Implant or the natural tooth – a contemporary treatment planning dilemma?

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Abstract

An assessment of whether to rehabilitate a tooth requiring endodontic treatment or to replace it with a dental implant can often involve a challenging and complex decision-making process. This paper reviews the literature pertaining to both treatment modalities and identifies key issues that need careful consideration in planning the most appropriate course of care in a given clinical situation. A need to appreciate advances across both disciplines is highlighted, allowing the development of effective interdisciplinary evidence-based treatment strategies to maximize treatment outcome.

Key words: Implant, endodontics, treatment planning.

INTRODUCTION

A fundamental principle in traditional dental practice has been the preservation and rehabilitation of natural teeth. Endodontic treatment procedures have played a key role in this context in the retention and restoration to function of teeth affected by pulp and/or periapical pathosis. The extraction of teeth has generally been considered undesirable and as a treatment of last resort due to the limitations of alternative prosthodontic replacements such as bridges and removable prostheses. In recent years however, this paradigm has been challenged by emerging trends in implant dentistry, with implant replacements being touted as equal to or even superior to the preservation of natural teeth. This has led to concern among endodontic circles regarding the extraction of teeth which may otherwise be managed with sound contemporary endodontic and prosthodontic treatment procedures.

This review will evaluate the current literature pertaining to both treatment modalities. An assessment will be made as to whether a valid comparison between the two treatment options (endodontic treatment and prosthodontic rehabilitation vs. extraction and implant replacement) can be made using the available evidence.

Endodontic treatment

Endodontics has had a long history in the management of teeth with pulp and/or periapical pathosis. Endodontic treatment is presently widely prescribed by both general dentists and specialists.[1] The aim of clinical endodontics has been defined in terms of the prevention and/or elimination of apical periodontitis.[2,3] The role of bacterial infection in pulpitis and apical periodontitis (AP) has been well established.[4,5] Recent years have also seen a new level of understanding of the pathophysiologic processes that are responsible for pulp and periapical disease.[6,7]

In addressing the clinical aims of endodontic therapy, dentistry has seen some major technological and biological advances, resulting in the development of innovative new treatment strategies in both non-surgical and surgical endodontics. Examples include conservative pulp therapy strategies,[8-10] contemporary instrumentation and disinfection procedures,[11,12] and the use of the operating microscope in endodontic treatment, endodontic re-treatment and during surgical endodontic procedures.[13-16] In this context, these advances in modern endodontic practice have allowed the clinician to provide a greater range of treatment options, with predictable management of cases which may have been considered to be "heroic" in the past.

(A detailed discussion of these advances is beyond the scope of this paper and is covered by other articles in this Supplement).

Implant therapy

The development of osseointegrated implants represents one of the most important breakthroughs in contemporary dental practice in the oral rehabilitation of partially or fully edentulous patients. Based on the pioneering work of Brånemark (University of Gothenburg, Sweden)[17,18] and Schroeder (University of Berne, Switzerland),[19,20] who first proposed the concept of osseointegration or functional ankylosis, respectively, implant dentistry has subsequently seen some major advances, particularly in the past two decades. A widespread, multidisciplinary research effort involving physiologists, histopathologists, oral surgeons, materials scientists, periodontists and prosthodontists has contributed to a better understanding of implant therapy, with continually evolving treatment protocols and practices.[21]

A shift towards improved aesthetics and simplified use has resulted in the application of oral implants in

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Table 1. Fundamental differences between endodontic and implant therapies (adapted from White *et al.*[30])

	Endodontic treatment	Implant treatment
Fundamental aim	To retain teeth	To replace teeth
Basic requirements	Addresses presence of disease	Requires absence of disease
Measurement of "success"	Healing or regeneration of previously inflamed, infected or lost periradicular tissue	Absence of inflammation, infection or bone loss
Management of "failure"*	Retreatment and/or apical surgery	Surgical replacement with or without hard and soft tissue augmentation
Consequences of irretrievable failure	Extraction and consideration of prosthodontic alternatives, including implants	Prosthodontic alternatives which may require bone +/- soft tissue augmentation

*Excludes less catastrophic problems such as chipping of materials or loosening of implant screw.

the replacement of single teeth. The original protocol of delayed attachment of the overlying prosthesis has been replaced by more or less immediate loading protocols, from the same day to six weeks following fixture placement. Extraction and immediate placement principles have been advocated to enable preservation of bone and soft tissue contours with less postoperative complications. Whereas previously most implants were either minimally rough (e.g., Brånemark turned screw design) or very rough (e.g., ITI plasma-sprayed implant), today the most commonly used implant is moderately roughened, i.e., surface roughness of 1–2μm.[22,23] A wide array of implant designs and procedures have also emerged in the marketplace, but with little or no long-term clinical studies supporting their efficacy.[24]

Surgical and prosthodontic procedures have also been simplified, with a trend towards flapless surgery and cement-retained prostheses, with implant companies proposing that simplified surgical and prosthodontic protocols allow the general dentist familiar with conventional crown and bridge procedures to also manage implant prosthodontic cases more easily.

Implant vs. the endodontically-treated tooth

The fundamental aim of both implant and endodontic therapy is to allow rehabilitation of the patient's masticatory system. However, these complementary treatments profoundly differ (Table 1).[25] The issue of whether to consider the retention of a natural tooth with endodontic treatment and conventional prosthodontic rehabilitation or to extract and replace with an implant-retained prosthesis is both an emotive and controversial one, with opinion leaders and experts in both fields arguing their case in the dental literature.[26-31]

In general terms, the arguments favouring tooth retention focus on the advances in endodontic treatment which allow the provision of a greater range of treatment options with greater predictability. This treatment option has also been proposed to be more conservative, less invasive and less costly than implant placement. The effects of "failure" are also seen to be more significant with implant therapy as compared to endodontic treatment (i.e., loss of fixture in implant therapy vs. non-healing after endodontic treatment which may still be managed and result in tooth retention). Arguments favouring implant placement focus on the perceived poor outcomes of endodontic treatment when compared to implant "success" rates of over 90 per cent and concerns over the structural durability of a weakened endodontically treated tooth to support a coronal restoration. An implant fixture is seen as a better foundation for restorative dentistry than an endodontically-treated tooth. The implant has also been seen as a restorative option that requires little follow-up when compared to endodontic-prosthodontic rehabilitations, which is seen to be at a greater risk of further problems due to caries, periodontal disease and structural deficiencies.[29]

