordinarily, the incisal edges of the lateral incisors (Fig. 29.53) are 0.5 to 2 mm shorter than the central incisors, which may touch the internal border of the lower lip when it is relaxed. This lateral incisor offset is important for natural esthetics[27] and also prevents interference from the mandibular canine during protrusive mandibular movement (see Chapter 4).

Fig. 29.51 (A) Periodontal disease associated with excessively contoured restorations. (B and C) Teeth reprepared to allow appropriate facial contours. (D) Correct emergence profile established in restoration. (E) Clinical adaptation verified. (F) Note tissue response to new restorations. (G) Appropriate embrasure form allows plaque control.

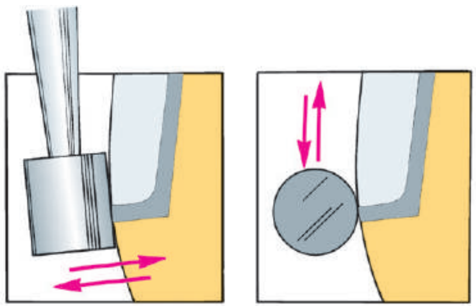

Fig. 29.52 If it is necessary to grind at the metal-porcelain junction, the stone should be held so that the direction of grinding is parallel to the metal-ceramic junction. Otherwise, metal particles may contaminate the porcelain.

Fig. 29.53 Typical incisal edge position. (From Monteith BD. A cephalometric method to determine the angulation of the occlusal plane in edentulous patients. *J Prosthet Dent.* 1985;54:81.)

5. Evaluate the *negative space:* the shape of the incisal embrasures (see Chapter 1).[28] Properly shaped embrasures (Fig. 29.54A and B) significantly enhance the apparent separation between restorations, whereas their absence draws attention to the prosthesis and reveals its artificial nature (see Fig. 29.54C). Similarly, when viewed from the incisal aspect, interproximal embrasures should be as narrow and deep as possible to enhance the shadows between components of the FPD. If these are absent, even the casual observer will recognize the teeth as artificial.
6. Mark the line angles directly on the porcelain restoration with a pencil, and compare these to the line angles of adjacent and contralateral teeth. If the ceramic is in a bisque stage, a red pencil is preferred because blue or black pencil may discolor the porcelain. Correct line angle delineation is one of the more critical procedures for achieving good

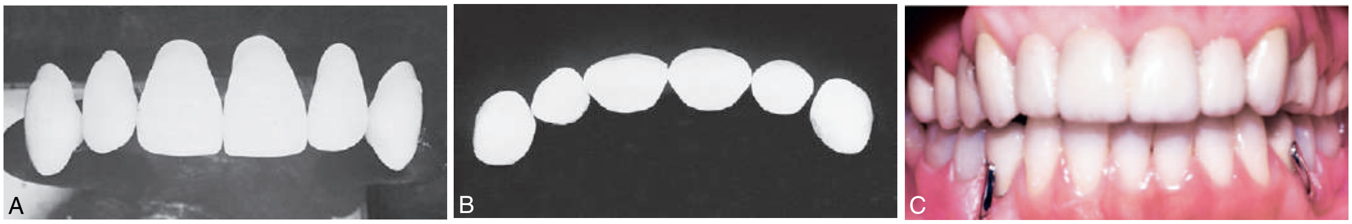

Fig. 29.54 (A and B) Properly shaped incisal embrasures. (C) Inadequate embrasures. Note the unnatural look.

Fig. 29.55 When insufficient space was available for a normal size pontic, an apparent overlap was created in the dental laboratory (A), which was then carefully evaluated clinically (B).

esthetics because the line angles define the shape of the tooth to an observer. (Line angles on wax patterns are discussed in Chapter 18.) By superimposing normal line angle distribution over teeth that are otherwise too large or too narrow,[29] creating the impression that the left and right sides are identical is possible (Fig. 29.55; see Chapter 23).

7. Evaluate the overall contour to see that it matches the shape of the adjacent teeth. With experience, most operators quickly develop an appreciation for evaluating "normal" contours and detecting areas that need correction. Moistening the teeth and observing light reflections may help. It also helps to have the patient stand up to be checked at normal conversational distance, as opposed to the extreme closeup of a dental examination.

Surface Texture Characterization

When the contour of the restoration has been finalized, the next goal is to duplicate the surface detail of the patient's natural teeth. Perikymata are horizontal growth lines that form on the surface of enamel as a result from tooth development. Perikymata are routinely visible on young unworn natural teeth. As one ages, perikymata tend to get polished away from normal function and use. As a result of enamel surfaces naturally becoming smoother with age, giving the patient's age to a ceramist is valuable information to create age specific teeth for a patient (Fig. 29.56). When multiple restorations are involved, the dentist and ceramist have more input on the amount of surface texture created as compared with a single restoration. In some patient treatments, fixed and removable prosthodontics are combined. In contrast to natural teeth, denture teeth typically have a highly polished and smooth surface texture. For a crown to match an adjacent denture tooth, it will typically require a high surface glaze and gloss on the ceramic (Fig. 29.57).

Armamentarium

- Diamond disk
- Carborundum stones
- Diamond stones

Step-by-step procedure

1. Dry the teeth, and examine their surfaces carefully. Perikymata and other defects can be simulated by grinding the porcelain with a diamond stone of appropriate texture. (Be careful not to overemphasize such details.) Flat or concave areas reflect light in a characteristic manner, producing highlights (Fig. 29.58).
2. Copy the details, and carefully blend them to mimic adjacent teeth. In general, the effort should aim at generating textures that follow the principal curvatures of the normal anatomic form of the tooth, to result in optimal perception of the characterized surface.
3. Similarly, mimic any vertical defects with careful grinding.
4. Be careful to avoid "overcharacterizing" restorations, which is a common error (Fig. 29.59).

On occasion, altering the apparent size of a restoration by these techniques may be possible. A smooth tooth appears larger than one that is identical in size but has intensive surface texture characterization.

CHARACTERIZATION AND GLAZING

The surface luster or degree of gloss of a porcelain restoration depends on the autoglazing procedure (see Chapter 24). Both time and temperature must be carefully controlled. During the

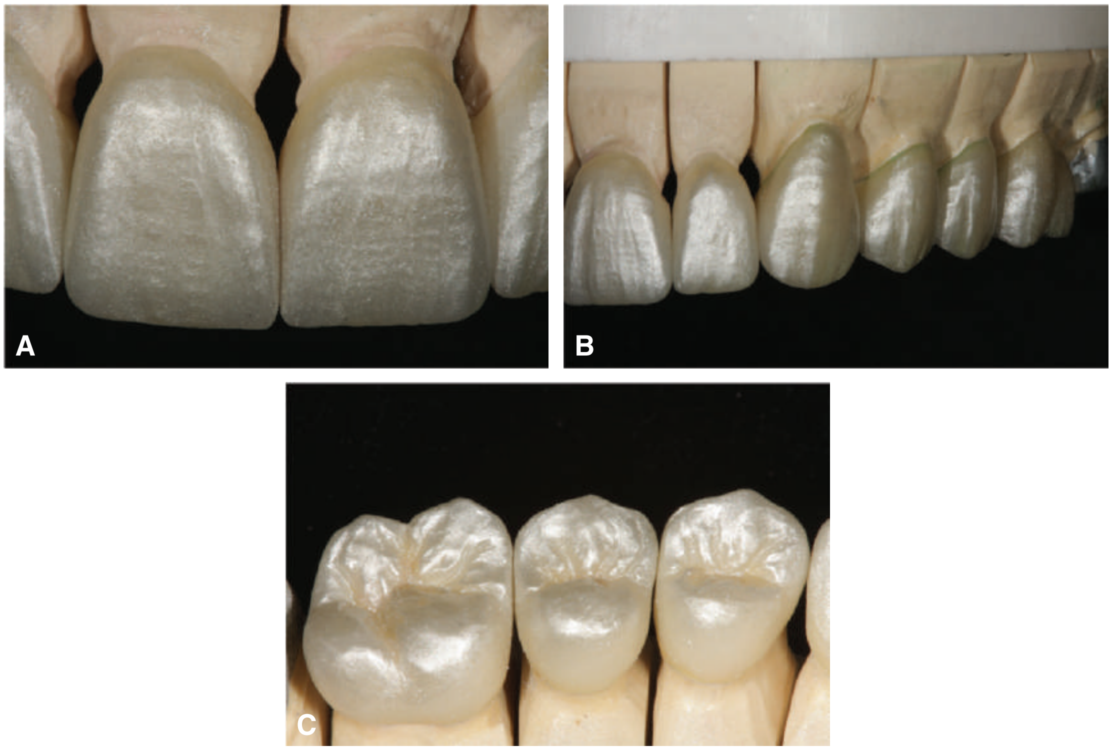

Fig. 29.56 (A) Silver-colored dust can be applied to ceramic surfaces for an extraoral evaluation of the surface texture. (Photograph courtesy Harald Heindl, CDT.) (B) Because of the patients age, little perikymata was developed; however, surface texture created a favorable effect with light reflection to produce a natural effect. (Photograph courtesy Harald Heindl, CDT.) (C) Silver-colored dust can also be applied to posterior ceramic restorations to aid in evaluation of occlusal anatomy. Note the organic form of the secondary occlusal grooves with no straight lines. (Photograph courtesy Harald Heindl, CDT.)

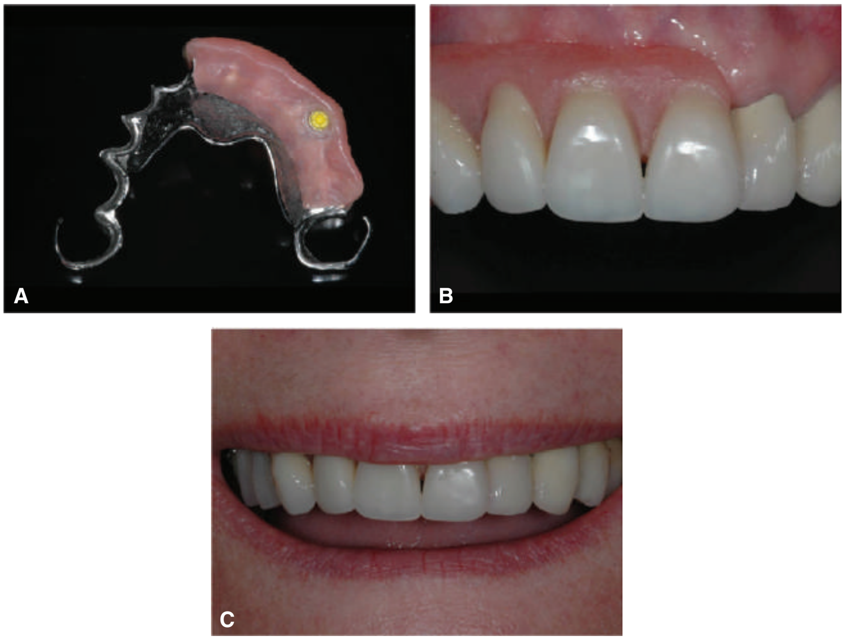

Fig. 29.57 Some patients required a combination of fixed and removable prosthodontics. Providing the dental laboratory technician with the denture teeth is useful information for matching contours and surface texture in the crowns. (A) A removable partial denture that was processed after the metal-ceramic crowns were finalized. (B) Intraoral evaluation of matching metal-ceramic crowns to denture teeth on a removable partial denture. (C) A smile is useful to evaluate lip mobility during the definitive assessment as part of the dentofacial analysis.

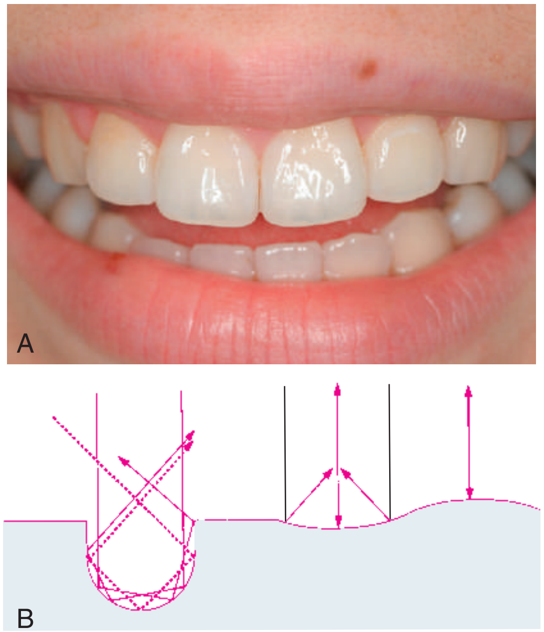

Fig. 29.58 (A) Restoration texture should closely match natural enamel. (B), Sharp grooves should not be cut into the ceramic surface because these "trap" light. A curved surface looks more natural and results in either converging or diverging reflections. (Courtesy Dr. D. Ketteman.)

Fig. 29.59 The texture of these metal-ceramic prostheses has been overemphasized, leading to an artificial appearance.

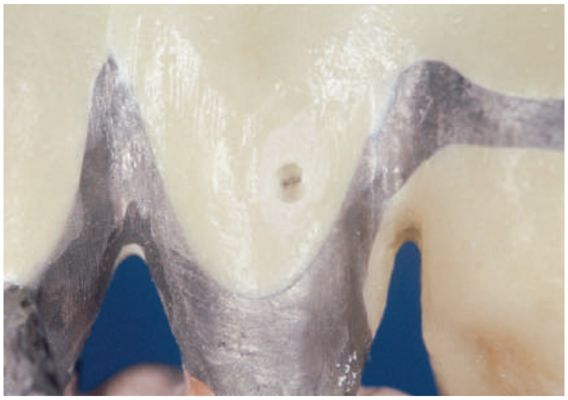

Fig. 29.60 A bubble that surfaced immediately before the evaluation stage. Such a defect must be addressed before delivery of the prosthesis.

glazing firing, the surface layers of porcelain melt slightly, causing the particles to coalesce and thereby fill in surface defects.

Restorations should not be glazed in a vacuum because included air may be drawn to the surface and result in bubbling (Fig. 29.60). Because air-fired glazing furnaces are relatively compact and inexpensive, some dentists prefer to glaze porcelain restorations in the office. This is particularly convenient if surface stains are to be used. Glazing is straightforward; the degree of glaze depends on furnace temperature and how long the restoration is held at the firing temperature. Excessively glazed anterior teeth look unnatural. During the clinical evaluation, the patient should be instructed to moisten the restoration because saliva affects its appearance. A dry crown looks misleadingly underglazed. However, underglazing and refiring a restoration is better than overglazing it. If a restoration is not sufficiently glazed, it will retain more plaque and may be more liable to fracture. After glazing, the metal surfaces of the restoration, which have oxidized during firing, are repolished.

An alternative to glazing is to polish the porcelain surfaces of the restoration.[30] This provides greater control of the surface luster and distribution than glazing.[31] For example, having a higher gloss on the cervical area and a lower gloss on the incisal area is possible. This is not possible with glazing because the entire crown is subjected to the same time-temperature combination.

Polishing dental ceramics has long been advocated as an expedient way of restoring luster after adjusting by grinding. A number of commercially available polishing kits are available for this purpose. If used correctly (i.e., without omitting the successively finer grits), most are capable of producing smooth porcelain surfaces.[32,33] As an alternative, the use of finishing wheels followed by pumice is satisfactory.[34] Ceramists have advocated polishing as a way to improve luster control. To achieve the precise degree and distribution of luster required, the porcelain is polished rather than glazed.

Despite the esthetic advantages of polishing, there is concern whether the strength of a polished restoration might be reduced or its abrasiveness increased. Glazing has been cited as strengthening a dental restoration,[35] presumably because it causes a reduction of the flaws that initiate fracture. However, polishing also reduces flaws, and in laboratory studies, polishing has not been found to reduce physical properties, in comparison with glazing.[36–40] Laboratory studies have shown that polished porcelain is no more abrasive than glazed porcelain.[41] However, unpolished porcelain is much more abrasive on opposing enamel and is more plaque retentive than is polished or glazed porcelain.[42]

External Color Modification and Characterization

Stuart H. Jacobs

The goal of all dental ceramists is to accomplish a perfect color match by using the basic shades supplied in the porcelain kits, without the need for chairside modification. However, there are difficulties and inaccuracies inherent in the technique. There are also difficulties in duplicating the appearance of a patient's

Fig. 29.61 Ney Miniglaze/2 glazing furnace. (Courtesy Dentsply Sirona, York, Pennsylvania.)

Fig. 29.62 The appearance of these veneered zirconia crowns has been enhanced with custom staining. (From Freedman G. *Contemporary Esthetic Dentistry*. St. Louis: Mosby; 2012.)

tooth without the patient's actually being present in the dental laboratory. These problems make perfect shade matching very difficult to achieve routinely. In many situations, a restoration that does not blend well with the adjacent teeth can be improved by simple chairside color modification or characterization procedures.[43] These are done concurrently with final glazing, and it is therefore recommended that restorations be tried in the patient's mouth when contoured but unglazed (at the bisque stage).

Armamentarium

- Porcelain furnace (a small air-fired furnace is suitable for the operatory; Fig. 29.61).
- Clean glass slab
- Sable hair brush
- Distilled water
- Tissue
- Stain kit

A number of stain kits are available from porcelain manufacturers, and most contain a fairly wide range of colors. The stains themselves are highly pigmented surface colorants that contain a small amount of glass, which allow the color to fuse into the porcelain surface. Ceramic systems generally have dedicated surface colorants that are normally applied by the dental technician in accordance with the dentist's shade prescription. However, some dentists like to apply these surface stains clinically to obtain an improved shade match (Fig. 29.62).

