Author Anders Westermark

1.5.7 Dental and alveolar trauma

1 Introduction

Dental and alveolar trauma may occur either as an isolated injury or as part of a more complex craniomaxillofacial trauma. Minor dental and alveolar injuries usually result from direct forces in accidents like falls, fist-fights, or sports related collisions. In more severe injuries, the impact of the trauma can be direct, but also indirect, as when the mandible is forced against the maxilla with such a force that teeth and alveolar tissues are injured.

There is a contradiction in the treatment of dental trauma. Certain isolated dental injuries will most often receive immediate treatment, while more severe dentoalveolar injuries, especially when they occur in combination with severe facial bone or soft-tissue injuries and in patients with a compromised general condition, may get delayed treatment. Thus, an isolated crown fracture with pulp exposure will require root canal treatment to relieve pain, and an avulsed tooth must be replanted immediately to improve the prognosis. In more complex injuries, however, life saving measures will take priority over dental procedures. The obvious treatment modalities for dental injuries may have to be postponed. In such cases one should still remember that the pain from exposed pulp may contribute to the restlessness in an unconscious patient.

It falls outside the scope of this text to give a detailed classification of all types of dentoalveolar injuries and their treatment. Such information can be found in specialist publications on the subject. The following will focus on tooth fracture, tooth luxation or avulsion, and alveolar trauma.

2 Tooth fracture

Isolated tooth fractures, needless to say, are most common in the maxillary incisor region. In a direct trauma resulting in a horizontal crown fracture, usually the periodontal tissues are unharmed. Then, the prognosis for tooth vitality will depend on the pulp status and how deep the fracture goes into the tooth. In a young tooth with an open apex, there is a good chance that pulp vitality will remain. The narrower the pulp is, the more likely it is that the pulp may undergo necrosis due to secondary circulatory collapse.

If the pulp is not exposed, the dentin should be treated with calcium hydroxide cements covered with acid-etch restoration of the tooth. Acid-etch techniques may also be used to reattach a crown fragment to the tooth.

Close follow-up with x-rays is recommended. It should be mentioned that immediately after injury, and even some time later, pulp testing with an electrical pulp stimulator or ice is of limited value as a sensitivity test. The trauma may have disturbed the nerve function so that the test is false negative. A nonsensitive tooth may still be vital.

If the crown fracture is deep enough to expose the pulp, the tooth will be very painful to all kinds of stimuli. Usually, pulpectomy at varying levels (depending on root development) must be carried out, followed by calcium hydroxide dressing, and later filling of the root canal.

A relatively common type of tooth fracture is one where the fracture line is oblique, extending subgingivally. In deep fractures, such a tooth must be extracted. Apart from the depth of the fracture, other factors may also influence the decision whether to save or extract the tooth. Such factors may include endodontic and prosthodontic considerations, the rest of the patient's dentition, and economic factors.

Tooth fractures with missing fragments in association with soft-tissue lacerations require thorough examination, including x-rays, to confirm that tooth fragments are not embedded in the soft tissues. The same precaution must be taken if a tooth or tooth fragment might have been inhaled. Then a chest x-ray must be obtained.

3 Tooth luxation

Tooth luxation may involve intrusive and extrusive luxations as well as lateral luxations. They may be combined with fractures of the alveolar bone. Tooth luxation with simultaneous buccal fracture of the alveolar process usually affects the maxillary incisors. Frequently, in such cases, the tooth/bone complex will be superiorly displaced. Upon repositioning, it is important, first to pull down the tooth, then to replace it in its place adjacent to the remaining alveolar bone (**Fig 1.5.7-1a–c**).

Once the tooth or group of teeth have been properly repositioned, they should be splinted with some kind of stabilization. Reliable, rigid or semirigid fixation can be designed either with acid-etch techniques, or in combination with orthodontic wires, plain steel wires, or similar appliances (**Fig 1.5.7-2a–c**). For isolated tooth luxations semirigid fixation is preferred over rigid fixation with stable splints or arch-bars. Rigid devices are used in patients with facial fractures in combination with tooth luxations. In order to improve the patient's ability to maintain good oral hygiene, one should make the fixation devices as small as possible. The duration of fixation varies with type and extent of the injury. Extrusion injuries should have semirigid fixation for 7–10 days; lateral luxation injuries should have semirigid fixation for 2–3 weeks; luxation injuries with simultaneous fracture of the buccal or lingual bone plate should have semirigid fixation for 4–6 weeks.