Outcome assessments of implant and endodontic treatment

Any discussion which compares the relative merit of one treatment modality over another must look at the criteria used to evaluate the outcome of each treatment. White *et. al.*,[25] in a recent evidence-based review of the outcomes of both treatment modalities, noted that if evidence-based principles are applied to the data available for both treatment modalities, few implant or endodontic outcome studies can be classified as being high in the evidence hierarchy. The authors also noted that broad outcome data may not be sufficiently specific to permit direct clinical comparisons and decision-making due to differences in outcome criteria, study design, sample sizes and duration in studies evaluating both treatment protocols.[25]

Study designs used in endodontics and the outcomes of endodontic treatment

A vast number of studies have been conducted on the prognosis of teeth with pulp or periapical disease following endodontic therapy over the past century. However, this information becomes confused due to the lack of standardization among studies, particularly with respect to material composition, treatment procedures and methodology. Applying the principles of evidence-based dentistry allows differentiation of clinical studies according to their level of evidence, thus allowing the selection of studies with the greatest level of evidence upon which to base our clinical decisions.[32] A recent series of papers reviewing the levels of evidence in the endodontic literature on the prognosis of non-surgical treatment,[33] retreatment[34] and apical surgery[35] over the past four decades revealed very few studies which could be classified as being high on the evidence hierarchy of research design. However, an evidence-based approach involves identifying the current "best evidence" available, while understanding the limitations associated with interpreting this information.[36]

A landmark series of publications by Friedman attempted to synthesize the information on endodontic treatment outcomes from 1956 onwards in a systematic review of the endodontic literature.[36-39] Some of the main issues identified from this comprehensive body of work were:

- An earlier review by Friedman identified a wide range in the reported "success" of endodontic treatment (without apical periodontitis (AP): 83–100 per cent; with AP: 46–93 per cent) and retreatment (without AP: 89–100 per cent; with AP: 56–84 per cent).[37]
- The traditional strict dichotomous classification of "success" and "failure" were inconsistently reported among the various studies using different outcome assessment criteria; one of the major reasons for the variability of reported outcomes in follow-up studies (e.g., while one study may have a strict definition of "success" requiring normal clinical and radiographic conditions, others may classify teeth with no clinical signs and a reduced radiolucency or a persistent, stable radiolucency in the same category).
- This issue is further confused by the fact that the terms "success-failure" are also being used to describe the outcomes of other dental treatment procedures such as implant therapy. The undiscerning use of these terms may confuse patients when they consider different treatment alternatives.
- The "success-failure" definition is ambiguous and should be avoided to promote effective communication, both within the profession and between clinicians and patients. Classifying the outcome of treatment in terms of "healed-healing-disease" better reflects terms that are directly related to the goals of treatment: prevention or curing of disease. This may also allow patients to relate to the concept of "disease-therapy-healing", unlike the concept of "success-failure".
- Friedman also proposed the use of the term "functional" to identify the proportion of teeth with no signs or symptoms. In most studies, this was the sum of "healed" and "healing", while for others it also included teeth where the radiolucency remained unchanged with normal clinical appearance. The percentage of "functional" teeth after initial endodontic therapy of apical periodontitis is likely to approach or even exceed 95 per cent.
- A good illustration of how these concepts may impact on the reported outcome of treatment is seen in the recent study by Farzaneh *et al.*[40]: following non-surgical retreatment of teeth with signs of continuing apical periodontitis, complete healing was reported in 78 per cent of cases; the number of cases that healed increased to 87 per cent when asymptomatic lesions that had a reduction in the size of the radiolucency were included; and 93 per cent of teeth were asymptomatic and fully functional 4–6 years after treatment.[40]
- Pre-operative apical periodontitis is the most important prognostic factor in both initial endodontic treatment and retreatment. Other pre-operative, intra-operative and postoperative factors appear to influence the outcome to a lesser extent, and thus their potential prognostic value may be difficult to demonstrate.
- Antimicrobial strategies such as increased apical enlargement, use of antimicrobial medicaments and irrigants facilitate maximal elimination of root canal micro-organisms, which enhance the prognosis of endodontic therapy of apical periodontitis.
- Apical surgery in conjunction with orthograde endodontic treatment offers a better outcome than apical surgery alone, as it addresses both intra- and extra-radicular sites of infection. Apical surgery alone depends on a shallow retrograde filling to seal off an infected root canal, and as such, "failure" rates are higher.

In reviewing the findings from clinical studies, it may be pertinent to note that certain clinical procedures performed in specific studies may no longer be relevant to contemporary endodontic practice. The studies reviewed by Friedman relate to traditional hand instrumentation and obturation protocols, with the majority managed without the aid of the operating microscope. Contemporary rotary nickel-titanium instrumentation procedures improve on traditional stainless steel procedures by producing rounder, more centred canals,[41] facilitating the safe preparation of the apical region of the tooth to larger sizes, thereby allowing better access for irrigants, medicaments and obturation materials. This may facilitate better bacterial control, potentially leading to better treatment outcomes in teeth with apical periodontitis, although high-level evidence for this is still lacking.[42-44]

A similar argument could also be made when assessing the healing rates reported in follow-up studies on non-surgical retreatment and apical surgery. Several studies, including the often-quoted paper by Sjögren *et al.*,[45] involved redundant obturation techniques (e.g., kloropercha and rosin chloroform) which have been shown to be associated with a poor prognosis compared with current techniques,[46,47] with some studies reporting on retreatment performed by undergraduate dental students. It is conceivable that the reported rates of healing may not be comparable with those that may be achieved using contemporary techniques.[48]

Recent developments in endodontic surgery have served to overcome many of the limitations of