Available characterization kits are illustrated in Fig. 29.63. Various colors are available. To make additional colors, the stains can be mixed with each other; the color intensity can also be toned down with a colorless porcelain.

Step-by-Step Procedure

The application of stain has advantages and disadvantages. One advantage is that the dentist or technician can modify the shade after a restoration is completed, with the patient present. The greatest disadvantage is that the color can be applied only to the surface, and so it is ineffective in producing characterizations that look realistic (i.e., deep within the tooth). In addition, excessive surface characterization[44] can cause a loss of fluorescence in the finished restoration and an increase in the metameric effect (shade mismatch is more apparent under some lighting conditions). Furthermore, a characterized crown is slightly rougher than an autoglazed one,[45] and the stain will eventually (in 10 to 12 years) wear away with normal toothbrushing.[46,47]

Three aspects of characterization may be used singly or in combination to achieve a natural appearance: shade modification (increasing the chroma, changing the hue, or reducing the value); specific characterization (e.g., hypocalcified areas or cracks); and special illusions of form or position (Fig. 29.64).

1. Mix the stain with the liquid provided in the kit (normally a glycerin-water mixture) to a creamy, stiff consistency (see Fig. 29.64A). If the mixture is too thin, it runs over the restorations and pools in certain areas. An even coat is essential for producing the best results.
2. Before applying the stain, thoroughly clean the restoration with steam. Apply stain to the restorations with the clean moist sable brush (see Fig. 29.64B). When moist, the brush becomes easier to draw to a point, and application of the stain is greatly facilitated.
3. When the effect has been created, make a note of which stain was used and where. This procedure usually must be duplicated because absolute cleanliness is essential; in addition, placing a unit in the mouth without some contamination is difficult. Removing the restorations without smudging is also challenging.
4. Take the restorations out of the mouth, wash them, and recreate the characterization (see Fig. 29.64C-E).
5. After the characterization is complete, transfer the restorations to a firing tray, and place it in front of the muffle of the furnace until the stain is dry and the surface appears chalky white (see Fig. 29.64F and G).
6. Remove the prosthesis, and examine it to ensure that no stain has run inside.
7. Remove any excess with a dry brush, and place the crown in the furnace.

A

B

Fig. 29.63 (A) Representative IPS stains. (B) The VITA Akzent Stain Kit. (A, Courtesy Ivoclar AG, Amherst, New York; B, Courtesy VITA North America, Yorba Linda, California.)

8. Increase the heat to the maturation temperature of the porcelain, and hold it there according to the degree of glaze desired (see Fig. 29.64H).
9. Remove the restorations, allow them to cool, and reevaluate them in the patient's mouth.

Shade Modification

When a porcelain shade is altered with external stain (see Chapter 23), certain limitations must be considered, particularly because use of surface stains causes a loss of fluorescence and increases the effect of metamerism. It cannot be used to make major corrections or compensate for gross shade mismatches.

When the shade match is evaluated, the appearance of glazed porcelain is necessary. To simulate this appearance, some of the liquid provided in the stain kit is painted onto the porcelain. It may also help to coat the adjacent natural tooth to prevent dehydration during the characterization procedure, which will increase the value of the tooth.

Chroma and hue adjustment. Increasing the chroma (saturation) is one of the simplest shade alterations to achieve.[48] The addition of yellow stain increases the chroma of a basically yellow shade, whereas adding orange has the same effect on a yellow-red shade. When an alteration in hue is necessary, pink-purple moves yellow toward yellow-red, whereas yellow decreases the red content of a yellow-red shade. These are the only two modifications that should be necessary because the hue of a natural tooth always lies in the yellow-red to yellow range.

A ceramic or metal-ceramic restoration that has too high a chroma is difficult to modify. Choosing a shade with a lower chroma is always safer because a lower chroma can be altered easily. Using the complementary color of a restoration reduces its chroma: For yellow, purple-blue is used, and for orange, blue or blue-green is necessary. However, the addition of these stains lowers the value of the restoration and increases the metameric effect; it is rarely successful.

Value adjustment. Value can be reduced by adding a complementary color (see Fig. 23.1). Violet is used on yellow restorations and has the added effect of increasing apparent translucency. Use of gray stains is not encouraged because it tends to reduce translucency and makes the surface cloudy.

Attempting to increase the value is generally less successful, although value can be increased if the dominant color added has a higher lightness ranking. For example, a crown can be stained with white, but opacity will be greatly increased.

Characterization. Characterization is the art of reproducing natural defects, and it can be particularly successful in making a crown blend with the adjacent natural teeth. Although the goal is

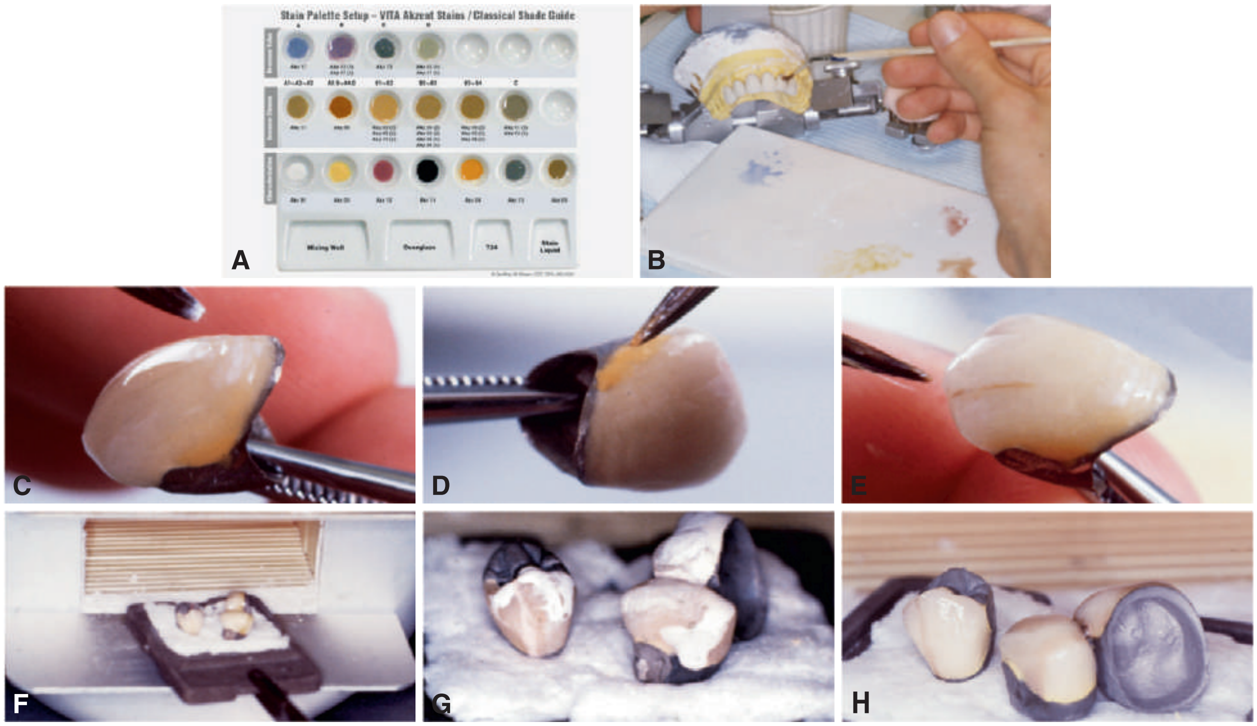

Fig. 29.64 Characterization and glazing technique. (A) The colored stains are mixed to a stiff consistency on a suitable palette. (B) Applying the stain. Often the procedure is repeated, or modifications are made after removal from the patient's mouth. (C) White stain is used to mimic hypocalcification. (D) Stain with increased chroma is used for proximal coloration. (E) A thin brown check line is made by painting a line of stain on the porcelain. To reduce this to the desired width, a clean brush is used to wipe on each side of it. (F and G) Stain is dried to a chalky consistency in front of the furnace muffle. (H) Characterized and glazed restorations after firing. (A, Courtesy Dr. G.W. Sheen.)

to mimic nature, care must be done to control the magnitude and position of the effect so that an observer will not quickly question a patient on what is on their tooth. In general, defects should be reproduced to a slightly lesser extent on the restoration than as they appear on the natural teeth. The temptation to overcharacterize is strong but only acceptable with a patient's approval.

Characterization looks slightly more natural and is more permanent if applied intrinsically during the buildup of the restoration (see Chapter 24) rather than by subsequent extrinsic application.[49] However, communicating the exact characterization needed to the laboratory may be difficult; therefore copying natural defects at chairside may be more successful.

Hypocalcified areas. These are produced with white stain and may be some of the easiest and most commonly made modifications.

Proximal coloration. Many natural teeth exhibit proximal characterization. By reproducing this in the restoration, the dentist is able to create the illusion of depth and separation and is also able to tone down excessive opacity at the cervical area. The stains used are brown and orange. They are applied lightly to the proximal area and extended slightly onto the buccal surface apical to the contact. Proximal coloring is particularly useful in creating the illusion of separate units of an FPD.

Enamel cracks. Crack and craze line affects can be done to mimic nature; however, care must be done to control the magnitude and position so that an observer will not quickly question what is on a patient's tooth.

Fig. 29.65 Thin brown check lines have been added to enhance the appearance of this prosthesis.

This characterization is better if done intrinsically, although it can be added extrinsically. A linear vertical crack interrupts the light transmission across the tooth surface, causing a shadow. Thus both the highlight and the shadow of the crack must be simulated for an authentic result.

The highlight is developed with white and yellow mixed in the ratio of 4:1, and gray stain is used for the shadow. A thin line is drawn with a brush in the desired area with the white and yellow stains. Then a thin line of gray is placed distal to the first line to create the illusion of a shadow.

Stained crack line. Cracked enamel stains quickly on natural teeth (Fig. 29.65). An orange-brown mixture applied in as thin a line as possible will effectively simulate a crack.

Exposed incisal dentin. This is usually seen on the mandibular incisors of older patients and is caused by enamel wear. The incisal edge should be "cupped out," with orange and brown colorants used to reproduce the dentinoenamel junction.

Incisal halo. Translucent incisal edges are more common on the incisors of younger patients. Often, although the incisal area is translucent, the edge is totally opaque. This may be difficult to reproduce internally. A mixture of white and yellow stains in the ratio of 4:1 is placed in the linguoincisal area, with an extension just onto the labial area, to produce the halo effect.

Translucency. Translucency can be mimicked with violet stain, although the results are usually disappointing in comparison with those achieved with correct application of the incisal porcelain. For optimum results, both labial and lingual surfaces should be coated. Decreasing the translucency is accomplished by adding the dominant hue over the labiolingual surface.

Special illusions. Form and position are undoubtedly the most important factors in achieving an attractive result. However, restoring the original form may not always be possible. Loss of supporting tissue, the size of a pontic space, or a poor occlusal position may impede the attempt.

An FPD pontic may be very long because of loss of supporting bone. Simulating a root surface can partially improve the appearance. The root extension is contoured for length and width, and then an orange-brown mixture is placed over the extension. Pink stain can be used to simulate gingival tissue, but results are better with pink body porcelain.

Recommended characterization procedures are summarized in Table 29.1.

▪ ▪ ▪

SUMMARY

Quality assessment of a new restoration is a two-part process. The prosthesis must be evaluated on receipt from the dental laboratory and once determined to be acceptable with the patient present. Traditional and digital methods of prosthesis fabrication each have their benefits and short comings. With the traditional method of fabrication, the definitive cast is a conduit between the laboratory and dentist, whereas when a cast is not available in a digital workflow, the dentist has a more immediate and direct involvement through check points on a computer screen. Although digital dentistry offers new methods for assessing the restoration outside of the patient's mouth, its intraoral evaluation is still identical to doing so for traditionally fabricated restorations. For the intraoral evaluation, the sequence of assessment has a logical approach. The proximal contacts are assessed first, followed by margin integrity, stability, and occlusion. Minor occlusal discrepancies can usually be adjusted intraorally before cementation. For extensive prosthodontic treatment, a remount procedure may be needed, which will reduce the chair time needed to achieve an optimum occlusal scheme in the restoration.

With any restoration, proper contouring in the cervical third is crucial for facilitating maintenance of health of the supporting structures. Proper shaping of the gingival and incisal embrasures, along with contouring and characterization, significantly improves the esthetic result. Small corrections and subtle changes can be made with surface stains. Certain ceramic restorations may be luted before final adjustment of the occlusion.

TABLE 29.1 Characterization Procedures

Characteristic	Basic Colors	Ivoclar IPS Stain	VITA Akzent Stain No.
Chroma increase	Yellow and yellow-red	Caramel brown, orange	See Fig. 29.29A
Chroma decrease	Violet and blue-green	Sky blue + basic red, sky blue	See Fig. 29.29A
Hue adjustment	Pink-purple or yellow	Basic red + basic blue, basic yellow	12 (Redwood) + 17 (Niagara), 03 (Sun Kiss)
Value adjustment	Violet and (white)[a]	Sky blue + basic red, white	See Fig. 29.29A
Hypocalcification	White	White	01 (Birch)
Proximal coloration	Brown and orange	Cork brown, orange	Use increased chroma (see Fig. 29.29A)
Enamel cracks	White-yellow and gray	Bamboo beige	01 (Birch) + 03 (Sun Kiss)
Stained crack line	Orange-brown	Cork brown + orange	01 (Birch) with 13 (Shak)
Exposed incisal dentin	Orange and brown	Orange, cork brown	Use increased chroma (see Fig. 29.29A)
Incisal halo	White-yellow	Bamboo beige	02 (Mellow Yellow)
Translucency	(Violet)[a]	Sky blue + basic red	13 (Shak)
Cervical staining			
A shades	Orange-browns	A1, A2/A3, A4[b]	Use increased chroma (see Fig. 29.29A)
B shades	Greenish-browns	B1, B2/B3/B4[b]	Use increased chroma (see Fig. 29.29A)
C shades	Greenish-browns	C1/C2, C3/C4[b]	Use increased chroma (see Fig. 29.29A)
D shades	Greenish-browns	D2/D3, D4[b]	Use increased chroma (see Fig. 29.29A)

[a]Modification may not be successful.
[b]IPS Shade V.

STUDY QUESTIONS

1. How is a prosthesis evaluated with stone casts. What are the recommended digital assessments for a prosthesis?
2. What is the recommended sequence for the clinical evaluation of a crown on a mechanically retentive tooth preparation? Why? How is the sequence different for a nonmechanically retentive tooth preparation that will be bonded?
3. How is a tight proximal contact most effectively identified and corrected?
4. Discuss the addition of a proximal contact for a monolithic ceramic crown, gold crown, and a metal-ceramic crown.
5. What is a remount procedure? Discuss the steps involved.
6. What is the "negative space"?
7. When shade modification is desired, how is chroma increased? What hue adjustments are feasible? How is value adjusted?

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30

Luting Agents and Cementation Procedures

Pooya Soltanzadeh, Contributing Author

A wide range of cements is available for indirect restorations, and failure can happen if the restorations are not handled and cemented properly. Choosing an appropriate luting agent should be done based on mechanical properties, biological compatibility to the tooth and tissue, working time, ease of excess removal, and completeness of moisture control.

It is emphasized that no ideal cement exists to meet the requirements of every clinical situation; therefore, product knowledge is crucial.[1]

LUTING AGENTS AND CEMENTATION PROCEDURES

Luting agents are used to ensure the stability of fixed prostheses throughout their serviceable lifespan. They can be interim luting agents, or definitive luting agents. Definitive luting agents are either water or polymer based.

INTERIM CEMENTATION

On occasion, cementing a restoration on an interim basis may be advised so that the patient and dentist can assess its appearance and function over a time longer than during a single visit. However, such trial cementations should be managed cautiously. Removing the restoration for definitive cementation may be difficult, even when interim zinc oxide–eugenol (ZOE) cement is used. To avoid this problem, the interim cement can be mixed with a little petrolatum. The modified luting agent is applied only to the margins of the restoration to seal them and allow subsequent removal without difficulty. However, an interim cemented restoration may come loose during function. If a single unit is displaced, it can be embarrassing or uncomfortable for the patient. If one abutment of a fixed partial denture (FPD) becomes loose, the consequences can be more severe. If the patient does not return promptly for recementation, caries can develop very rapidly.[2]

Eugenol inhibits the polymerization of resin, if a crown is planned to be bonded to the tooth, a eugenol-free interim luting agent should be used for the interim crown. Interim resin-based cement is an alternative to conventional zinc oxide eugenol cements, especially in the esthetic zone due to its better translucency and reduced shade mismatching.[3]

Interim resin-based cements can be also used when the axial reduction is minimal, and the cement layer may show through the interim restoration. Temp-Bond Clear (Kerr Corporation, Pomona, CA) is a transparent, dual polymerizing, eugenol-free cement, suitable for interim restorations, while ClearTemp LC (Ultradent Products, Inc., South Jordan, UT) is a light-polymerized interim veneer cement, which makes it a good option for interim veneers. ClearTemp LC has fluorescing properties to aid in the detection, and complete removal, of interim cement under a UV light source before proceeding to definitive cementation.[4]

Interim cementation should not be undertaken unless the patient is given clear instructions about the objectives of the procedure, the intended duration of the trial cementation, and the importance of returning promptly if the restoration loosens. If removing an interim cemented FPD is difficult, the use of a crown-removal device such as the CORONAflex (KaVo Dental Corporation, Charlotte, NC) or the Crown Tractor (Practicon Inc., Greenville, NC; see Chapter 31) is recommended; also, warming the restoration slightly will weaken a zinc oxide eugenol interim luting agent, but it may not be an effective method on definitive luting agents such as polycarboxylate or glass ionomer.[5]

DEFINITIVE CEMENTATION

The definitive cements can be categorized as resin-based, and water-based acid-base cements. Resin-based cements are used with a tooth primer that forms a hybrid layer with collagen in dentin. In this group, self-adhesive resin cements can create a hybrid layer by partially demineralizing the tooth structure without a separate primer.[6] Therefore, the use of a resin cement is termed "bonding a crown" because of this hybrid layer formed at the tooth-cement interface.[7]

Water-based acid-base cements include zinc phosphate, glass ionomer (GI), and resin-modified glass ionomer (RMGI) cements. Zinc phosphate cement is not capable of bonding chemically to the tooth.[1]

Polyacrylic acid in GI and RMGI cements can form an ionic bond with calcium ions in the hydroxyapatite of enamel and dentin.[8] Since the chemical bond between GI and RMGI cements with tooth structure is significantly weaker than resin-based cements, cementation of crowns with water-based acid-base cements is not considered bonding.[9]

The clinician's choice to bond a crown may depend on several clinical factors, such as the need for additional retention, the need to improve the strength of the crown, or whether or not adequate isolation can be achieved.