After luxation injuries, root canal treatment is indicated for all involved teeth with a closed apex. It is usually done shortly after initial treatment when primary wound healing is completed. During follow-up one should pay special attention to possible signs of root resorption.

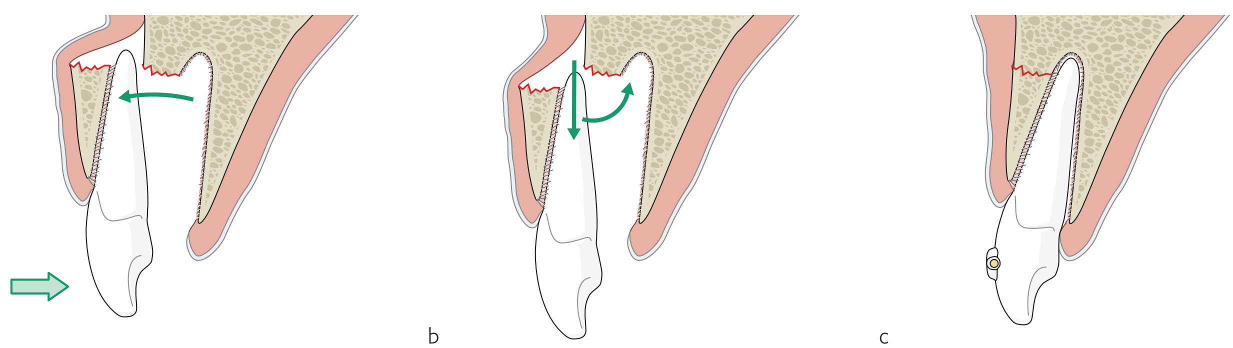

a b c

Fig 1.5.7-1a–c
a A part of the buccal bone is fractured along with a luxated upper incisor. The tooth/bone complex is superiorly displaced.
b Before the tooth can be replaced, it must be pulled down over the bone margin.
c After the tooth has been properly positioned, it can be fixed with semirigid fixation appliances.

4 Tooth avulsion

Many factors will have an impact on the decision whether or not to replant an avulsed tooth. Most avulsion injuries involve the upper incisors, which in itself creates compelling esthetic indications for replantation. Root development, periodontal status, and general condition of the remaining dentition are other factors to consider. The most important factor, however, is the length of time the avulsed tooth was allowed to dry. After a dry period exceeding 30 minutes, the cells of the periodontal ligament will have dried to an extent where the chance of success after replantation will be very low. Thus, immediate or very early replantation must be the treatment most of the time, although immediate replacement is not possible. The viability of the periodontal cells is supported if the tooth is kept in a suitable transport fluid. The periodontal cells can maintain their viability up to two hours in the patient's saliva and up to six hours in fresh milk. Water should not be used since the cells will die from osmolytic lysis.

Before the tooth is replanted, it should be gently rinsed with saline until free of all debris. Scrubbing or trauma to the periodontal cell layer must be avoided. If there is a reason to suspect foreign material in the tooth socket, the socket should be gently cleaned by suction. Otherwise, no special attention is needed for the socket. The tooth is firmly replanted in the socket by firmly gripping the crown. One should pay attention to possible injury to bony margins as after tooth luxations. When the tooth has been replanted in proper position, it can be fixed with methods similar to those employed after luxation. After tooth avulsion, a semi-rigid fixation for 7–10 days should be applied. Usually, antibiotic treatment is recommended following replantation of avulsed teeth.