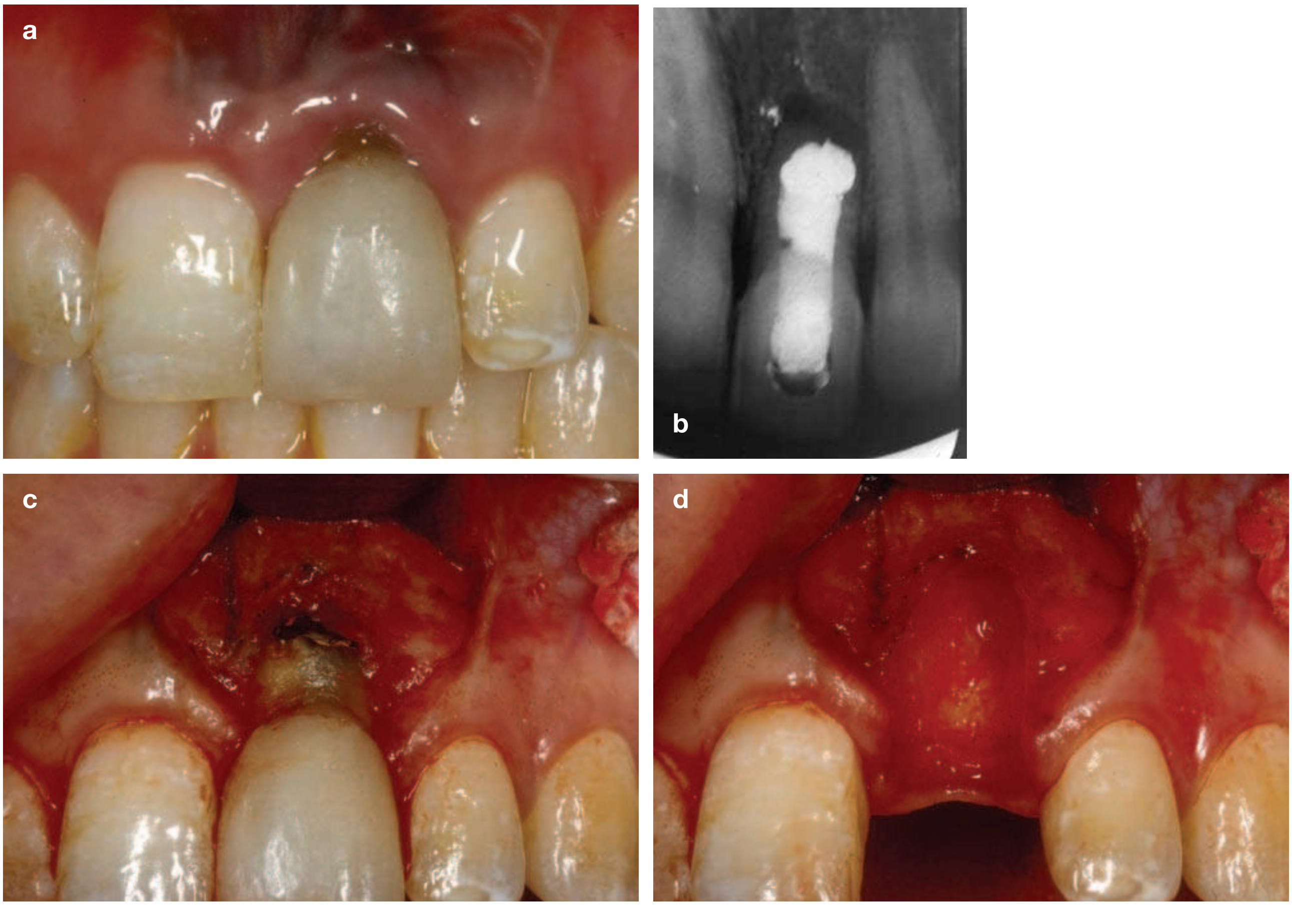

Fig 1. (a) Labial view of tooth 21 that had apical surgery performed twice using traditional techniques. Note the scarring of the gingiva, the amalgam tattoo and the marginal gingival recession. (b) Radiograph of the 21 showing the shortened root, large retrograde amalgam restoration and persistent periapical area. (c) Surgical view of the labial aspect of 21 following reflection of a full-thickness mucoperiosteal flap. The apex of the root was visible. (d) Following extraction of the tooth, a large residual defect remained with loss of the labial plate. This extensive defect would require significant augmentation, both bone and soft tissue, to provide adequate support for an implant restoration.

traditional apical surgery. Major developments in the field of endodontic surgery in recent years include the use of the operating microscope, alternative flap designs to prevent gingival recession and loss of inter-dental papilla, ultrasonic retro-preparation instruments allowing precise isthmus management utilizing a shallow resection angle, and the development of superior root end filling materials as alternatives to amalgam.[16] Figure 1 demonstrates some of the problems associated with outdated techniques and philosophies. Most of the long-term follow-up studies in the literature do not reflect current techniques in apical surgery and thus have questionable relevance to contemporary clinical practice. Figure 2 demonstrates what may be possible with contemporary materials and techniques. The limited numbers of recent studies incorporating contemporary surgical techniques report comparatively high rates of healing: Zuolo[49] (91 per cent healed), Chong *et al.*[50] (90 per cent healed, 6 per cent healing), Gagliani *et al.*[51] (78 per cent healed, 10 per cent healing).

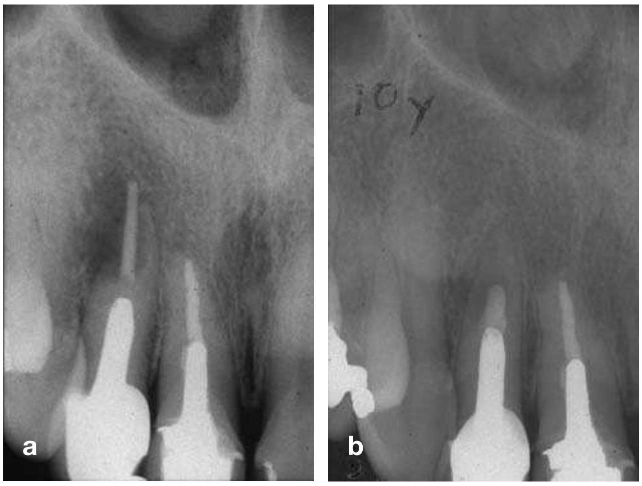

Fig 2. (a) Extensive inflammatory root resorption of the upper right lateral incisor restored with large post-retained crown. (b) 10-year follow-up after apical surgery using contemporary techniques, including removal of the previous root filling, curettage of the bowl-shaped root defect and placement of a Super-EBA retrograde root filling.