Bonding Versus Cementing

Resin bonding is recommended in cases of compromised retention and resistance form (tooth preparation with a taper greater than 12 degrees and height less than 3 mm), high dislodging forces, minimal ceramic thickness (e.g., porcelain laminate veneers), and low inherent strength. These suggestions are also applicable for translucent zirconia due to its lower flexural strength to prevent fractures and ensure long-term clinical success.[10–12]

Conventional Cast Restorations

Definitive cementation often does not receive the same attention to detail as do other aspects of restorative dentistry. Careless luting agent selection can result in margin discrepancies and improper occlusion, and may even necessitate sectioning and removal of the restoration in order to make a new one. The choice of luting agent depends first on whether a conventional casting or an adhesively bonded restoration, such as a ceramic inlay or resin-bonded FPD is to be cemented. Traditional water-based dental cements can be used for cast crowns and FPDs, but not where adhesion is needed. Adhesive resins are indicated for some restorations, but, unless the newer self-etch formulations are chosen, they are technique sensitive and can be difficult to use; in addition, long-term data justifying their more general use with conventional cast restorations are limited.

Fig. 30.1 Representative cement-based luting agents.

Dental Cements

Most luting agents that are traditionally used for cast restorations are dental cements (Fig. 30.1). These consist of an acid combined with a metal oxide base to form a salt and water cement. The setting mechanism results from the binding of unreacted powder particles by a matrix of salt to harden the mass. However, because they are ionic, these agents are susceptible to acid attack and are therefore somewhat soluble in oral fluids.[13–16] Traditionally, the success of restorations cemented with these luting agents has been attributed to excellent adaptation between the casting and the prepared tooth. In vitro, however, cement dissolution is independent of the marginal width up to a certain critical value. After that, it increases only slightly, which is explained by Fick's first law of diffusion[17]: The flux of a component of concentration across a membrane of unit area, in a predefined plane, is proportional to the concentration that is differentia across that plane. Dupuis and colleagues,[18] as well as other researchers, have identified dissolution (rather than physical disintegration) as the mechanism for cement erosion. Such helps understand the success of cast restorations, despite the prevalence of relatively large subgingival marginal discrepancies, which are difficult to detect even at 0.1 mm.[19]

Zinc Phosphate Cement

Traditional zinc phosphate cement continues to be used for cast restorations. It has adequate strength, a film (layer) thickness of approximately 25 µm (Fig. 30.2) (which is within the tolerance limits required for making cast restorations),[20,21] and a

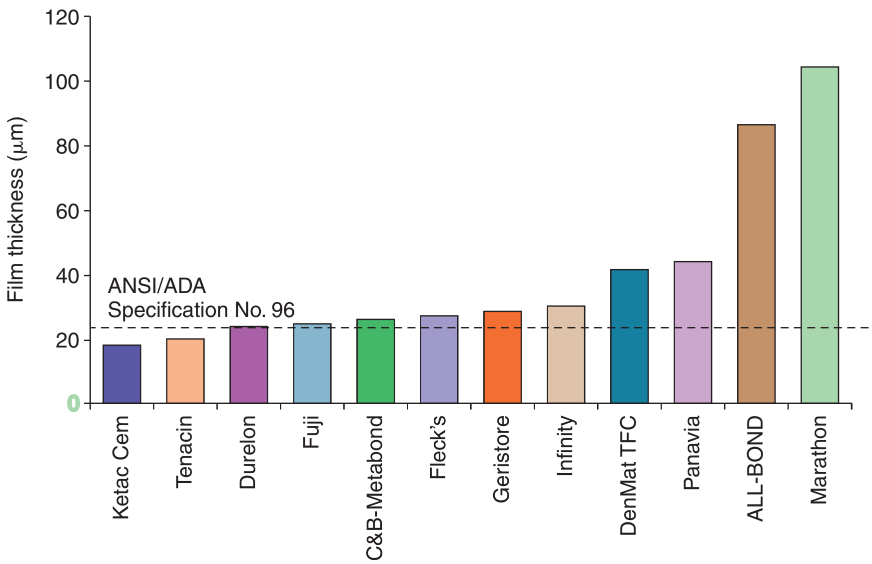

Fig. 30.2 The film thickness of a range of luting agents was tested according to American Dental Association (ADA) specification No. 8 for zinc phosphate cement (now American National Standards Institute [ANSI]/ADA Specification No. 96) by White and Yu.[21] Some of the adhesive materials possessed unacceptably high film thicknesses, which may translate into clinical problems for complete restoration seating. (From Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: a review of the current literature. *J Prosthet Dent*. 1998;80:280.)

reasonable working time. After setting, excess material can be easily removed with a sharp explorer or scaler.

The toxic effects of zinc phosphate, or, more specifically, phosphoric acid, are well-documented.[22] However, the success of the use of this material over many years suggests that its effect on the dental pulp is clinically acceptable as long as normal precautions are taken and the preparation is not too close to the pulp.

Zinc Polycarboxylate Cement

One advantage of zinc polycarboxylate is its relative biocompatibility,[23] which may stem from the fact that the polyacrylic acid molecule is large and therefore does not penetrate into the dentinal tubule. Zinc polycarboxylate cement exhibits specific adhesion to tooth structure because it chelates the calcium (although it has no adhesion to gold castings). Because of its high viscosity, this cement can be difficult to mix, but that problem can be overcome by using encapsulated products (Durelon Maxicap, 3 M ESPE Dental, Maplewood, MN).

In clinical trials, polycarboxylate performs as well as, or slightly better than, zinc phosphate.[24,25] However, dentists have reported varying success rates and inferior long-term retention. These problems may be related to use of an incorrect powder-to-liquid ratio. By using manufacturers' recommended powder-to-liquid ratios, mixed polycarboxylate cement is initially quite viscous. Some dentists may prefer a more fluid working consistency for reliable seating during cementation. However, the rheologic, or flow properties, of polycarboxylate cements are different from those of zinc phosphate; polycarboxylate cements exhibit thinning with an increased shear rate.[21] This means that they are capable of forming low film thicknesses despite their viscous appearance. When the dentist unnecessarily reduces the powder-to-liquid ratio, the solubility (how susceptible something is to being dissolved) of the cement increases dramatically (as much as threefold).[26] This may be the cause of increased clinical failures. By fabricating luting agents, including polycarboxylate in encapsulated form, manufacturers have reduced problems arising from manipulative variables.

The working time of polycarboxylate is much shorter than that of zinc phosphate (≈2.5 minutes, in comparison with 5 minutes). This may be a problem when multiple units are being cemented. Residual zinc polycarboxylate is more difficult to remove than zinc phosphate, and there is some evidence[27,28] that it provides less crown retention than zinc phosphate (Fig. 30.3). Its selection therefore should probably be limited to restorations with good retention and resistance form for which minimum pulp irritation is desired, for example, in children with large pulp chambers. Its use as a base material and to block out minor undercuts in preparations on vital teeth may also be worth considering. Because of a chemical interaction between zinc polycarboxylate and titanium, it is contraindicated when cementing implant crowns on titanium abutments.[29]

Glass Ionomer Cement

Glass ionomer cement adheres to enamel and dentin and exhibits good biocompatibility. In addition, because it releases fluoride,[30,31] it may have an anticariogenic effect, although this has not been documented clinically.[32] The set cement is somewhat translucent, which is an advantage when it is used with restorations with a porcelain labial margin design (see Chapter 24).

The mechanical properties of glass ionomer cement are generally superior to those of the zinc phosphate or polycarboxylate cements (Fig. 30.4). A disadvantage is that during setting, glass ionomer is particularly susceptible to moisture contamination[33] and should be protected with a foil or resin coat, or a band of cement should be left undisturbed for 10 minutes.[34] The water changes the setting reaction of the glass ionomer as cement-forming cations are flushed away and water is absorbed, which leads to erosion.[35] However, zinc phosphate has also demonstrated significant early erosion when exposed to moisture.[31] Glass ionomers should not be allowed to desiccate during this critical initial setting period. The newer RMGIs are less susceptible to early moisture exposure.[36]

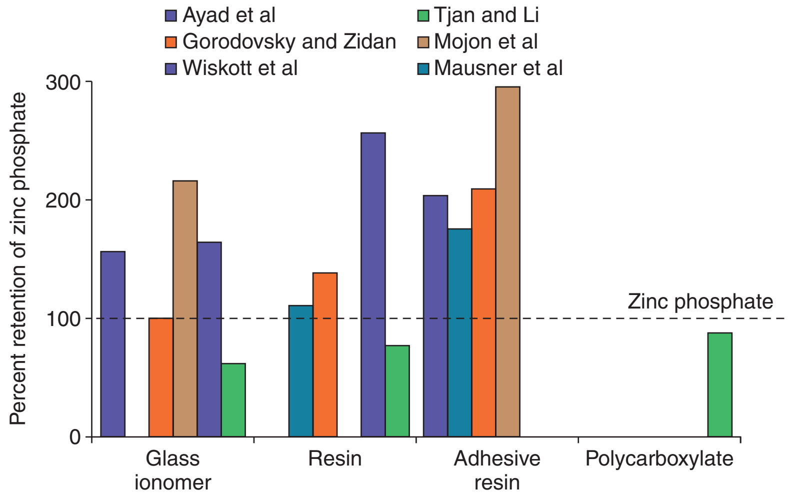

Fig. 30.3 Crown retention studies: effect of luting agent. In the six in vitro studies cited, researchers evaluated the effect of luting agent on crown retention. The data were normalized as percentages of the retention value with zinc phosphate cement. Adhesive resins had consistently greater retention than did zinc phosphate. Conventional resins and glass ionomers yielded less consistent results. (From Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: a review of the current literature. *J Prosthet Dent*. 1998;80:280.)

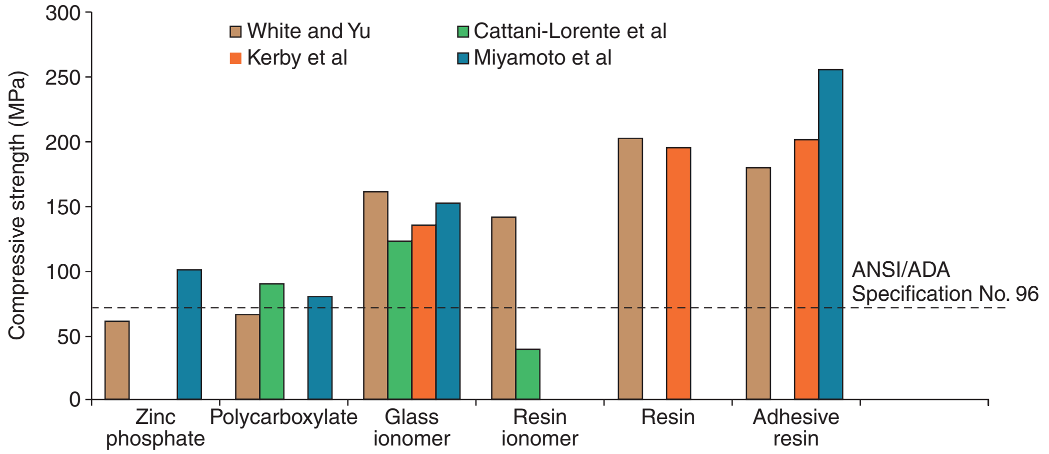

Fig. 30.4 Compressive strength of luting agents. In the studies cited, higher strength values were reported with the resin cements and glass ionomers than with zinc phosphate or polycarboxylate. Resin-modified glass ionomer exhibited greater variation than did other cements. *ANSI/ADA*, American Dental Association/American National Standards Institute. (From Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: a review of the current literature. *J Prosthet Dent*. 1998;80:280.)

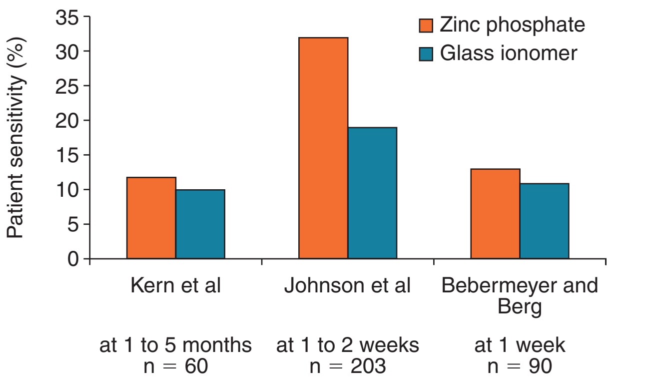

Fig. 30.5 Postcementation sensitivity of patients with crowns cemented with zinc phosphate or glass ionomer cement, as evaluated in three clinical trials.[40–42] Contrary to anecdotal evidence, patients with glass ionomer–cemented crowns did not exhibit increased postcementation sensitivity. (From Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: a review of the current literature. *J Prosthet Dent*. 1998;80:280.)

Although glass ionomers have been reported to cause sensitivity,[37] there appears to be little pulpal response at the histologic level,[38] particularly if the remaining dentin thickness exceeds 1 mm.[39] Side effects such as posttreatment sensitivity, that were thought to have resulted from a lack of biocompatibility, may actually be a result of desiccation or bacterial contamination[40] of the dentin, rather than irritation by the cement. Anecdotal findings that glass ionomer causes more posttreatment sensitivity have not been replicated in clinical trials. Authors have reported little association between the choice of zinc phosphate or glass ionomer cement and increased pulpal sensitivity, provided that manufacturers' recommendations were followed (Fig. 30.5).[41–43] If postcementation sensitivity becomes a problem, dentists should carefully evaluate their technique, particularly avoiding desiccation of the prepared dentin surface.[44] RMGI materials and self-adhesive resins have been reported to provoke less posttreatment sensitivity.[45] A desensitizing agent may prevent sensitivity, although it may also reduce retention, at least with some luting cements.[28,46] Some formulations of glass ionomer and resin cements are radiolucent (Fig. 30.6), which may prevent the practitioner from distinguishing a cement line from recurrent caries, as well as detecting cement overhangs.[47] The use of a glass ionomer luting agents in general practice has been favorable[48]; however, any reduction in caries activity that might be anticipated by the fluoride content has not been demonstrated by clinical research.[49]

Zinc Oxide–Eugenol With and Without Ethoxybenzoic Acid

Reinforced ZOE cement is extremely biocompatible and provides an excellent seal. However, its physical properties are generally inferior to those of other cements, limiting its use.[50] In terms of compressive strength, solubility, and film thickness, another luting agent (e.g., zinc phosphate) should be used. The ethoxybenzoic acid (EBA) modifier replaces a portion of the eugenol in conventional ZOE cement, although the change improves compressive strength without affecting its resistance to deformation; the cement should be used only in restorations with good inherent retention form in which emphasis is on biocompatibility and pulpal protection. The EBA cement has a relatively short working time, and excess material is difficult to remove.

Resin-Modified Glass Ionomer Luting Agents

RMGIs were introduced in the 1990s in an attempt to combine some of the desirable properties of glass ionomer (i.e., fluoride release and adhesion) with the higher strength and low solubility of resins. (The terminology for some of the newer glass ionomer/resin combinations is rather confusing. In this textbook, the term *resin-modified glass ionomer* has been used. Other terms used for luting agents and restorative materials with a combination of glass ionomer and resin chemistries include *compomer* [mostly composite with some glass ionomer chemistry], *hybrid ionomer* [now considered obsolete], and *resin-reinforced glass ionomer*.)

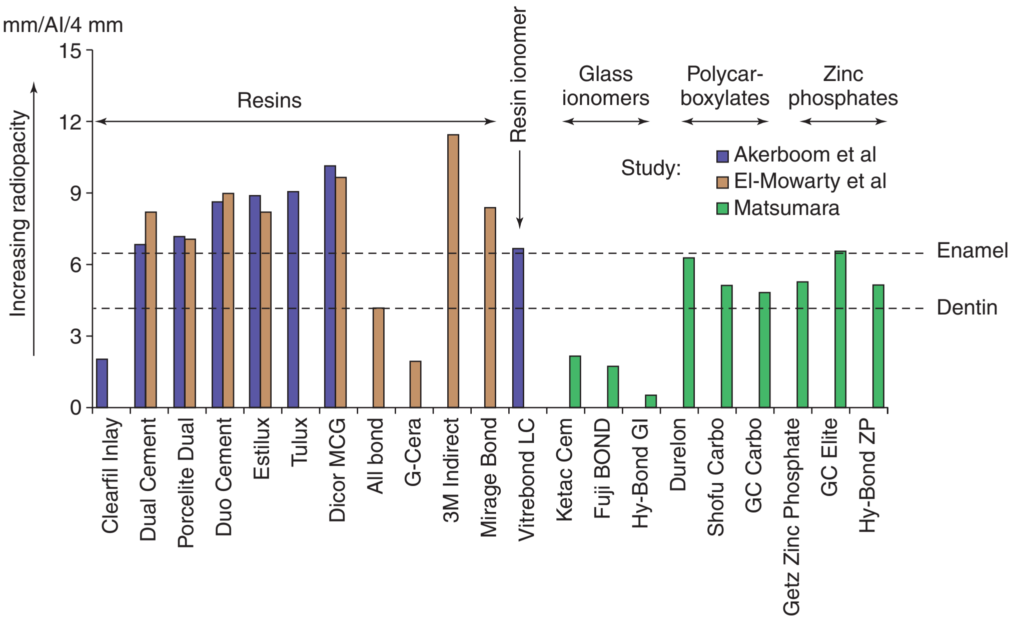

Fig. 30.6 Radiopacity of luting agents. In three in vitro studies, investigators compared the radiographic appearance of various luting agents to aluminum. The data were normalized to account for different specimen thicknesses used by the investigators. Excess luting agent is more difficult to detect if materials with lower values are chosen. In addition, margin gaps and recurrent caries are more difficult to diagnose. (From Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: a review of the current literature. *J Prosthet Dent*. 1998;80:280.)

These materials are less susceptible to early moisture exposure[36] than is glass ionomer and are currently among the most popular materials in general practice. Empirically, postcementation sensitivity resulting from their use is minimal. They exhibit higher strength than the conventional cements, having strength values similar to those of the resin luting agents.[51]

Resin Luting Agents

Unfilled resins have been used for cementation since the 1950s. Because of their high polymerization shrinkage and poor biocompatibility, these early products were unsuccessful, although they had very low solubility. Composite resin cements with greatly improved properties were developed for resin-bonded prostheses (see Chapter 26) and are used extensively for the bonded ceramic technique (see Chapter 25). Resin cements with adhesive properties (i.e., capable of bonding chemically to dentin) are available.[52] Bonding is usually achieved with organophosphonates, hydroxyethyl methacrylate (HEMA), or 4-methacryloxyethyl trimellitic anhydride (4-META).[53] These developments, and their lack of solubility, have rekindled an interest in the use of resin cements, particularly self-etching systems[54] for crowns and conventional FPDs (Fig. 30.7). Resin luting agents are less biocompatible than cements such as glass ionomer, especially if they are not fully polymerized. The self-adhesive resins have been shown to have the lowest incidence of postcementation sensitivity.[55]

Choice of Luting Agent

An ideal luting agent has a long working time, adheres well to both tooth structure and restorative materials, provides a good seal, is nontoxic to the pulp, has adequate strength properties, is compressible into thin layers, has low viscosity and solubility, and exhibits good working and setting characteristics. In addition, any excess can be easily removed. Unfortunately, no such product exists (Tables 30.1–30.3).

Zinc Phosphate Cement

Despite its limited biocompatibility in terms of pulp irritation, zinc phosphate has a long history, and its limitations are well-documented. This factor is important for cast restorations, which should be designed for long-term service. Zinc phosphate cement remains an excellent choice for luting restorations on otherwise normal, conservatively prepared teeth. Incremental mixing is necessary because exothermic heat, resulting from the chemical reaction, would otherwise cause the mix to set too rapidly. Slow mixing over a frozen slab by incorporating the powder into liquid within 2 minutes in a larger area is recommended by some clinicians.[56] Cavity varnish can be used to protect the pulp against irritation by phosphoric acid and appears to have little effect on the amount of retention of the cemented restorations.[57] In addition, crowns cemented with zinc phosphate displayed increased resistance to dislodgment on preparations that lack resistance form.[44]

Zinc Polycarboxylate Cement

Zinc polycarboxylate cement is recommended for retentive preparations when minimal pulp irritation is important (i.e., in children with large pulp chambers).

Glass Ionomer Cement

Glass ionomer cement has become a popular cement for luting cast restorations. It has good working properties and is more

A

B

C

Fig. 30.7 Representative resin luting agents. (A) RelyX Unicem 2. (B) PANAVIA F 2.0. (C) C&B-Metabond Quick. (A, Courtesy 3M ESPE Dental, St. Paul, MN. B, Courtesy Kuraray America, Inc., New York, New York. C, Courtesy Parkell Inc., Edgewood, NJ.)

translucent than zinc phosphate. The material sets more rapidly than zinc phosphate cement does and is easily mixable.

Resin-Modified Glass Ionomer Luting Agents

Currently, among the most popular luting agents, RMGI luting agents have low solubility, adhesion, and low rates of microleakage (the seepage of fluids and microorganisms at the interface between a restoration and the walls of a cavity preparation; Fig. 30.8). The popularity of these materials is derived mainly from the perceived benefit of reduced postcementation sensitivity.[58,59]

Adhesive Resins

Adhesive resin luting agents are indicated for ceramic and laboratory-processed composite resin restorations. Laboratory testing yields high retention strength values,[60] but there is concern that stresses caused by polymerization shrinkage, which are magnified in thin films,[61] lead to marginal leakage. Adhesive resin may be indicated when a casting has become displaced through lack of retention, and resins are recommended for all-ceramic restorations.[62]

The self-etching systems have become increasingly popular because they combine the simplicity of traditional cements with the reduced solubility of traditional adhesive resins. Patients appear to experience the lowest incidence of posttreatment sensitivity with self-etch resin cements.[56] In comparison to total-etch systems, these types of cements may have less aggressive effects on the pulp-dentin complex by maintaining the smear layer. It was shown that good bond strength to dentin was not affected by storage up to 2 years or mechanical load cycling.[62]

Preparation of the Restoration and Tooth Surface for Cementation

The performance of all luting agents is degraded if the material is contaminated with water, blood, or saliva. Therefore, the restoration and tooth must be carefully cleaned and dried after the evaluation procedure, although excessive drying of the tooth must be avoided to prevent damage to the odontoblasts if the tooth preparation involves dentin (Fig. 30.9). Cast restorations are best prepared by airborne-particle abrasion of the fitting surface with 50-μm alumina particles. This should be done carefully to avoid abrading the polished surfaces or margins. Airborne-particle abrasion has increased the in vitro retention of castings by 64%.[63] Alternative cleaning methods include steam cleaning, the use of ultrasonic units, and the use of organic solvents.

Before the selected cement is mixed, the area of cementation must be isolated, and the tooth must be cleaned and dried. However, the tooth should never be excessively desiccated; overdrying the prepared tooth leads to postoperative sensitivity. (The techniques for moisture control, essential to proper cementation, are described in Chapter 14). If a non-adhesive cement (e.g., zinc phosphate, glass ionomer) is to be used, the tooth should be cleaned, gently dried, and coated with cavity varnish or dentin-bonding resin. (Pumice or a chlorhexidine preparation such as Consepsis [Ultradent Products, Inc.] is recommended.)

Sodium hypochlorite (NaOCl) or hypochlorous acid (HOCl) solutions have been recently introduced as a pretreatment method for self-etch resin adhesives in order to improve their bonding performance, especially to caries-affected dentin.[64] Both solutions are able to remove the organic components of biological substrates, and it has been shown that they can dissolve the superficial organic phase of the smear layer-covered

TABLE 30.1 Comparison of Available Luting Agents

Property	Ideal Material	Zinc Phosphate	Poly-carboxylate	Glass Ionomer	Resin Ionomer	Composite Resin	Adhesive Resin	Self-Etch Adhesive Resin
Film thickness (μm)[a]	Low	≤25	<25	<25	>25	>25	>25	>25
Working time (min)	Long	1.5–5	1.75–2.5	2.3–5	2–4	3–10	0.5–5	2–2.5
Setting time (min)	Short	5–14	6–9	6–9	2	3–7	1–15	5–6
Compressive strength (MPa) (see Fig. 30.4)	High	62–101	67–91	122–162	40–141	194–200	179–255	195–240
Elastic modulus (GPa)[b]	Dentin = 13.7 Enamel = 84–130[c]	13.2	Not tested	11.2	Not tested	17	4.5–9.8	Not tested
Pulp irritation	Low	Moderate	Low	High	High	High	High	Low
Solubility	Very low	High	High	Low	Very low	Low to very low	Very low to low	Very low
Microleakage (see Fig. 30.8)	Very low	High	High to very high	Low to very low	Very low	High to very high	Very low to low	Very low
Ease of removal of excess	Easy	Easy	Medium	Medium	Medium	Medium	Difficult	Difficult
Retention (see Fig. 30.3)	High	Moderate	Low/moderate	Moderate to high	High[d]	Moderate	High	Very high

[a]From White SN, Yu Z. Film thickness of new adhesive luting agents. *J Prosthet Dent*. 1992;67:782; see also Fig. 30.2.
[b]From Rosenstiel SF, Denry IL, Zhu W, et al. Strength of dental ceramics with adhesive cement coatings. *J Dent Res*. 1992;71:320.
[c]From O'Brien WJ. *Dental Materials and Their Selection*. 2nd ed. Chicago, IL: Quintessence Publishing; 1997:351.
[d]From Cheylan JM, Gonthier S, Degrange M. In vitro push-out strength of seven luting agents to dentin. *Int J Prosthodont*. 2002;15:365.

TABLE 30.2 Indications for and Contraindications to Luting Agent Types

Restoration	Indication	Contraindication
Cast crown, metal-ceramic crown, FPD	1, 2, 3, 4, 5, 6, 7	—
Crown or FPD with poor retention	1, 2	3, 4, 5, 6, 7
MCC with porcelain margin	1, 2, 3, 4, 5, 6, 7	—
Casting on patient with history of post-treatment sensitivity	Consider 4 or 7	2
Pressed, high-leucite, ceramic crown	1, 2	3, 4, 5, 6, 7
Slip-cast alumina crown	1, 2, 3, 4, 6, 7	5
Ceramic inlay	1, 2	3, 4, 5, 6, 7
Ceramic veneer	1, 2	3, 4, 5, 6, 7
Resin-retained FPD	1, 2	3, 4, 5, 6, 7
Cast post-and-core	1, 2, 3, 5, 6	4, 7

KEY

LUTING AGENT TYPE	CHIEF ADVANTAGES	CHIEF CONCERNS	PRECAUTIONS
1. Adhesive resin	Adhesive, low solubility	Film thickness, history of use	Moisture control
2. Self-etch adhesive resin	Low solubility, ease of use, bonding to dentin	Film thickness	Moisture control
3. Glass ionomer	Translucency	Solubility, leakage	Avoid early moisture exposure
4. Reinforced ZOE	Biocompatible	Low strength	Only for very retentive restorations
5. Resin ionomer	Low solubility, low microleakage	Water sorption, history of use	Avoid with ceramic restorations
6. Zinc phosphate	History of use	Solubility, leakage	Use for "traditional" cast restorations
7. Zinc polycarboxylate	Biocompatible	Low strength, solubility	Do not reduce powder-to-liquid ratio

FPD, Fixed partial denture; *MCC*, metal-ceramic crown; *ZOE*, zinc oxide–eugenol.

TABLE 30.3 Product Information

CEMENT PRODUCTS

Conventional (Water-based) Weak Cements

Zinc Phosphate Cement	Zinc Polycarboxylate Cement	Glass-Ionomer Cement	Resin Ionomer Cements[a]
Fleck's Zinc (Mizzy)	Durelon (3 M ESPE Dental)	Fuji I (GC America)	FujiCEM (GC America)
Hy-Bond Zinc Phosphate (Shofu)	Fleck's PCA (Mizzy)	Ketac Cem (3 M ESPE Dental)	RelyX Luting (3 M ESPE Dental)
Modern Tenacin (LD Caulk)	Liv Carbo (GC America)	CX-Plus (Shofu)	
	Hy-Bond Polycarboxylate (Shofu)		
	Tylok-Plus (LD Caulk)		

Composite (Resin-based) Strong Cements

Dual Polymerized (With Adhesive)	Autopolymerized (With Adhesive)	Light/Dual Polymerized (With Adhesive)	Dual Polymerized (Self-Adhesive)
Panavia F 2.0 (Kuraray)	Panavia 21[b] (Kuraray)	Insure (Cosmedent)	RelyX Unicem[b] (3 M ESPE Dental)
RelyX ARC (3 M ESPE Dental)	C&B-Metabond (Parkell)	Nexus 2 (Kerr)	MaxCem[b] (Kerr)
Duo-Link (Bisco)	Multilink[b] (Ivoclar AG)	Variolink II (Ivoclar AG)	MonoCem (Shofu)
LinkMax (GC America)	C&B Cement (Bisco)	Appeal (Ivoclar AG)	Dyract CEM[b] (DENTSPLY)
		RelyX Veneer (3 M ESPE Dental)	

CERAMIC PRODUCTS

Silica-Based Weaker Ceramics (Require Silane Coupler and Resin Cements)

Feldspathic Porcelains	Leucite-Reinforced Porcelains	Lithium Disilicate Glass-Ceramics
Ceramco 3 (DENTSPLY)	IPS Empress Esthetics (Ivoclar AG)	IPS Empress 2 (Ivoclar AG)
VITA VMK, Omega 900 (VITA North America)	OPC (Pentron)	G3 (Pentron)
IPS dSIGN (Ivoclar AG)	Finess (DENTSPLY)	IPS e.max CAD (Ivoclar AG)
Numerous products for metal veneering	ProCAD, IPS Empress CAD (Ivoclar AG)	
	Cerinate (DenMat)	

Non–Silica-Based Oxides (Stronger Ceramics Can Be Used With Any Cements Except RMGIs)

Glass-Infiltrated Oxides	Dense Sintered Aluminum Oxides	Dense Sintered Zirconium Oxides
VITA In-Ceram ALUMINA,	NobelProcera (Nobel Biocare)	LAVA (3 M ESPE Dental)
VITA In-Ceram ZIRCONIA,		Cercon (DENTSPLY)
VITA In-Ceram SPINELL (VITA North America)		IPS e.max ZirCAD (Ivoclar AG)
Wol-Ceram (Electro Phorectic Ceramic)		Procera Crown Zirconia (Nobel Biocare)
		Anatomic-contour zirconia crowns (all brands)

WHICH CEMENT SHOULD I USE?

Ceramic Type	Surface Preparation	Coupling Agent	Cement Type	Uses
Silica-Based (Weaker)				
Feldspathic porcelain	Hydrofluoric acid etch	Yes (silane)	Composite resin only Adhesive assisted preferred	Veneers, inlays
Leucite-reinforced porcelain	Hydrofluoric acid etch	Yes (silane)	Composite resin only Adhesive assisted preferred	Veneers, inlays, onlays, anterior and premolar crowns
• Option 2	None	None	Conventional	
Non–Silica-Based (Stronger)				
• Option 4	Airborne-particle abrasion[d]	NA	Composite resin[c]	
• Option 4 (for nonretentive preparation)	Rocatec (silica-coated particles)	Yes (silane)	Composite resin	Improved cement bond to zirconia

[a]This category is not recommended for silica-based ceramics; stresses are generated from expansion.
[b]Phosphate ester–modified; best on non–silica-based oxide ceramics.
[c]Phosphate ester–modified composite resin cements.
[d]In general airborne-particle abrasion and internal grinding of the ceramic introduces surface flaws (roughness) that can lead to improved bonding but weaken ceramic. Airborne-particle abrasion on dense sintered zirconia surfaces may not be as detrimental as it can be with other weaker ceramic materials.
FPD, Fixed partial denture; *NA*, not applicable; *RMGI*, resin-modified glass ionomer.
Courtesy Dr. R.R. Seghi.

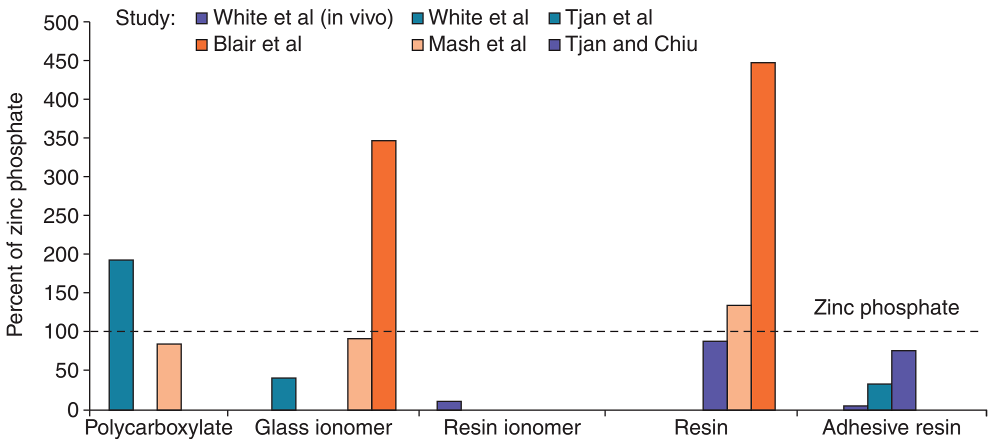

Fig. 30.8 Microleakage of luting agent. A comparison of data from one clinical study and five laboratory studies, expressed as percentages of the value obtained for zinc phosphate cement. Considerable variation was reported; adhesive resins and resin-modified glass ionomer agents exhibited low microleakage values. (From Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: a review of the current literature. *J Prosthet Dent.* 1998;80:280.)