Restoration of the endodontically-treated tooth

The endodontically-treated tooth has been regarded by some as a weak foundation for restorative dentistry due to concerns over recurrent caries, periodontal disease and root fracture, favouring its replacement with a titanium fixture.[29,31] It is presently widely accepted that the major factor contributing to weakening of root-filled teeth is the loss of strategic tooth structure

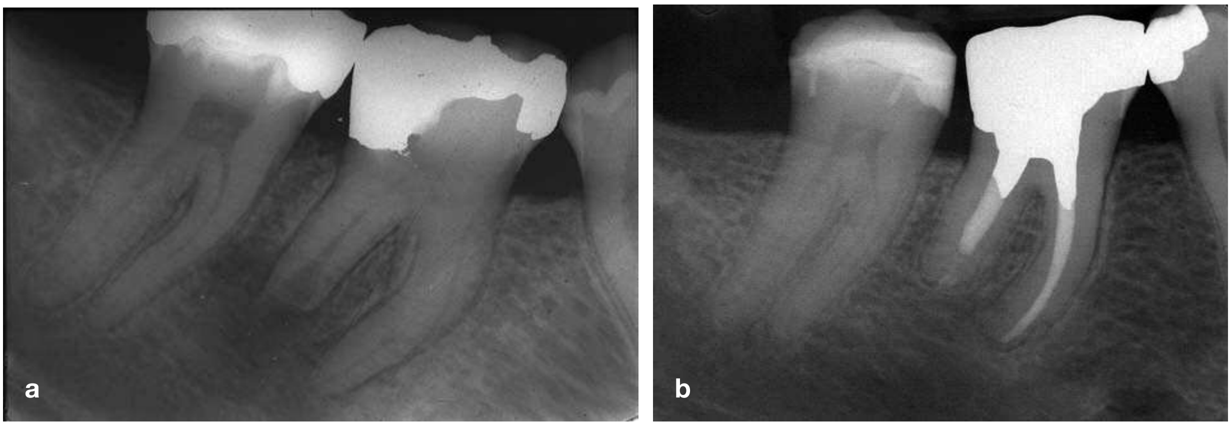

Fig 3. (a) Pre-operative radiograph of a heavily restored lower right first molar with significant apical inflammatory root resorption and chronic apical periodontitis. (b) 15-year review following orthograde endodontic treatment and full coverage amalgam overlay restoration.

through restorative procedures and caries rather than endodontic procedures.[52] In this context, the importance of judicious case selection prior to commencing endodontic treatment and the use of appropriate restorative techniques, most notably cusp coverage with a definitive restoration has been highlighted in both *ex vivo*[53,54] and clinical studies.[55-57]

Sorensen and Martinoff[55] retrospectively compared the success of root filled posterior teeth with and without crowns. Success rates of crowned teeth were found to be twice that of teeth with only intracoronal restorations. Success rates of crowned teeth over an observation period spanning 1–25 years were reported to range between 94–97 per cent for various tooth types. Caplan and Weintraub,[58] in a retrospective case controlled study, identified additional variables that may be risk factors for tooth loss. Among their findings, teeth with two proximal contacts when endodontic treatment was commenced were three times less likely to be lost than teeth with one or no proximal contact.[58] Aquilino and Caplan,[59] in a retrospective survival analysis of patients who had undergone endodontic treatment at a university dental hospital, noted that teeth which were not crowned were lost at a six times greater rate than those that were crowned. The authors indicated that although treatment recommendations should be made on an individual basis, the association between crowns and the survival of root-filled teeth should be recognized during treatment planning if long-term tooth survival is the goal. This was also implied by the findings from a recent retrospective study by Salehrabi and Rotstein[60] which evaluated the outcome of 1.4 million teeth based on their analysis of insurance records. Over an eight-year period, a retention rate of 97 per cent was reported, with only 3 per cent of teeth requiring retreatment, apical surgery or extraction. Although the restorative status of the retained teeth was not reported, analysis of the extracted teeth revealed that 85 per cent did not have a full coverage restoration.

These observations indicate that, provided endodontic treatment is performed with good case selection and sound restorative procedures, long-term survival rates are comparable to implant survival rates (Fig 3). In this context, it is also pertinent to note that operator competency and the ability to follow sound treatment procedures is essential in improving treatment outcomes. While the degree of loss of tooth structure may be considered to be a significant factor for long-term clinical restorative outcome, there is presently no high-level clinical evidence that quantifies this key issue.[25]

In this regard, the need for appropriate case selection and treatment planning from both endodontic and restorative aspects is highlighted to facilitate a favourable long-term treatment outcome. Dawson and Cardaci[61] recently noted that the restorative prognosis of a tooth being planned for endodontic treatment or retreatment is likely to be the most important factor in deciding whether to retain or replace. The patient's own preferences are also likely to play a key role in this decision-making process.[61]

Study designs used in implant dentistry and the outcomes of implant treatment

Eckert *et al.*[62] recently assessed the quality of current evidence of clinical performance provided by the six major American Dental Association – certified implant manufacturers in the United States. A letter was sent to the implant manufacturers requesting 10 references each that validated the manufacturer's implant system in a variety of clinical applications. When all data were pooled, the five-year survival rate of 96 per cent (CI: 93 to 98 per cent) was observed for a total of 7398 implants. However, the authors found that this evidence was generally derived from level-4 case series rather than higher-level cohort or controlled clinical trials. The authors also noted that articles that directly compared different implant systems were not found.[62]