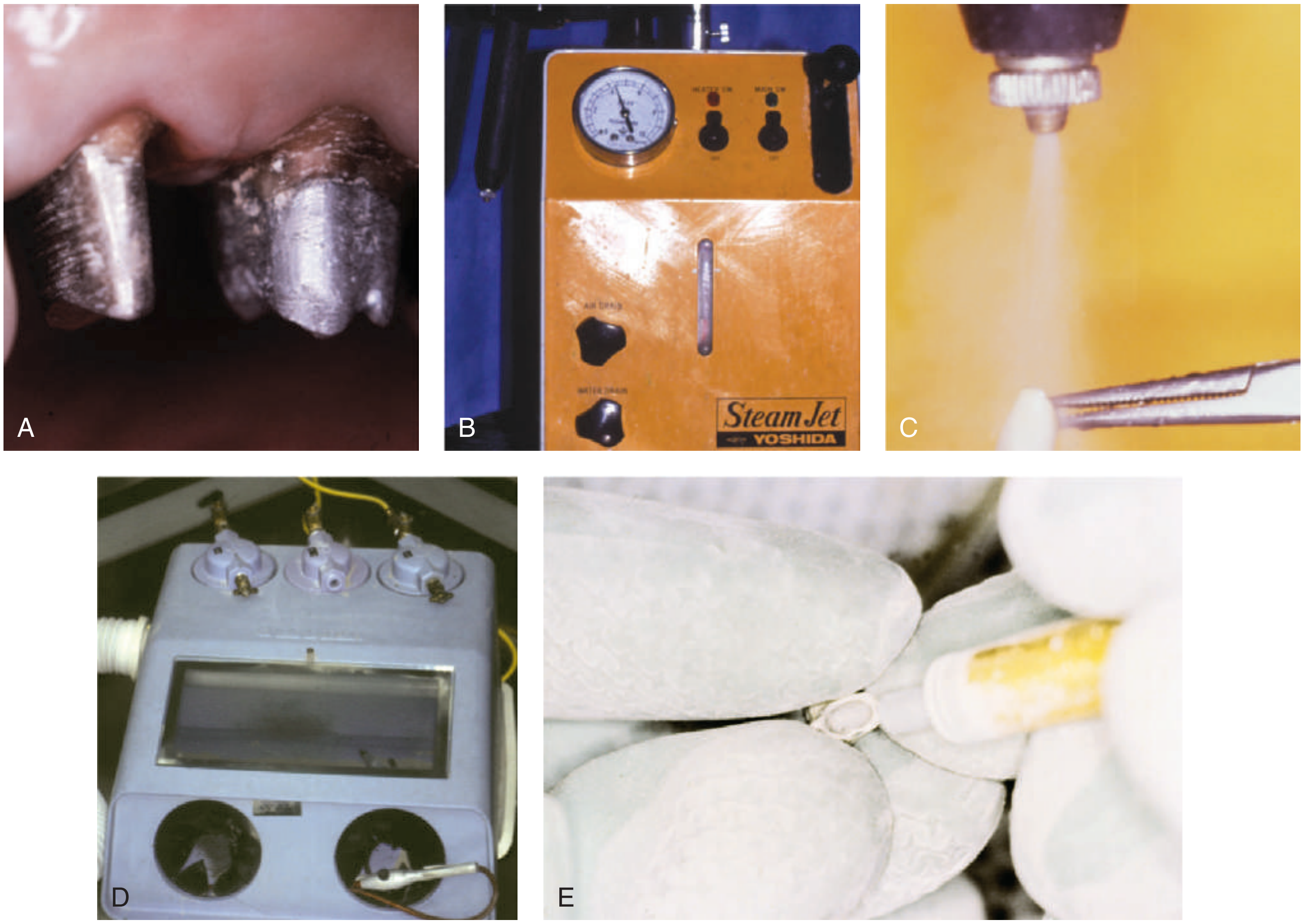

Fig. 30.9 Teeth and restorations must be carefully prepared immediately before cementation. (A) These preparations need to be cleaned of interim luting agent and dried but not excessively desiccated. (B and C) A steam cleaner is convenient for removing traces of polishing compound from the restorations. (D and E) Airborne-particle abrasion of internal restoration surface.

dentin.[64] The pre-removal of the organic debris of dentin smear layer enhanced the infiltration of self-etch resin adhesives into the underlying dentin and eliminated the hybridized smear layer.[65,66]

Adversely, both NaOCL and HOCL can produce free radicals. These residual radicals could interfere with the polymerization of the resin. Studies showed that HOCl is a more effective oxidizing deproteinizer than NaOCl and it leaves fewer residual radicals.[64,67] Applying HOCl for 15 seconds is sufficient to completely remove the organic smear layer before using self-etch adhesives.[65]

Armamentarium

The following equipment is needed (Fig. 30.10):

- Mirror
- Explorer
- Dental floss
- Cotton rolls
- Prophylaxis cup
- Flour of pumice
- Cement
- White stones
- Cuttle disks
- Local anesthetic (if needed)
- Saliva evacuator
- Forceps
- Thick glass slab (chilled)
- Cement spatula
- Gauze squares
- Adhesive foil
- Plastic instrument

Step-by-Step Procedure

Self-etch resin cement is used to illustrate a typical procedure with ceramic restorations, but the steps may vary slightly, depending on the restorations and the cement chosen (Fig. 30.11).

1. Immediately before cementation, inspect all preparation surfaces for cleanliness. Remove any interim luting agent with a pumice wash or hydrogen peroxide. A eugenol-free interim luting agent should be used with resin cements, because eugenol inhibits the polymerization of the resin. Because the restoration-cement interface is where failure occurs when a crown is displaced, the intaglio of the restoration must be clean and prepared to maximize the bond between the restoration surface and the luting agent. Cast metal restorations should be airborne-particle abraded, steam cleaned, or cleaned ultrasonically and washed with alcohol to remove any remaining polishing compound that might interfere with retention of the finished restoration (see Fig. 30.9B–E).
2. Isolate the area with cotton rolls and place the saliva evacuator. On occasion, a dental dam can be used, but only rarely for extracoronal restorations. Avoid using cavity cleaners to aid in drying the preparation, because they may adversely affect pulpal health.
3. Dispense the cement into the clean internal surface of the restoration (see Fig. 30.11E). To extend working time, the cement should be applied to a cool restoration rather than to a warm tooth.
4. Dry the tooth again with a light blast of air and push the restoration into place (see Fig. 30.11F). The final seating of posterior restorations is achieved by rocking with an orangewood stick until all excess cement has escaped. Seating the restoration firmly with a rocking, dynamic seating force is important (see Fig. 30.11G). Using a static load may cause binding of the restoration and lead to incomplete seating. If the casting is not rocked, increasing the load seems only to increase the binding reaction.[68] Excessive force during seating should be avoided, especially with metal-ceramic or all-ceramic restorations, which may fracture.
5. After the crown is seated, check the margins to verify that the restoration is fully in place. Protect the setting cement from moisture by covering it with an adhesive foil (e.g., Dryfoil, Jelenko Dental Alloys; Heraeus Kulzer, Inc.).
6. When it is fully set, remove excess cement with an explorer. Early cement removal may lead to early moisture exposure at the margins with increased solubility. Some cements, such as polycarboxylate or resin, tend to pull away from the margins if excess cement is removed too early, and the integrity of many contemporary cements is disturbed if finished in the first 24 hours.[69] Dental floss with a small knot in it can be used to remove any irritating residual cement interproximally and from the gingival sulcus. The sulcus should contain no cement. After the excess has been removed, the occlusion can be checked once more with Mylar shim stock.
7. Cements take at least 24 hours to develop their final strength. Therefore, the patient should be cautioned to chew carefully for a day or two.

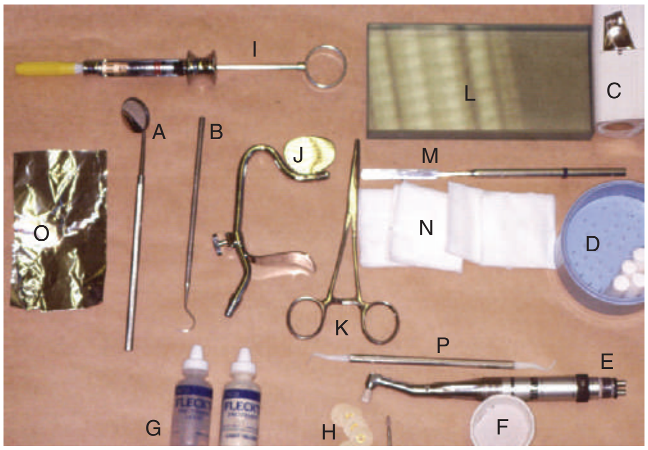

Fig. 30.10 Armamentarium for definitive cementation. *A*, Mirror; *B*, explorer; *C*, dental floss; *D*, cotton rolls; *E*, prophylaxis cup; *F*, flour of pumice; *G*, cement; *H*, white stones and cuttle disks; *I*, local anesthetic; *J*, saliva evacuator; *K*, forceps; *L*, thick glass slab; *M*, cement spatula; *N*, gauze squares; *O*, adhesive foil; *P*, plastic instrument.

Resin Luting Agents

Resin luting agents are available in a wide range of formulations. These can be categorized on the basis of polymerization method (chemical-polymerization, light-polymerization, or dual-polymerization), the presence of dentin-bonding mechanisms, and whether or not they incorporate the acid etchant. A chemically polymerized system is appropriate for metal restorations, whereas a light- or dual-polymerized system is appropriate with ceramics. Resins formulated for cementing conventional castings must

Fig. 30.11 Cementation technique with self-adhesive resin. Demonstration of the use of a self-adhesive composite resin cement with alumina core ceramic crowns (NobelProcera, Nobel Biocare, Göteborg, Sweden). Preoperative facial (A) and lingual (B) views of the teeth of a patient with a history of bulimia. (C) Completed crown preparations of maxillary lateral and central incisors. (D) All-ceramic, alumina core crowns (NobelProcera) returned from laboratory. (E) Self-adhesive resin cement (BisCem, Bisco, Schaumburg, Illinois) being placed into the all-ceramic crown with an automixing tip. (F) Completed all-ceramic crowns for the maxillary lateral and central incisors. (G) When a posterior restoration is seated, an orangewood stick is applied with a rocking motion against the restoration to ensure that all excess cement is expressed. (A–F, From Freedman G. *Contemporary Esthetic Dentistry*. St. Louis: Mosby; 2012. G, From Campagni WV. The final touch in the delivery of a fixed prosthesis. *CDA J*. 1984;12[2]:21.)

have lower film thickness than materials designed for ceramics or orthodontic brackets. However, this may be achieved at the expense of filler particle content and will adversely affect other properties, such as polymerization shrinkage.

Manipulative techniques vary widely, depending on the brand of resin cement. For example, Panavia EX (Kuraray America Inc., Houston, TX) sets very rapidly when air is excluded. The directions call for the material to be spatulated into a thin film, as it sets rapidly if piled up on the mixing pad. Another material, C&B-Metabond (Parkell Inc., Brentwood, NY), is mixed in a ceramic well that must be chilled to prevent premature setting. The self-etching dual polymerizing resin RelyX UniCEM (3M ESPE Dental) is a two-paste system that is delivered in appropriate proportions via a dispensing system or in capsules. Mixing techniques for these materials are illustrated in Figs. 30.12 and 30.13.

BONDING TO ZIRCONIA

Polycrystalline ceramic restorations offer greater mechanical strength that exceeds natural chewing forces and can, therefore, be cemented conventionally if the tooth preparation has sufficient retention and resistance form.[70,71]

However, zinc-phosphate cement seems less suitable for cementing zirconia crowns. Greater success with composite resins, or self-adhesive resin cements has been achieved following proper bonding protocol.[72]

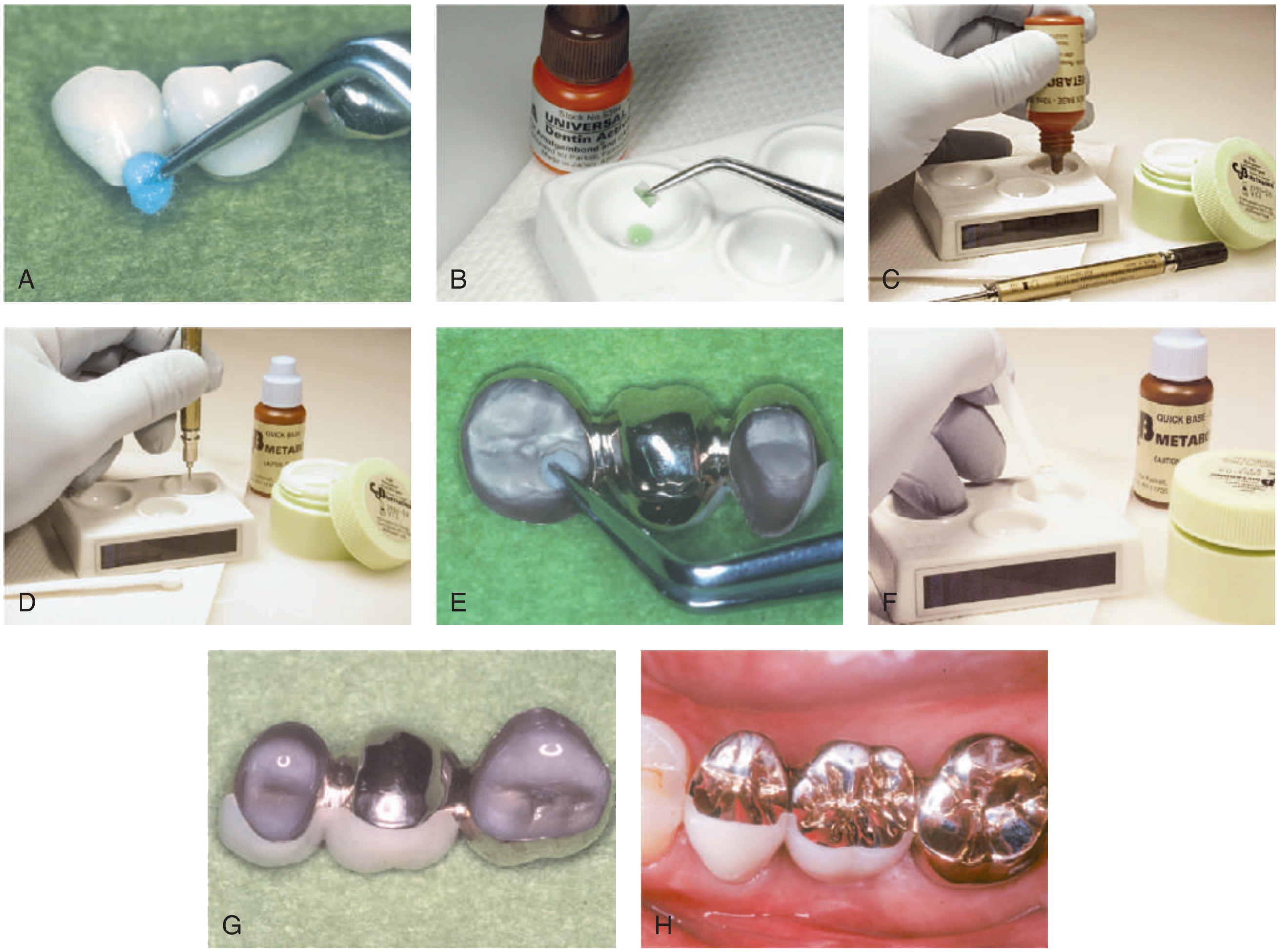

Fig. 30.12 Cementation with C&B-Metabond resin cement. (A) The brush-on separating film is applied to the prosthesis, the proximal teeth, in order to prevent the adhesive from bonding where it is not wanted. (B) The recommended dentin conditioner is applied for 10 seconds and rinsed off, and the tooth is dried. (C and D) Four drops of base and one drop of catalyst are mixed for each crown. After the preparation and interior of the crown are wetted with this mixed liquid (E), the powder is added (F). (G) The casting is painted, and the crown is seated. (H) Excess resin is removed after it has completely set. Cleanup is greatly facilitated when the separating film is used. It is important not to remove resin before it has fully set because the rubbery material will pull away from the margins. (Courtesy Parkell Inc., Edgewood, NJ.)

Zirconia bonding involves conditioning the tooth and the crown. Conditioning the tooth as it was previously described can be done with total or self-etch systems, and surface treatment of zirconia crown that involves mechanical and chemical preparation.

Hydrofluoric acid (HF) etching, along with silane application, is a recommended method used to roughen the surface of silica-based ceramic and to increase its wettability. However, zirconia's structural integrity and high content of crystalline phase render zirconia ceramic acid resistant and nonreactive.[73,74]

A combined micromechanical and chemical pretreatment is crucial for long-term durable resin bonds.[72,75,76] This includes grit blasting, tribochemical silica coating, chemical etching, selective infiltration etching, laser irradiation, and chemical vapor deposition.[77]

Application of 10-methacryloyloxydecyl dihydrogen phosphate (MDP) as a primer inside the crown prior to cementation is recommended in numerous studies. This monomer has two functional groups: one phosphate group which is responsible for bonding to the hydroxyl group on the zirconia surface and one carboxylic acid group which is bonded to composite resin.[72,75,77]

Airborne-particle abrasion with alumina (50 µm to 60 µm at 0.2 MPa for 5 seconds) and application of an MDP-containing primer (e.g., Z-PRIME Plus [BISCO], Clearfil Ceramic Primer [Kuraray Noritake] and Monobond Plus [Ivoclar AG]) provide an optimized adhesive interface.

These three steps of airborne-particle abrasion, primer application, and composite resin luting agents (the "APC Concept") are now a standard protocol for zirconia bonding.[78]

Saliva, phosphoric acid, or blood contamination can adversely affect the bond strength. Primer application should be done after intraoral evaluation and decontamination of the crown. Decontamination could be done by applying 5% NaOCl, alcohol, or Ivoclean (Ivoclar AG, Amherst, NY) followed by water rinsing and air drying.[79,80]

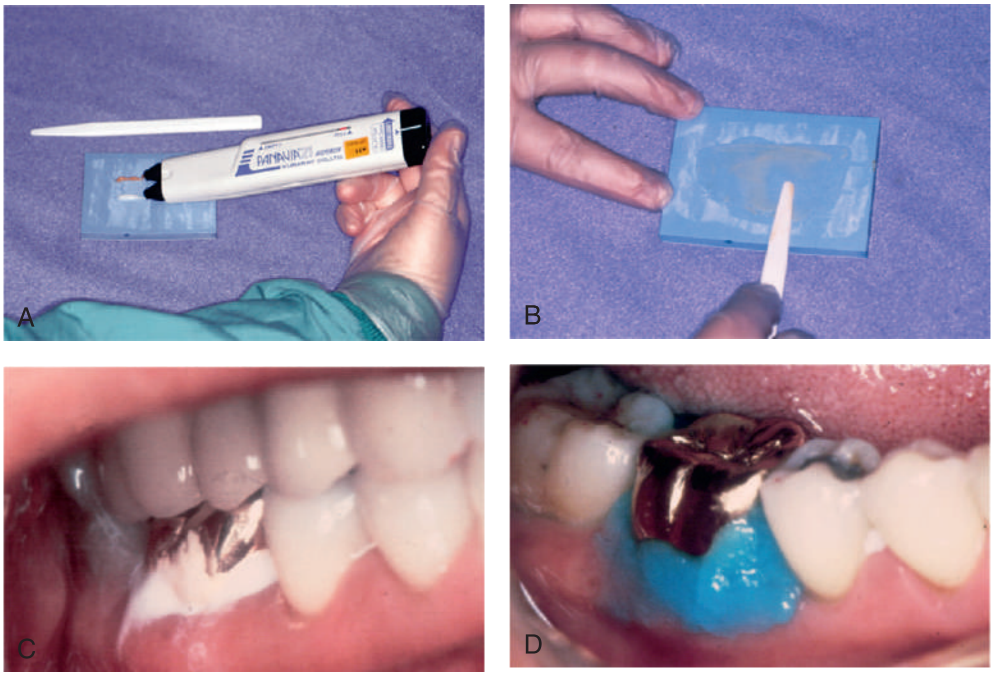

Fig. 30.13 (A) Panavia resin cement. (B) Measured powder and liquid are spatulated for 60 to 90 seconds. The mix becomes creamier as it is mixed. The cement sets if oxygen is excluded, and so the cement should not be piled up; instead, it should be spread out over a large surface area. (C) A thin coat of the cement is applied, the restoration is seated, and excess cement is removed. (D) The cement is coated with oxygen-inhibiting gel to promote polymerization. (Courtesy J. Morita USA, Inc., Irvine, CA.)

CEMENTATION FOR CEMENT-RETAINED IMPLANT CROWNS

Before starting the cementation process, the dentist should inspect the abutment and crown carefully. Creating some horizontal grooves or airborne-particle abrasion of the abutment is recommended for better retention of the crown.

Prior to cementation, blocking out the screw access channel with polytetrafluoroethylene (PTFE), known as "plumber tape," is advantageous over cotton due to reduced bacterial contamination.[81]

Different kinds of luting cements can be applied for a cement-retained implant crown, such as temporary cement (Temp-Bond, Kerr Corporation; Dycal, LD Caulk Co, Dentsply International Inc., Milford, DE), IRM, zinc phosphate cement, and resin cement (Panavia, Kuraray; RelyX, 3M ESPE).

Fluoride-releasing cements, like RMGI or polycarboxylate (Durelon Maxicap, 3M ESPE Dental), should not be used when using titanium abutments since fluoride can corrode titanium.[82] Temp-Bond is one of the most common cements to be used for definitive cementation of implant crowns; however, loss of retention is a major reported complication in the literature.[83–87] Therefore, it is not recommended for short or tapered abutments lacking sufficient retention and resistance form.[88]

Cement remnants around implants have been associated with clinical and radiographic signs of peri-implantitis. Therefore, establishing a technique to control the flow and amount of the luting cement extruded during crown placement can minimize future complications.[89–91]

A deep crown-abutment margin position negatively influences the clinician's ability to remove cement. The margin of abutments should be located as coronally as possible and not deeper than 2 mm for the ease of cement remnants removal.[92,93]

It is recommended to select a cement that is as radio-opaque as possible while meeting the other required physical properties. For example, the zinc found in zinc phosphate and zinc oxide/eugenol cements is highly radio-opaque. Post-operative radiographs then facilitate the identification of residual cement.[94]

There is no set protocol on the amount of cement that should be applied to the intaglio surface of an implant-supported crown. Different methods have been suggested to minimize cement extrusion, such as lining specific sites,[95] half filling the crown,[96] and applying the cement at the crown margins.[97]

Comparing all techniques, the least amount of cement residues are produced by using a cementation device to displace excess before seating an implant-supported crown on an abutment.[98] This technique uses a temporary putty abutment (putty index formed to internal configuration of the restoration), or an abutment analog. The crown is filled with luting cement, and is seated extraorally on the putty abutment, or implant analog. Then, any extruded excess cement is wiped off, the crown is removed immediately from the analog, and then luted in place on the definitive abutment.[99] Theses steps are relatively time consuming and must be completed within the working time of the luting agent.

Abutment design can also play an important role in controlling cement flow. Creating internal vent holes in the abutment reduces the amount of excess cement extrusion. It is recommended to partially fill the screw access channel by means of a PTFE tape or a polyvinyl siloxane impression material.[100,101]

CEMENTATION PROCEDURES FOR CERAMIC VENEERS AND INLAYS

These restorations rely on resin bonding for additional retention and strength, which is executed under a properly moisture-controlled field (Fig. 30.14). The cementation steps are crucial for the restoration's success; careless handling of the resin luting agent may adversely affect their longevity. Bonding is achieved with the following steps:

1. Etching the fitting surface of the ceramic with HF acid
2. Applying a silane coupling agent to the ceramic material
3. Etching the enamel with phosphoric acid. In case of insufficient enamel especially in the cervical areas, airborne-particle abrasion with aluminum oxide or aluminum trihydroxide is recommended (Fig. 30.15A)
4. Applying a resin-bonding agent to etched enamel and dentin.[102]
5. Seating the restoration with a composite resin luting agent. Bond pairs of veneers starting from the midline distally. To avoid etchant or resin contamination on the adjacent teeth and for the ease of cleaning, cover neighboring teeth with PTFE tape (Fig. 30.15B–D).
6. Upon bonding of each pair of veneer(s), excess cement should be removed not to block the path of insertion and bonding for the next veneer(s).

The etching and silanating steps are described in Chapter 25.

Porcelain veneers provide a predictable and successful treatment; however, higher failure rates were seen in patients with bruxism or in non-vital teeth. Fabrication of an occlusal guard after the treatment can increase the long-term success rate of these restorations (Fig. 30.16).[103,104]

Selection of Resin Luting Agent

Composite resin luting agents are available in a range of formulations. For veneers, a light-polymerized material can be used.

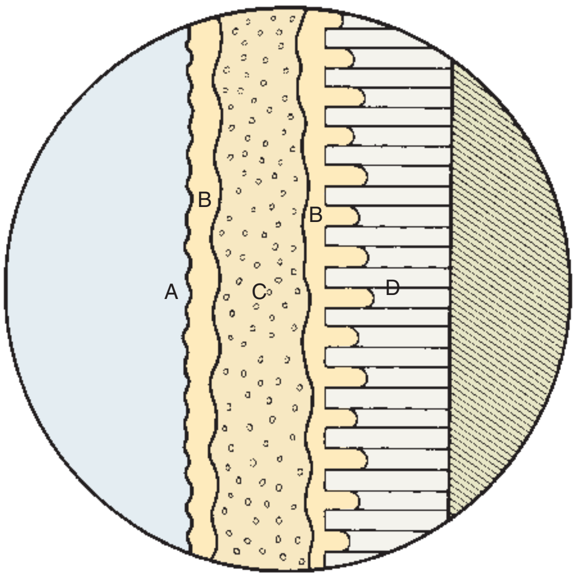

Fig. 30.14 Schematic of resin-bonding technique. *A*, Ceramic surface (etched and silanated); *B*, unfilled resin; *C*, resin luting agent; *D*, etched enamel.

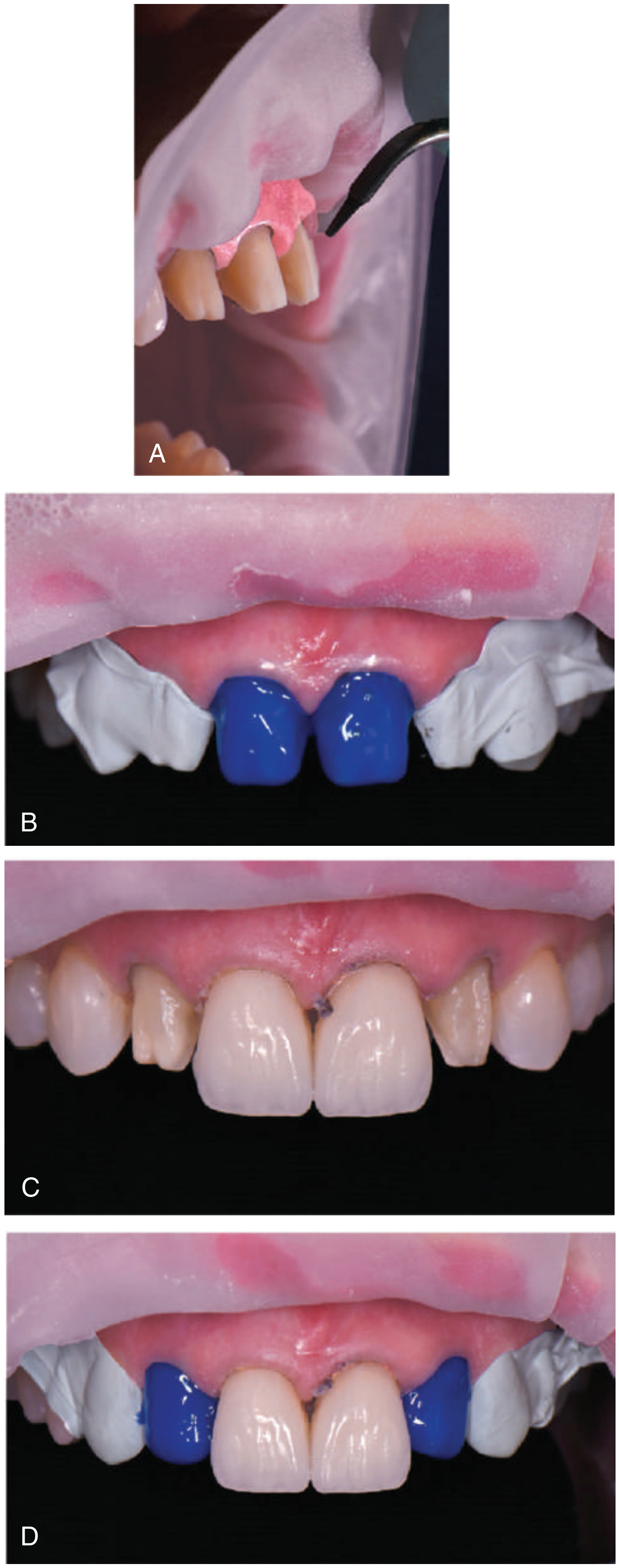

Fig. 30.15 Cementation steps for ceramic veneers and inlays. (A) Because of insufficient enamel, the preparation was airborne-particle abraded at a 45-degree angle from the gingival margin to the incisal edge. (B) #00 cord was packed. Neighboring teeth were protected with polytetrafluoroethylene (PTFE) tape. Only the two incisors were etched. (C) The first two veneers bonded with the cords in place. Excess cement was removed with scaler, blade, and floss. (D) Next two teeth etched. No need to isolate previously bonded veneers with PTFE tape.

Fig. 30.16 Clear occlusal device with soft intaglio surface and hard occlusal surface fabricated.

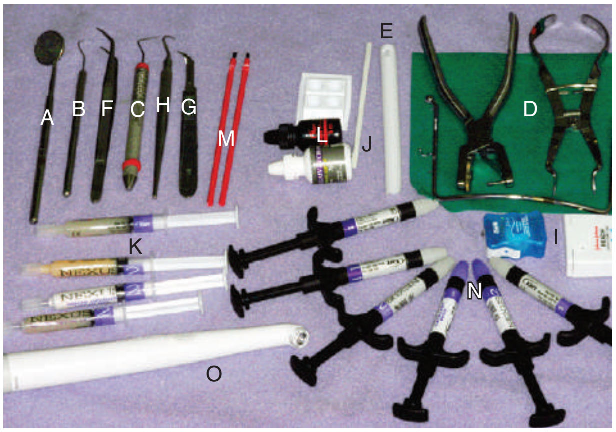

Fig. 30.17 Armamentarium for bonding procedure. *A*, Mirror. *B*, Explorer. *C*, Periodontal Probe. *D*, Dental dam kit. *E*, Saliva evacuator. *F*, Cotton pliers. *G*, Scalpel. *H*, Curette. *I*, Dental tape. *J*, Mylar strips. *K*, Evaluation paste. *L*, Bonding agent. *M*, Brush. *N*, Resin luting agent. *O*, Polymerization light.

For inlays, a chemical-polymerized material is preferred, to ensure maximum polymerization of the resin in the less accessible proximal areas. In clinical testing, inlay restorations luted with chemically polymerized materials had performed better than dual-polymerized luted restorations.[105]

The shade of veneers can be modified by the shade of the luting agent. To facilitate shade selection, color-matched evaluation pastes are available from some manufacturers (e.g., NX3 Nexus, Kerr Corporation). However, there may be some color differences between try-in pastes and the polymerized resin of the same shade.[106]

Bonding the Restoration

Armamentarium

The equipment needed is shown in Fig. 30.17.

- Mirror
- Explorer
- Periodontal probe
- Dental dam kit
- Local anesthetic
- Saliva evacuator
- Cotton pliers
- Scalpel
- Curette
- Dental tape
- Mylar strips
- Cotton rolls
- Prophylaxis cup
- Flour of pumice paste
- Acid etchant
- Porcelain etchant
- Silane coupling agent
- Acetone
- Glycerin or evaluation paste
- Bonding agent
- Brush
- Resin luting agent
- Polymerization light
- Fine-grit diamonds
- Porcelain polishing kit

Step-by-Step Procedure

This process is illustrated in Fig. 30.18.