As discussed in previous sections, endodontic treatment outcomes are usually measured by specific clinical and radiographic criteria which indicate healing. In contrast, many implant studies report their findings on the basis of "survival". Implant survival has been defined as "a retained non-mobile implant capable of supporting a crown". However, some of these implants may have associated bone loss and periodontal defects.[63] El Askary *et al.*[64,65] further classified implants as "ailing, failing and failed". With such broad criteria proposed to evaluate implant outcome, a direct comparison between endodontic treatment and implant therapy cannot be made.[66]

Interestingly, as far back as 1978, recommendations for the assessment of the outcome of implant placement and restoration had been made involving criteria such as follow-up periods of 10 years, use of life table methods for analysis, the recording of objective parameters related to bone loss, occlusion, gingival health, mobility, damage to adjacent teeth, sensation, and integrity of surrounding anatomic structure, and subjective parameters related to function, comfort, aesthetics and patient attitude.[67] Albrektsson *et al.*[68] proposed new criteria that included absence of mobility and radiolucency, rates of vertical bone loss, absence of signs and symptoms, and a minimum 10-year success rate of 80 per cent. Despite this, very few implant studies have used these criteria in reporting outcomes, generally opting to report short-medium term implant survival results. Several studies have reported five-year implant survival rates of 95 per cent and above[69,70] and Kaplan-Meier 10-year survival estimates of approximately 90 per cent.[71]

Creugers *et al.*,[70] in a systematic review of single tooth restorations supported by implants, reported that single tooth implants showed an acceptable four-year survival of 97 per cent. Implant failure was defined as "removed or lost implants". However, a complication rate of 17 per cent was also reported for problems such as screw loosening or screw fracture of the abutment or crown fracture. More recently, a systematic review by Berglundh *et al.*[72] assessed the reporting of technical and biological complications in prospective implant studies of at least five years duration. The authors found that while implant survival/implant loss was reported in all studies, biological complications (e.g., sensory disturbance, soft tissue complications, peri-implantitis, crestal bone loss) were considered in only 40–60 per cent and technical complications (e.g., implant components and connection failure, super-structure failure) in only 60–80 per cent of the studies. The authors concluded that data on the incidence of biological and technical complications may be under-estimated and should be interpreted with caution.[72]

Wallace *et al.*[73] conducted a systematic review on the outcome of implant placement with the aid of various maxillary sinus augmentation procedures. Survival rates of 61.7–100 per cent were reported, with an average survival rate of 91.8 per cent. Graziani *et al.*[74] conducted a systematic review comparing implant survival following sinus floor augmentation with implants placed in pristine posterior maxillary bone. Six papers were identified and evaluated. Implant survival ranged from 73 to 100 per cent for non-augmented sinuses and from 36 to 100 per cent for augmented sinuses using patient-based data. Implant-based data produced survival ranging from 75–100 per cent for both augmented and non-augmented sites. The authors concluded that implant survival appears to show greater variability in grafted sinuses than in the posterior maxilla, but also noted that the wide range in reported outcomes and poor reporting of associated variables highlighted the need for well designed prospective studies.[74]

With current trends in a highly competitive implant marketplace, a wide range of implant designs and surfaces have been introduced by different manufacturers. Many of the clinically well documented systems have been abandoned for the potential benefit of new, untested devices. Jokstad *et al.*[24] identified over 220 implant brands in the marketplace, produced by about 80 manufacturers. With a wide range of materials, surface treatments, shapes, lengths, widths and forms, the authors deduced that the dentist can in theory choose among more than 2000 implants in a given patient treatment situation. The authors noted that a substantial number of claims made by different manufacturers on alleged superiority due to design characteristics were not based on sound and long-term clinical scientific research. The authors found that in some parts of the world, implants were being manufactured and sold with no demonstration of adherence to any international standards.[24] Albrektsson and Wennerberg[23] also noted that in general, implant companies tended to initiate clinical documentation only after product launch. As discussed previously, the biologic process of osseointegration is yet to be fully understood. Until this is elucidated, the choice of implant selection is presently based on empirical experience (clinical success or failure) as well as other considerations such as cost, ease of use and customer support.

Concern has been expressed by the pioneers in implant dentistry over whether marketing pressures were forcing treatment decisions to be made empirically, with relatively untested materials and techniques being utilized in a similar way to the early days of implant development.[75,76] A need for better long-term data on outcome of contemporary implant systems, along with more rigorous training of clinicians has been advocated to facilitate predictable outcomes of implant placement and restoration.

Complications with implant treatment

Implant complications may be broadly divided into two categories: biological and technical (mechanical). Biological complications refer to disturbances in the function of the tissues supporting the implant. These include implant loss, which can be distinguished into early and late losses. Early failures (pre-osseointegration) are associated with surgical or postoperative complications. Late failures (post-osseointegration) can occur after the restorative phase and has been

Table 2. Predictors of implant success or failure (adapted from Porter *et al.*)[81]

Positive factors	Negative factors
Bone type (Type 1 and 2)	Bone type (Type 3 and 4)
High bone volume	Low bone volume
Patient is less than 60 years old	Patient is more than 60 years old
Clinical experience (more than 50 cases)	Limited clinical experience
Mandibular placement	Systemic diseases (e.g., uncontrolled diabetes)
Single tooth implant	Autoimmune diseases (e.g., Lupus or HIV)
Implant length >8mm	Chronic periodontitis
Fixed partial denture with more than two implants	Smoking and tobacco use
Axial loading of implant	Unresolved caries, endodontic pathology
Regular postoperative recalls	Maxillary placement, particularly posteriorly
Good oral hygiene	Short implants (<7mm)
	Eccentric loading
	Inappropriate early clinical loading
	Fixed partial denture with two implants
	Bruxism and other parafunctional habits

attributed to peri-implantitis (marginal and retrograde) and biomechanical overloading. Biological complications also include reactions in the peri-implant hard and soft tissues, which may require adequate clinical and radiographic examination methods for detection. Technical complications refer to mechanical damage of the implant, implant components and superstructures. As discussed previously, the reporting of biological and technical complications is poor in the implant literature, with an emphasis on implant survival rates.[72]