1. Remove any interim restorations (see Fig. 30.18A), and clean the teeth with pumice and water (or a chlorhexidine preparation). A luting agent that contains ZOE should be avoided for cementing interim restorations before resin bonding because eugenol inhibits the polymerization of the resin. Cleansing with pumice leaves a ZOE residue mixed with pumice, which can inhibit bonding.[107] Etching with 37% phosphoric acid after cleaning with pumice may be the best way to remove ZOE.[108]
2. Evaluate the restorations with glycerin or an evaluation paste (see Fig. 30.18B). Verify fit, shade, and insertion sequence.
3. Clean the restorations thoroughly in water with ultrasonic agitation. Use acetone if luting resin was used to verify the shade at evaluation. (This technique requires care. The restoration should not be exposed to the unit light; otherwise, the resin polymerizes prematurely.) Dry the restorations.
4. Etch and silanate the restorations as described in Chapter 25.
5. Isolate the adjacent teeth with matrix bands (see Fig. 30.18C). Acid etch the enamel; 37% phosphoric acid is generally used and is applied for 20 seconds (see Fig. 30.18D). Rinse thoroughly and dry (see Fig. 30.18E).
6. Apply a thin layer of bonding resin to the preparation (see Fig. 30.18F and G). Do not polymerize this layer because it might interfere with complete seating.
7. Apply the composite resin luting agent to the restoration (see Fig. 30.18H); be especially careful to avoid trapping air.
8. Position the restoration gently (see Fig. 30.18I and J), removing excess luting agent with an instrument or a microbrush (see Fig. 30.18K).
9. Hold the restoration in place while briefly applying the polymerizing resin. Do not press on the center of veneers; they may flex and break (see Fig. 30.18L).
10. Use dental tape to remove resin flash from the interproximal margins (see Fig. 30.18M).
11. Complete the polymerization of the luting agent (see Fig. 30.18N). Do not underpolymerize the resin cement. Allow at least 40 seconds for each area.
12. Remove resin flash with a scalpel, sharp curette, or finishing tungsten carbide bur (see Fig. 30.18O).
13. Finish facial margins with a polishing cup (see Fig. 30.18P), finish the lingual margins with a finishing tungsten carbide

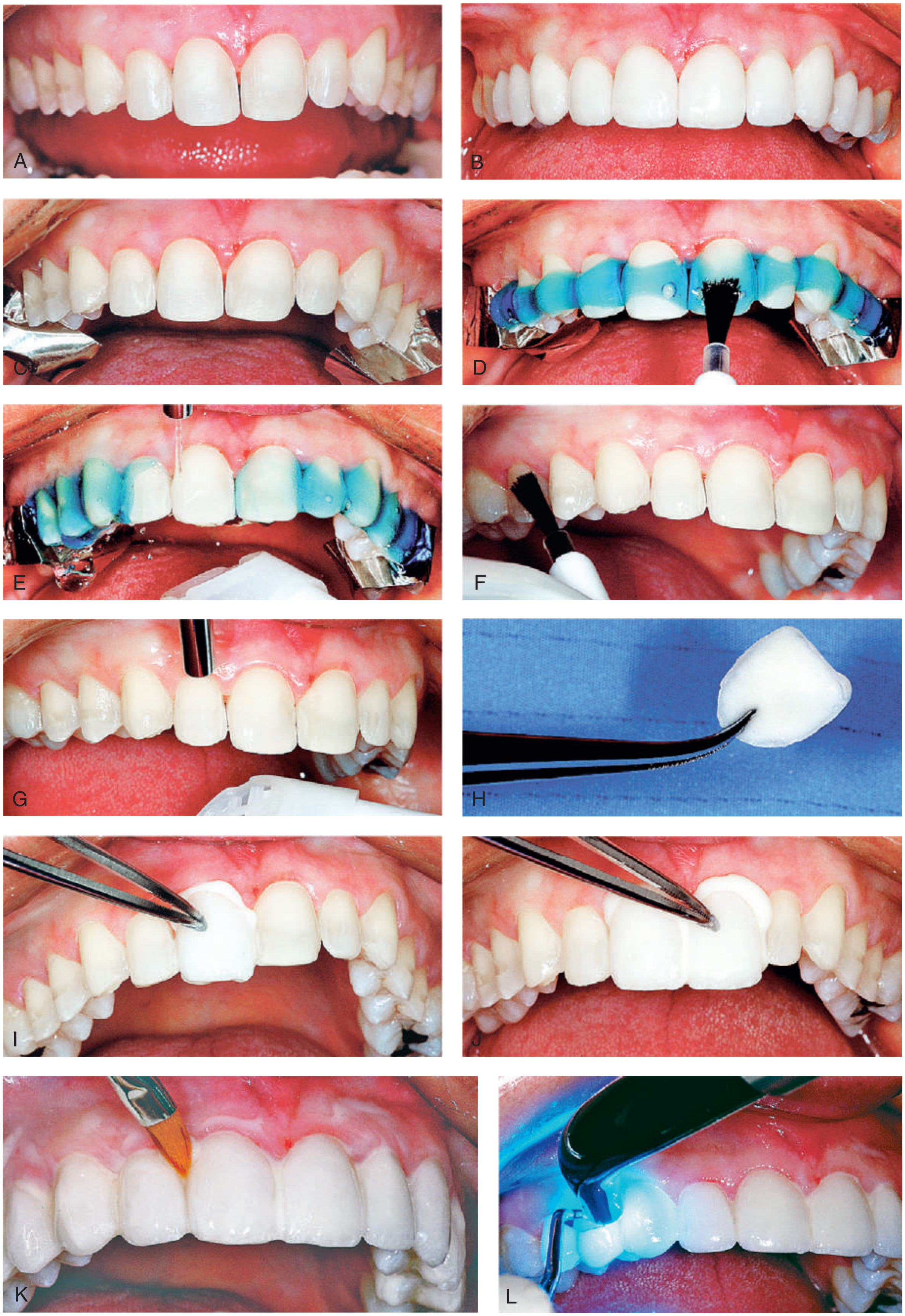

Fig. 30.18 (A) Interim restorations removed. (B) Evaluating the porcelain veneers. (C) Matrix bands in place. (D) Acid etching the enamel. (E) Rinsing off the etching gel. (F) Applying the bonding agent. (G) Air thinning the bonding agent. (H) Applying the luting composite resin. (I) Placing the first veneer. (J) Placing the second veneer. (K) Removing excess unpolymerized luting composite resin. (L) Tack polymerizing each veneer.

Fig. 30.18 Cont'd (M) Cleaning excess unpolymerized luting composite resin. (M) Light polymerizing the material to completion. (O) Removing excess polymerized luting composite resin with a finishing tungsten carbide bur. (P) Using an polishing cup to remove excess luting composite resin. (Q) Removing excess luting composite resin on the lingual surface. (R) Using a diamond strip to finish the interproximal area. (S) Using an aluminum oxide strip to polish the interproximal area. (T) Ten porcelain veneers in place, facial view. (U) Lateral view of definitive result. (V) Incisal view of definitive result. (W) Patient's new smile. (From Freedman G. *Contemporary Esthetic Dentistry*. St. Louis: Mosby; 2012.)

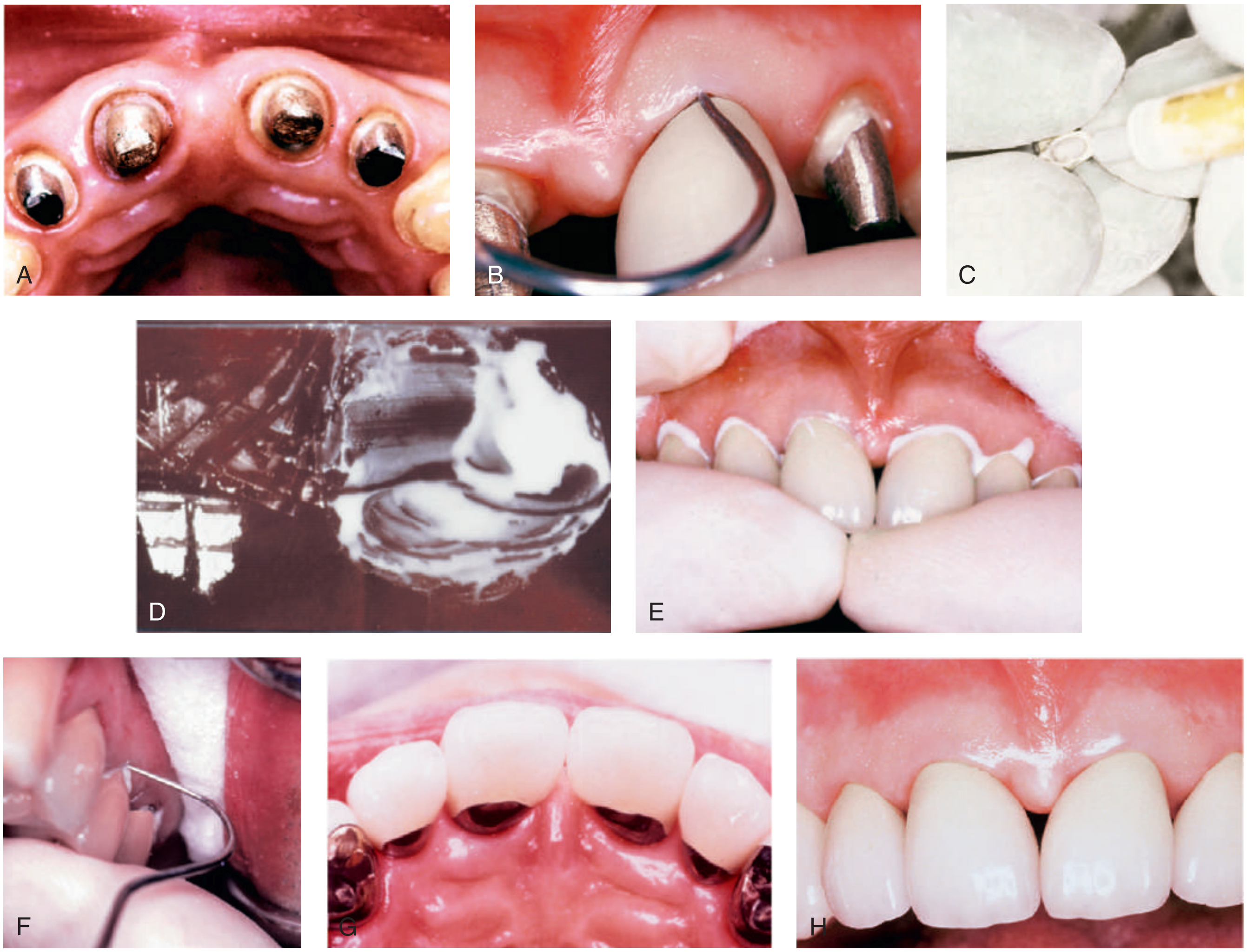

Fig. 30.19 Technique review. (A) The preparations are thoroughly cleaned; all interim luting agent should be removed. (B) The restorations are seated, and a readily accessible area of the margin is examined with an explorer. (C) The restorations are thoroughly cleaned with airborne-particle abrasion, steam cleaning, or an ultrasonic unit. (D) The luting agent is mixed according to the manufacturer's recommendations. (E) The restorations are seated to place with a firm rocking pressure. (F) The accessible margin area is quickly reexamined to ensure complete seating. (G and H) Once the luting agent has completely set, all excess is removed.

bur (see Fig. 30.18Q), and use diamond and aluminum oxide finishing strips to finish and polish the interproximal margins (see Fig. 30.18R and S).

14. The completed restorations and the patient's new smile can be seen in Fig. 30.18T–W).

REMOVAL OF A BONDED CERAMIC VENEER

Occasionally, a bonded veneer requires removal and recementation, such as when air is inadvertently trapped on the intaglio surface. Although not always successful, the application of an Er:YAG laser has been found to be an effective removal method.[109]

REVIEW OF TECHNIQUE

Fig. 30.19 illustrates the cementation of six maxillary anterior metal-ceramic crowns.

1. The preparations are thoroughly cleaned; the clinician makes sure all interim luting agent is removed (see Fig. 30.19A).
2. The restorations are seated, and a readily accessible area of the margin is examined with an explorer (see Fig. 30.19B); this evaluation provides a reference for complete seating during cementation.
3. The restorations are thoroughly cleaned with airborne-particle abrasion, steam cleaning, or an ultrasonic unit (see Fig. 30.19C).
4. The luting agent is mixed according to the manufacturer's recommendations (see Fig. 30.19D).
5. The restorations are seated into place with a firm rocking pressure (see Fig. 30.19E).
6. The accessible margin area is quickly reexamined to ensure complete seating (see Fig. 30.19F).
7. Once the luting agent has completely set, all excess is removed (see Fig. 30.19G and H).

SUMMARY

Proper moisture control is critical for the cementation step. Both the tooth and restoration must be carefully prepared for cementation; such preparation includes the removal of any residual polishing compounds. Airborne-particle abrasion of the fitting surface is recommended. The selected luting agent is mixed according to the manufacturer's recommendations, and the restoration is seated, after applying pressure through a rocking action. The luting agent must be protected from moisture during its initial setting. Removal of excess luting agent from the gingival sulcus is crucial for continued periodontal health.

Additional steps are necessary for adhesively bonded restorations. These steps must be carefully sequenced and timed, in accordance with the manufacturer's directions.

STUDY QUESTIONS

1. Discuss the principal differences in chemistry, physical properties, and manipulative variables for three different types of luting agents. How do the differences affect their clinically indicated use?
2. What are properties of the "ideal" luting agent?
3. Compare the recommended technique for mixing zinc phosphate cement with that of mixing Panavia EX.
4. Describe how the tooth and the restoration are prepared before a metal-ceramic crown is cemented with glass ionomer cement. How does this change when a different luting agent is selected?
5. Discuss the steps involved in cementation of two laminate veneers on the maxillary central incisors.

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31

Postoperative Care

After placement and cementation of a fixed partial denture (FPD), treatment continues with a carefully structured sequence of postoperative appointments designed to monitor the patient's oral health (Fig. 31.1), ensure meticulous plaque control habits, identify any incipient disease, and introduce any corrective treatment that may be needed before irreversible damage occurs.

Patients should be instructed to brush at least twice a day. Also, they must be taught special plaque-control measures, especially around pontics, and connectors, and the use of special oral hygiene aids such as floss threaders, water flossers, air flossers, and interdental cleaners (Fig. 31.2). If pontics are properly designed (see Chapter 20), floss can be looped through the embrasure spaces on each side, and the loop can be pulled tightly against the convex pontic tissue surface. A sliding motion is then used to remove dental plaque (Fig. 31.3). Flossing under pontics is essential to improve prosthesis longevity. When dental floss is used, the mucosa beneath pontics remains healthy; without its use, mild or moderate inflammation results.[1] Tissue response has been shown to be independent of the pontic material.[2] Patients with fixed restorations on natural teeth should use a topical agent such as toothpaste or oral rinse with 5000 ppm fluoride.[3]

Maintenance examinations are especially important for patients with extensive restorations and should be carried out by the dentist. Responsibility for follow-up care should not be delegated to auxiliary personnel (although good cooperation with a dental hygienist is beneficial for success).

Detecting disease around an FPD can be extremely difficult at a stage when corrective treatment is still relatively simple. For instance, partial dissolution of the luting agent may be difficult to diagnose with a subgingival margin. Caries is often detected only after irreversible pulp involvement has resulted. Caries under a crown is more difficult to detect radiographically, although bitewing images provide some interproximal information. Follow-up studies on patients with FPDs reveal that identifying risk factors and predicting the development of caries in any particular patient are complicated. However, there is no indication that caries is more likely to occur in association with prostheses than on unrestored teeth.[4]

If caries is overlooked, disease may rapidly progress to the point at which the fabrication of a new prosthesis becomes inevitable or, even worse, tooth loss results.

POST-CEMENTATION APPOINTMENTS

To enable the dentist to monitor the function and comfort of the prosthesis and to verify that the patient has mastered proper plaque control (Fig. 31.4), an appointment is generally scheduled within a week to 10 days after the cementation of an FPD. The dentist should check carefully that the gingival sulcus is clear of any residual luting agent that may have been overlooked previously and that all aspects of the occlusion remain satisfactory.

Radiolucent cements should be avoided because detecting excess luting agent radiographically is impossible if that material is effectively radiolucent. With luting agents of greater radiopacity, excess cement is spotted more easily on routine radiographs; therefore, the dentist should choose a luting agent that is as radiopaque as possible. In practice, luting agents are available in a wide range of radiopacities.[5–7]

The presence of fremitus (see Chapter 1), or "polished" facets, on the occluding surfaces of cast restorations at the postcementation appointment should prompt a careful reassessment and correction of the occlusion. If any minor shift in tooth position has occurred, some occlusal adjustment may be necessary. If so, the patient is rescheduled to visit the following week to confirm that no further correction is needed.

ROUTINE MAINTENANCE APPOINTMENTS

Patients with fixed restorations should attend recall visits at 6-month intervals. If appointments are less frequent, recurrent caries or the development of the periodontal disease may go undetected. Patients who have been classified as a high risk for caries, periodontal, or occlusal factors may need to be seen more frequently. Also, patients who have been provided with extensive FPDs (Fig. 31.5) need more frequent recall appointments, particularly when advanced periodontal disease is present (Fig. 31.6A–K). The restorative dentist or the periodontist can coordinate these appointments. To ensure treatment continuity, it is imperative to establish in advance who will assume primary responsibility for coordinating maintenance appointments.

History and Cancer Screening

The patient's medical history should be reviewed and updated at each appointment. The patient should be examined according to the principles introduced in Chapter 1. A head and neck cancer screening should be conducted at the maintenance appointments to detect pathosis early and make appropriate referrals. If a lesion of concern is detected at a dental appointment, reevaluation of the patient is warranted to confirm that the patient followed through with the referral and needed therapy at the following maintenance appointment. Particular attention is

Fig. 31.1 Treatment after placement of multiple restorations. To ensure tissue health and long-term success, proper oral hygiene is mandatory.

Fig. 31.2 Oral hygiene aids designed to maintain partial fixed dental prostheses.

Fig. 31.3 The patient should be instructed in the use of floss to clean a fixed partial denture.

paid to the intraoral soft tissues because early signs of oral cancer may be detected at a recall appointment.

Oral Hygiene, Diet, and Saliva

Patients tend to become somewhat less diligent in their plaque control efforts when the active phase of their treatment is

Fig. 31.4 Post-cementation monitoring of plaque control is necessary around recently cemented restorations. In this patient, poor oral hygiene has led to gingival inflammation *(arrows)*.

Fig. 31.5 Patients who have received extensive fixed dental prostheses require frequent follow-up care.

completed. The dentist should look carefully for any signs of deterioration in oral hygiene and assess the general effectiveness of plaque control at every recall with an objective index (Fig. 31.7A and B). Deficiencies must be identified early, and corrective therapy should be initiated. Periodic usage of at-home plaque disclosing tablets are useful to train and show patients places where they are not cleaning well, and a lighted vanity mirror with magnification can be helpful (Fig. 31.8). The dentist also should ask about changes in diet, particularly increased sugar consumption or "fad" diets. Excessive weight loss or gain should be investigated. For instance, a patient who has recently stopped smoking may start ingesting large amounts of carbohydrates at a high frequency, which can result in an increase in dental caries.