A recent review of the literature by Porter and Von Fraunhofer[77] identified several factors which may influence implant outcome (Table 2). The authors also highlighted the evidence supporting the need for appropriate implant maintenance and review protocols following implant therapy. Bragger[78] stated that technical complications of implant prostheses frequently occur, with certain implant systems associated with particular types of complications. Goodacre *et al.*[79] conducted a comprehensive review of the types of complications reported with implants since 1981. Whilst an overall complication rate of implant therapy could not be determined due to differences in data sets between studies, the authors did indicate a definite trend towards a greater incidence of complications with implant prostheses than conventional fixed prosthodontic treatment. Interestingly, a comparatively low rate of complications was associated with endodontically-treated post-retained crowns.[79] A recent 10-year prospective cohort study revealed that implant-supported single crowns had lower complication rates than implant-supported fixed bridges, which in turn had lower complication rates than combined tooth-implant supported bridges. Complications were also found to increase the risk of implant failure.[80]

Peri-implantitis has been defined as an inflammatory process affecting the tissues around an osseointegrated implant in function, resulting in loss of supporting bone.[81] While the prevalence of peri-implantitis is presently unknown, Berglundh *et al.*[72] reported an overall frequency of 5–8 per cent for selected implant systems. In peri-implantitis, a bone defect develops in the marginal portion of the implant site, resulting in a cratered appearance. The apical part of the bone-implant interface remains intact until a late stage in the disease process. It has been suggested that microbial colonization of dental implants and infection of the peri-implant tissues may result in peri-implant bone destruction and possibly implant failure.[82,83] The microbial flora at sites with peri-implantitis appear to have many features in common with the microflora found in a site with advanced periodontitis. Karoussis *et al.*,[84] in a 10-year prospective study, proposed an association between periodontal and peri-implant conditions. Risk factors for biological complications may include smoking, some systemic or local conditions (e.g., diabetes, irradiation) as well as the presence of subgingivally located periopathogenic bacteria.[85]

Recent studies have reported on the prevalence of progressive bone loss around implant fixtures over long-term observation periods. Fransson *et al.*[86] reported radiographic evidence of progressive bone loss over a minimum five-year period in 28 per cent of 662 patients restored with Brånemark implant-retained prostheses. These patients were also found to have a greater number of implants when compared to patients with no progressive bone loss. More recently, a series of three papers reported on the factors associated with implant loss and peri-implant conditions in patients who had received implant therapy (Brånemark system) 9–14 years previously.[87-89] A significant relationship was identified between implant loss and periodontal bone loss of the remaining teeth at implant placement.[87] Of the surviving implants, peri-implant mucositis (bleeding on probing, probing depth ≥4mm) was evident around 48 per cent of the implants. The authors concluded that after 10 years in function without systematic supportive treatment, peri-implant lesions were commonly observed around titanium implants.[88] Patients with a history of periodontitis and smokers were found to be more likely to develop peri-implantitis.[89]

A variety of therapies have been proposed for the management of peri-implantitis. These include access flap surgery, debridement of the implant surface, chemical conditioning of the implant surface, bone regenerative procedures, and topical and/or systemic antimicrobial therapy.[90] To date, however, there is insufficient evidence to support a specific treatment protocol.[91]

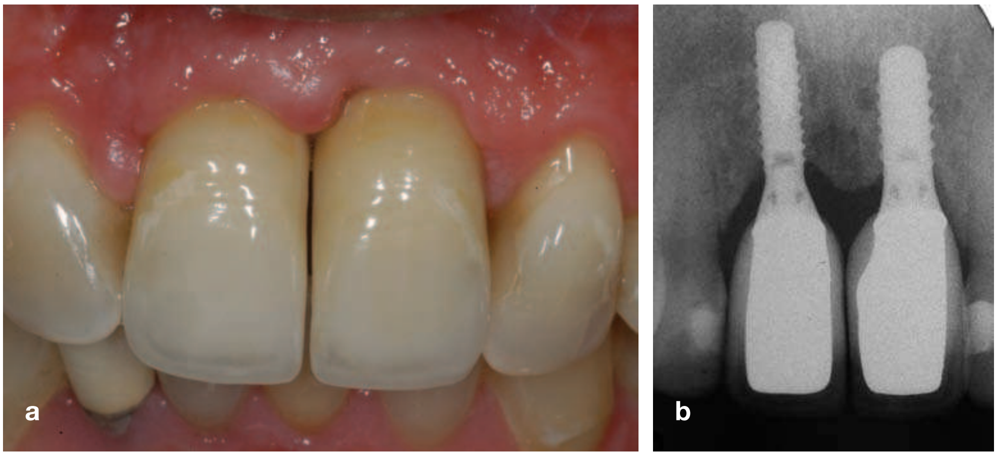

Fig 4. (a) Labial view of two adjacent implants replacing 11 and 21. Note the elongated contact region, and shortened inter-implant papilla. (b) Radiograph of the implants as seen in Fig 4(a). Although adequately separated, the blunting of the crestal bone between the two implants is evident.

Occlusion

Implants lack a periodontal ligament and therefore the ability to buffer or dampen the forces of occlusal trauma. Dental implants also lack the periodontal mechano-receptors of the natural tooth that signal information about tooth loads (proprioception). Patients who lack information from periodontal receptors show an impaired fine motor control of the mandible.[92] Implant function is proposed to be regulated by osseoperception, a sensory feedback mechanism associated with implants which is thought to be dependent on central influences and peripheral mechano-receptors in orofacial and temporomandibular tissues.[93] Implant-retained prostheses may have a lower level of fine tactile perception when compared to natural teeth. Hammerle *et al*.[94] concluded that a more than eight-fold higher threshold value for tactile perception exists for implants compared with teeth.

While implants can tolerate vertical forces, lateral forces may be detrimental to outcome.[95] Precise occlusal relationships are critical in the construction of implant-supported prostheses. In the same way that parafunction can lead to tooth fracture of natural teeth, bruxism can also produce implant fracture and failure of implant components such as abutment screw loosening and crown fracture. Clenching and bruxism can potentially produce excessive forces that will lead to bone loss and biomechanical failure. Bruxism is the primary cause of bone loss and implant mobility in the first year. Occlusal trauma may cause a more rapid destruction of the bone supporting an implant compared with similar forces on a natural tooth.[65]

It may be pertinent to note that occlusal overloading and parafunction can play a significant role in failure of endodontically treated teeth due to crown and root fracture. When planning implant replacement in such patients, the same underlying factors may also predispose to implant failure if not recognized and resolved. While parafunction does not preclude implant placement, it must influence treatment planning. Recommendations include more implants and a wider implant diameter to share the occlusal load, narrow dimensions of the restoration, eliminating contacts in lateral excursion and using an occlusal splint.

Aesthetics

Belser[96] reviewed implant outcomes in the anterior maxilla. The authors noted that although the use of implants in the aesthetic zone is well documented, most studies failed to include well-defined aesthetic parameters, with outcomes based mainly on survival. The effect of certain surgical procedures such as flapless surgery and immediate implant placement with or without immediate loading/restoration on aesthetic outcome is presently inconclusive in the anterior maxilla. The authors also noted that predictable soft tissue aesthetics can be achieved with single tooth replacement as a result of the tissue support provided by adjacent natural teeth. Aesthetic inter-implant contours may be unpredictable with the replacement of multiple missing teeth in the anterior maxilla, with soft tissue outcomes poorly documented.[96]

Depending on the type of tissue and the height of the smile line, changes to the marginal tissue and interdental papilla may create aesthetic problems. Both vertical and horizontal distances between adjacent implants and between a tooth and an implant have an impact on the incidence of loss of the interproximal papilla.[97]

One of the most difficult clinical situations to manage is the replacement of two adjacent teeth with implant restorations. It has been demonstrated that fixtures need to be placed a minimum of 3mm apart to preserve a peak of crestal bone between the implants.[98] It has also been shown that only 3–4mm of soft tissue forms coronal to the inter-implant crestal bone.[99] In many clinical situations, this may result in loss of the papilla between the two implants, necessitating alterations to the morphology of the crowns and contact region to compensate for this tissue loss. This may have an adverse impact on tooth aesthetics in the anterior region of the oral cavity (Fig 4). Retention of a natural tooth, even if compromised restoratively and

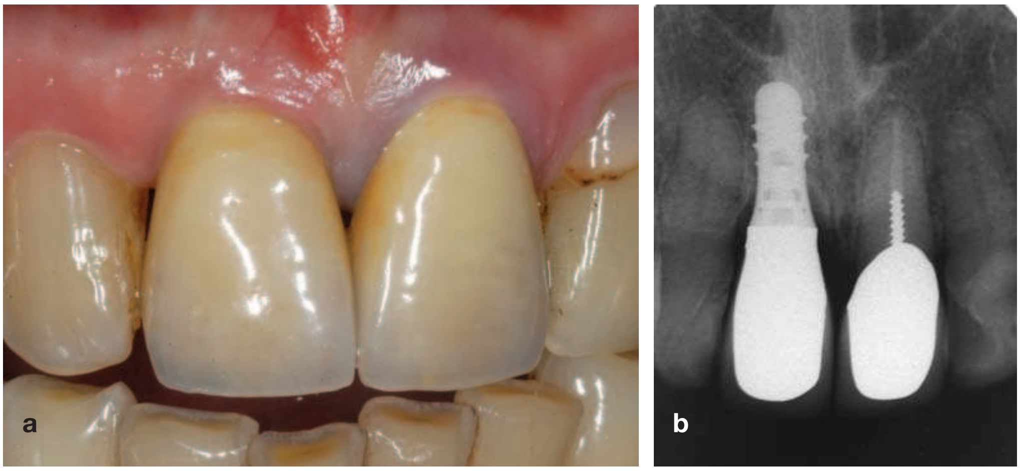

Fig 5. (a) Labial view of implant crown replacing the 11, adjacent to a natural tooth 21 that was restored with a crown. Note the intact interdental papilla present between the 11 and 21. (b) Radiograph of the clinical situation seen in Fig 5(a). Although the endodontic and restorative status of the 21 was less than ideal, retention of tooth 21 allowed maintenance of the interdental papilla between the 21 and the 11 implant.

endodontically, assists in the maintenance of the proximal crestal bone and papilla (Fig 5).

Myshin and Wiens[100] reviewed the various factors that may affect the soft tissues around an implant. Healing around dental implants was found to be affected by the patient's health, soft and hard-tissue contours, and the use and care of the prosthesis, as well as the manufacturer's implant-abutment designs, surgical augmentation and placement, and the design of the definitive prosthesis. It was also found that there were no specific guidelines relative to the amount of space or clearance necessary for a patient to clean beneath a fixed implant-supported prosthesis and whether these tissues change predictably over time.[100]

Influence of experience and expertise

It is conceivable that a significant predictor of both implant and endodontic treatment may be the expertise of the clinician and the technical quality of the treatment. Currently, most endodontic care is provided by general dentists. Initially, most endosseous implants were placed by specialists, but it is expected that over time most implants will be placed and restored by general dentists. The literature on outcomes reflects this history; much data on endodontic outcomes has been derived from dental school general teaching clinics or general practices, whereas most of the data on implant outcomes has been derived from multi-specialty clinics.[25]

While it has been only in recent years that general dentists have started to provide implant treatment, Listgarten[101] noted that the high success rates for implants may not be duplicated at general practice level. Pure training courses as opposed to formal education and academically-based experiences may be only of a few days' duration and the practitioner may lack the necessary diagnostic, surgical and prosthetic skills. Patient selection may not be as strict as required for a clinical trial, and deviations from the recommended treatment are more likely when the dentist is confronted with an unexpected clinical problem and has to improvise. This may also be a problem in endodontics with training in new technology. Cohn[66] noted that while short training courses in rotary instrumentation procedures are very popular, it is unknown whether they supply sufficient knowledge and skills. Reducing the number of instruments to "simplify" the technique may potentially be detrimental to bacterial control and ultimate success, particularly as it relates to chemomechanical debridement in the apical 1/3rd of the canal. However, endodontic treatment is widely prescribed in general dental practice and as such, most practitioners should have a baseline level of experience.