Saliva plays an important role in caries development. Patients with xerostomia can rapidly develop extensive carious lesions.[8] Diagnosing the cause of reduced saliva is imperative; the origin is often a drug side effect.[9] Patients with dry mouth should be on a more frequent recall schedule (e.g., every 3 months), and fluoride varnish may be applied. A protocol of a chlorhexidine 0.12% 10-mL rinse for 1 minute daily for 1 week each month, in combination with xylitol gum or candies and high-fluoride toothpaste, has been advocated.[10]

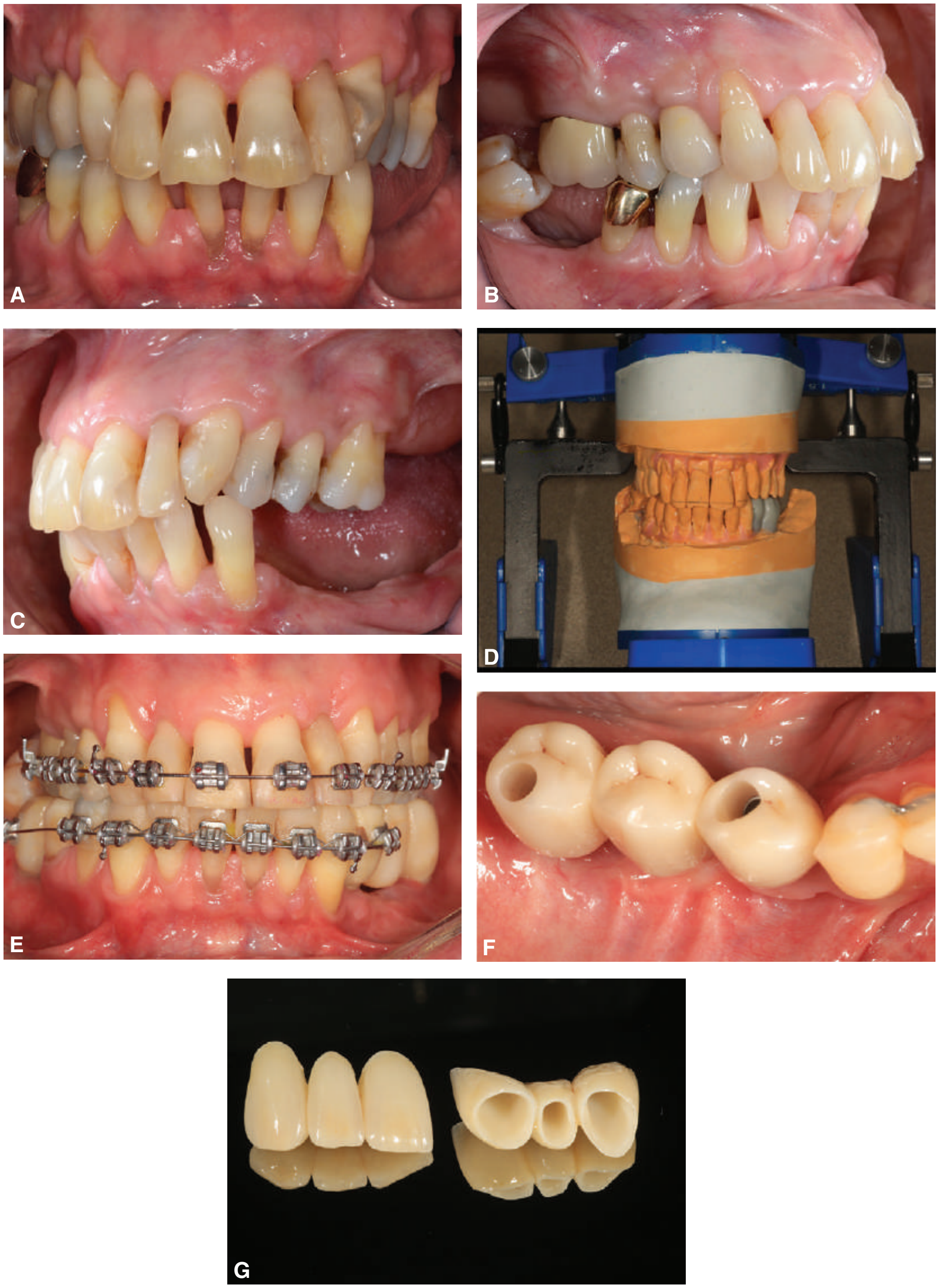

Fig. 31.6 (A) Patient initial presentation with severe periodontal disease and caries. Patient is determined to save the teeth. (B and C) Reevaluation after 1 year. Gross caries have been removed and the patient has been on a 3-month periodontal maintenance program. The anterior teeth are flared because of the lack of posterior support and the weakened periodontium, but the patient has demonstrated a high level of compliance and determination to retain the dentition. (D) Diagnostic and orthodontic setup. The plan is to restore the posterior occlusion and to deliver mutually protected occlusion. The anterior teeth will be retracted orthodontically, and the maxillary incisal edges repositioned apically with restorative dentistry to improve the crown-to-root ratio and make the anterior occlusal plane equal to the posterior occlusal plane. (E) Since the patient is highly motivated to retain the teeth, dental implants were planned to deliver posterior support and supplement orthodontic anchorage for retraction of the mandibular anterior teeth. (F) Screw retained monolithic zirconia fixed partial denture was chosen for the retrievability in its design and material property of low bacterial adhesion. (G) Three-unit splinted bilayered zirconia crowns. The periodontally weakened maxillary anterior teeth required splinting after orthodontics for long-term retention and esthetics. The restorations were not splinted at the dental midline to minimize future complications.

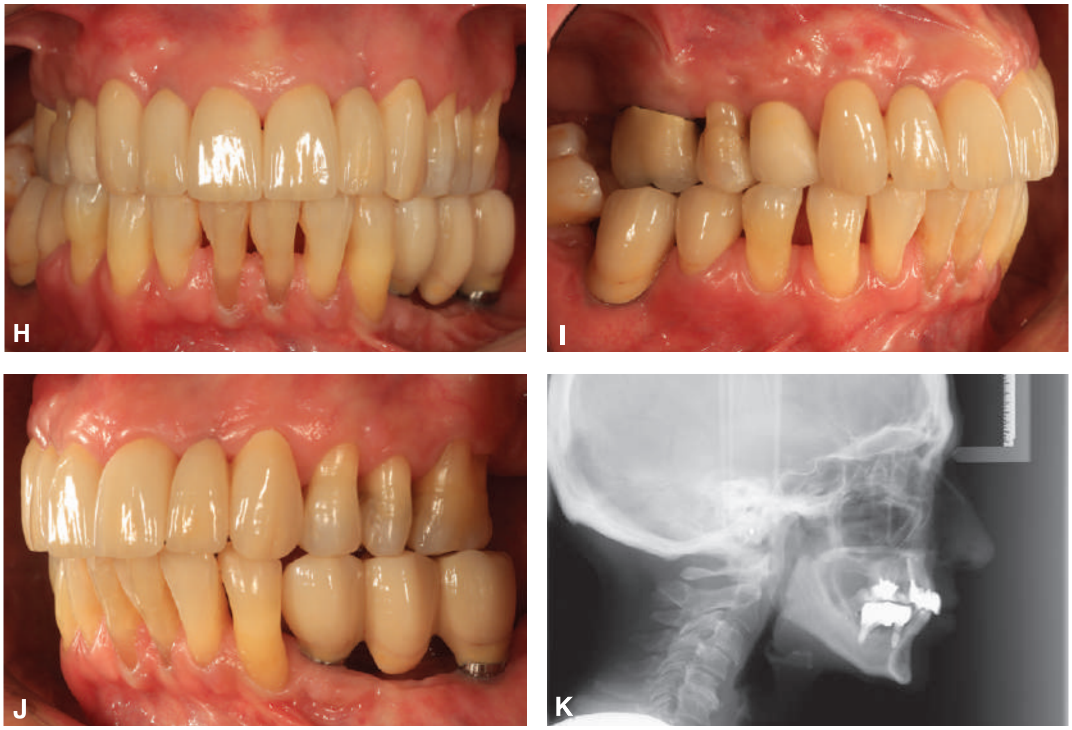

Fig. 31.6 Cont'd (H–J) Post-insertion evaluation at a short-term maintenance appointment. (K) Lateral cephalogram post-treatment.

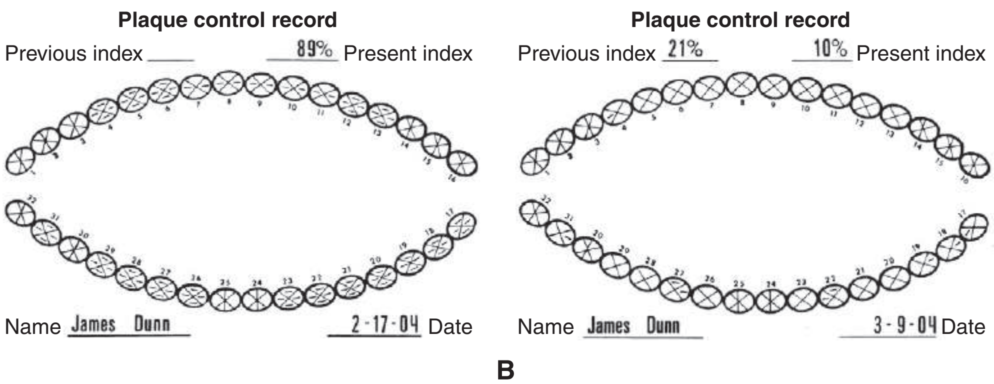

Fig. 31.7 (A) Plaque control record filled out at the first appointment for teaching proper oral hygiene measures. (B) Plaque control record after four sessions of instruction. This patient's plaque level is such that definitive treatment can begin. This level of plaque control needs to be maintained during the postoperative phase of treatment. (Modified from Goldman HM, Cohen DW. *Periodontal Therapy*. 5th ed. St. Louis: Mosby; 1973.)

Dental Caries

Dental caries (Fig. 31.9) is the most common cause of failure of a fixed restoration.[11–14] As a multifactorial disease, the primary etiology of dental caries is bacteria. The secondary etiologies are dependent on both genetic and environmental risk factors.[15] Detection can be very difficult,[16] particularly when radiopaque complete crowns are used. At each appointment, the teeth should be thoroughly dried and visually inspected (Fig. 31.10). The explorer must be used very carefully when early enamel lesions are assessed because a heavy-handed examination may damage the fragile demineralized enamel matrix. An intact enamel matrix is essential for procedures that induce remineralization (e.g., improved plaque control, dietary changes, topical 5000 ppm fluoride applications).[17]

Conservative treatment of caries at the cavosurface margin is especially problematic. The lesion can spread rapidly, particularly if the restoration has a suboptimal marginal fit. The use of a small restoration made with amalgam, composite resin, or glass ionomer sometimes corrects the problem (Fig. 31.11). If the restoration is supported by an amalgam or composite resin core, the extent of the caries may be difficult to determine. When there is doubt that all carious

Fig. 31.8 A vanity mirror with a dedicated light source and magnification has been found to be very helpful with patients being able to see their own teeth during cleaning.

Fig. 31.11 Occasionally, cervical glass ionomer or amalgam restorations *(arrows)* can extend the useful life of a previously placed cast restoration and postpone the complicated replacement of the prosthesis.

Fig. 31.9 Undetected caries beneath this partial fixed dental prosthesis resulted in serious complications.

Fig. 31.12 Advantage Arrest silver diamine fluoride applied to arrest the progress of an already formed cavity in the maxillary lateral incisor.

Fig. 31.10 Drying the teeth facilitates the assessment of the margin integrity of a cemented prosthesis.

dentin has been removed, replacing the entire restoration is recommended.

Silver diamine fluoride application (Advantage Arrest; Elevate Oral Care, LLC) has been shown to be effective at arresting carious lesions[18] and is particularly suitable for application around posterior crowns with recurrent caries (Fig. 31.12). The treatment is straightforward and cost-effective. However, the patient should be informed that black staining is characteristic of the treatment, making it unsuitable for lesions in the esthetic zone.

Root Caries

Caries of exposed root surfaces (Fig. 31.13) can be a severe problem in patients older than 50 (the age group of patients who most commonly seek fixed prosthodontic care).[19–21] In the classic Vipeholm study,[22] root caries accounted for more than 50% of new lesions in patients in that age group. Root caries incidence increased considerably with age.[23] In the caries examination from phase 1 of the Third National Health and Nutrition

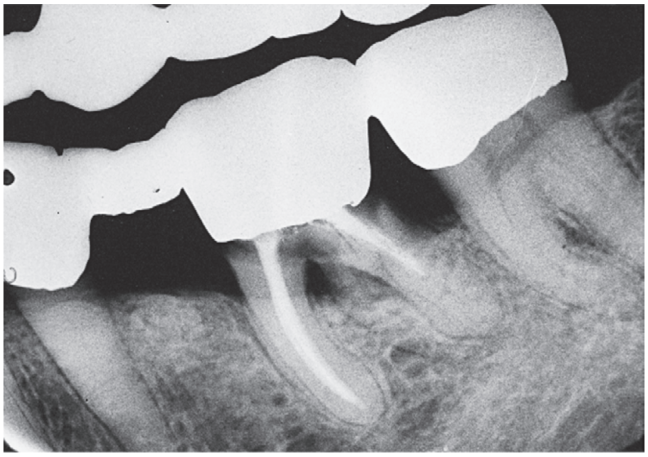

Fig. 31.13 Extensive root caries beneath a cemented fixed partial denture. (Courtesy Dr. J. Keene.)

Examination Survey, root caries affected 22.5% of the dentate population.[24] Root caries seems to be associated with individual dental plaque scores and high counts of salivary *Streptococcus mutans*.[25] Xerostomia that is age-related or caused by medication or radiation treatment has been implicated in the origin of rampant caries.[26–28] Other factors include the patient's economic status, diet, oral hygiene, and ethnic background.[29] Only a most vigorous effort on the part of the dentist and patient leads to the resolution of the problem. Prevention is focused on diet counseling and fluoride treatment. Treatment often requires the placement of a large cervical glass ionomer or amalgam restorations that wrap around the periphery of previously placed cast restorations. Such restorations are difficult to place. However, in view of the constraints, they are a preferred alternative to comprehensive re-treatment with elaborate FPDs.

Periodontal Disease

Unfortunately, periodontal disease often occurs after placement of FPDs,[30] especially where the cavosurface margin has been placed subgingivally[31–33] or if the prosthesis is overcontoured.[34] Inflammation is more severe with poorly fitting restorations (Fig. 31.14A–F),[35] but even "perfect" margins have been associated with periodontitis.[36] At recall appointments, the dentist should be particularly alert for sulcular hemorrhage, furcation involvement, and calculus formation as early signs of periodontal disease. Improperly contoured restorations should be recontoured or replaced. One area often overlooked is the furcation area of molars. Crown contours involved with furcations should be fluted to facilitate hygiene (Fig. 31.15).

Peri-implantitis

Although bone integrates into dental implants, soft tissues do not. As a result, patients need to understand that the peri-implant soft tissues are a weak link in the success of dental implant therapy. The concern is inflammation which may lead to bone loss.

Gingival health starts with an optimally designed prosthesis. A fixed implant prosthesis should never have a flange (Fig. 31.16). If a flange is required to improve the function or esthetics of a prosthesis, it should be designed to be removable (Fig. 31.17). Beyond the prosthesis design, the patient's home care is critical for long-term success (Fig. 31.18A and B). To minimize and prevent tissue inflammation, patient home care must be meticulous. Home care can consist of brushing twice a day, interproximal cleaning, and short-term use of chlorhexidine gluconate.[37] At the maintenance appointments, annual radiographs and charting probing depths with a plastic periodontal probe are useful clinical markers of maintenance of bone levels (Fig. 31.19A and B). However, the clinician must understand that a pocket around a dental implant is not equal to a pocket around a tooth because soft tissues do not attach to implants as they do to teeth. The crown on a dental implant may also impede a periodontal probe from measuring a true sulcus depth. Some clinicians do not believe in recording pocket depths around implants because of the differences between natural teeth and implants. However, comparing the probing depths to previous measurements may help early detection of bone loss.

Occlusal Dysfunction

At each recall appointment, the patient is examined for signs of occlusal dysfunction. The patient should be asked about any noxious habits such as bruxism. An examination of the occlusal surfaces may reveal abnormal wear facets (Fig. 31.20). In particular, the canines should be inspected because wear in this area soon leads to other excursive interferences. If parafunctional activity is a cause of tooth wear, the progression of facet formation often begins on the canines. In a slightly more advanced state of wear, additional facets can be observed on the incisor teeth, after which excursive interfering contacts result in wear facets on the posterior teeth. Abnormal tooth mobility is investigated, as is muscular and joint pain. A standardized muscle-and-joint palpation technique (see Chapter 1) is helpful. Articulated diagnostic casts should be periodically remade (Fig. 31.21A–H) and compared with previous records so that any occlusal changes can be monitored and corrective treatment initiated.

A small number of patients may not have responded well to previous occlusal treatment or may resume parafunctional activity sometime after completion of the active phase of fixed prosthodontic treatment. Although resolving the underlying cause is preferable, prescribing an occlusal guard is almost always indicated after a comprehensive reconstruction (Fig. 31.22A and B). Its design is identical to that of the occlusal device described in Chapter 4 for treating neuromuscular symptoms. If the patient primarily clenches, the dentist should consider a slightly flatter anterior ramp than is ordinarily incorporated in the conventional device. The device is prescribed to be worn for a maximum of 8 hours in a 24-hour period and for when the parafunctional movements occur. Initially, the occlusal device is only worn at night. At the following maintenance appointment, the device has to be evaluated for fit and occlusal wear facets (Fig. 31.23A and B). Through careful inspection, the dentist can learn much about the patient. In situations where the device no longer fits the teeth, the clinician must question the patient about compliance. Another situation may pose itself when the device fits the teeth, but no occlusal wear facets are