Friedman[36] recognized the disparity in endodontic outcomes when comparing follow-up studies ("potential outcome" – 83–94 per cent or higher for initial treatment) and cross-sectional epidemiological studies ("realistic outcome" – 61–77 per cent or lower) as measured largely by radiographic assessment. When survival criteria are applied, studies have reported a high retention rate of endodontically treated teeth. Alley *et al.*[102] reviewed records of private general practices and compared their success rates with that of specialists over a five-year period. Success was categorized as presence of the tooth at the time of review. The reason for tooth loss may have been due to fracture, restorative failure or other non-endodontic reason, but was not recorded. Specialists demonstrated a 98.1 per cent success rate, whereas GPs demonstrated an 89.7 per cent rate of success. Salehrabi *et al.*[61] reviewed the survival of endodontically-treated teeth over an eight-year period. The treatments were provided by both general dentists and endodontists and a 97 per cent retention rate was reported over eight years. An earlier study using the same parameters reported a retention rate of 94 per cent of 44 000 teeth reviewed for an average of 3.5 years.[103] Interestingly, this study also reported that specialist practice provided similar rates of clinical success, even when treating significantly more complex cases. These "real-world" figures compare favourably with implant survival outcomes in controlled follow-up studies.

When evaluating epidemiological data, Cohn[66] made a key observation that there is an important difference between the epidemiological evidence of the persistence of periapical lesions following endodontic treatment and the acceptance of this fact as a measure of positive or acceptable outcomes. The evaluation of endodontically treated teeth using "functional" and "survival" measures recognizes that pulp and periradicular disease may be managed but not eliminated and is an important departure from the traditional methods of evaluating outcomes based on clinical symptoms and radiographic findings. While this shift in guidelines may be partly as a response to a perceived challenge of implantology to endodontic treatment principles, a more realistic and biological comparison between the two disciplines may be achieved by applying stricter criteria to implant outcomes.[69,104]

In this context, a recent retrospective cross-sectional evaluation comparing the outcome of initial endodontic treatment with single-tooth implant restorations found that restored endodontically-treated teeth and single-tooth implant restorations had similar failure rates, but noted that the implant group had a longer average and median time to function and a higher incidence of post-operative complications.[105]

A lack of diagnostic and clinical skills in both areas may be reflected in the rate of malpractice claims.[66] In Australia, the incidence of claims is increasing, with implant claims four times the rate of those for endodontics. The average cost to one insurance company of an implant claim was four times the average claim size for all events, while for endodontics it was slightly above the average claim size.[106] In general, implant claims involved dentists with limited experience or insufficient training, with the majority of problems due to inappropriate diagnosis and case selection, prosthetic failure after osseointegration, and unsatisfactory aesthetics. Endodontic claims were skewed toward new or inexperienced dentists, with the majority of claims due to failed or inadequate root canal fillings and broken instruments.[66,106]

Patient:dentist considerations and cost:benefit

Friedman[36] noted that just as researchers and clinicians appear to differ in their interpretation of treatment success and failure, patients too may have difficulties relating to these terms, particularly when applied to alternative treatment strategies such as endodontic therapy or implant replacement, which may have very different outcome assessment criteria. Friedman noted that "the patient weighing one 'success' rate against the other may erroneously assume their definitions to be comparable, and select the treatment alternative that appears to be offering the better chance of 'success'".[36] Importantly, it should be recognized that "success" does not necessarily equate to the "probability" of a favoured outcome when applied to a particular case or clinical scenario. It is the onus of the clinician to ethically convey information on dental treatment alternatives in an appropriate way such that the patient can make an informed decision.

Factors such as patient expectations, dental and medical health status, regional anatomy and bone characteristics, risk associated with treatment, treatment time, costs, prognosis and consequences of a negative outcome need to be individually assessed for a specific clinical situation. When evaluating these issues in comparing implant therapy vs. endodontic treatment, it is apparent that endodontic treatment is more widely applicable in most situations, is less invasive and is associated with fewer complications when compared to implant therapy. A simplified cost:benefit analysis comparing endodontic treatment and a single tooth implant concluded that endodontics, crown lengthening and crown was less expensive, entailed fewer office visits and was completed more quickly than implant placement and restoration.[107] As discussed previously, comparisons of prognosis are difficult when comparing endodontic treatment and implant therapy due to differences in treatment procedures, outcome measures and complications. If the available data are based on survival, it is apparent that "real world" endodontic treatment outcome in general practice is comparable to implant therapy in prospective studies. While this may be considered to be an academic point and not applicable clinically, at an individual patient and tooth level it must be recognized that endodontic treatment is applicable in most situations, with restorability and periodontal stability being the major factors in determining whether to replace or rehabilitate.

CONCLUSIONS

In reviewing the literature comparing endodontics and implant therapy, it is evident that the major advances in both fields presently allow us to provide treatment to a high standard with better treatment outcomes. Some of the key points identified are:

- Both implant therapy and endodontic treatment can be open to inappropriate treatment planning and treatment. Commercial and market-driven pressures may detract from the best treatment. Hence the need for appropriate evidence-based background information and clinical training for both implant and endodontic therapy.
- When comparable criteria are applied to outcome, survival rates of endodontically-treated teeth and implant fixtures are similar.
- An argument comparing "endodontic treatment vs. implant therapy" overlooks the crucial finding that it is often the restorative prognosis and not the endodontic prognosis *per se*, that becomes the critical decision-making determinant of whether a tooth is replaced or rehabilitated.
- The following factors require careful consideration in planning the most appropriate course of care for a particular patient:

(i) Tooth variables – endodontic, restorative and periodontal status, occlusion,
(ii) Implant variables – bone quality and quantity, implant site, coronal prosthesis, occlusion, soft tissue aesthetics,
(iii) Patient variables – general oral and systemic health status, economics, motivation and compliance, and
(iv) Dentist variables – clinical experience and competence.

- Both implant-retained prostheses and endodontically-treated teeth are at risk of long-term complications and as such require appropriate follow-up and maintenance protocols.
- There is a need for better communication and collaboration between different disciplines to allow the development of effective interdisciplinary evidence-based treatment strategies to maximize treatment outcome.

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