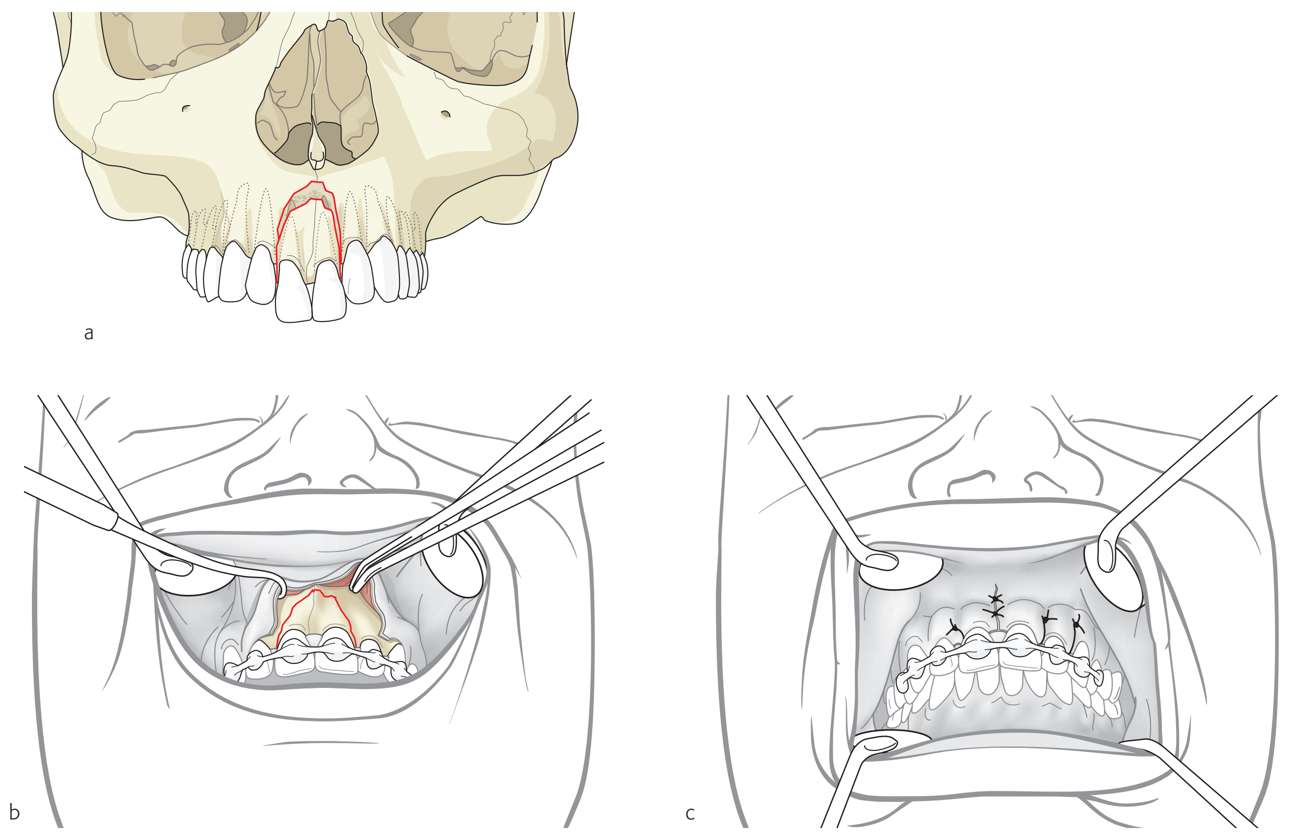


Fig 1.5.7-2a–c

a The two central incisors have been luxated and displaced.

b After repositioning, one can inspect the reduced fracture and the buccal bone plate through the preexisting mucosal laceration. In cases without soft-tissue lacerations, small bone fragments should not be denuded. Semirigid fixation has been created with acid-etch techniques in combination with thin, plain steel wire, covered with light cured resin.

c The condition after closure of the mucosal lacerations.

The postoperative treatment will be similar to that after luxation injuries. An avulsed tooth with a closed apex should undergo early pulpectomy and root canal treatment. Even so, the risk for root resorption will be higher in proportion to the length of the "dry" period.

Often, the prognosis may be regarded as so poor that it is tempting not to replant the avulsed tooth. Even then however, there may be things to gain from a replantation. The alveolar bone may be preserved to a much larger degree with the tooth in position in the socket, if only for a limited period of time, than if the tooth had not been replanted. Thereby, the conditions for future dental implant installation may be greatly improved.

5 Alveolar trauma

Obviously, alveolar trauma seldom occurs alone, almost invariably a tooth or group of teeth are involved. Typically fractures of the alveolar process are stabilized through indirect management by splinting of the dentition. Only in rare indications and in the presence of larger bone blocks is microplate or rarely miniplate fixation of alveolar segments indicated. Care must be taken to maximally preserve the blood supply and thus the viability of the segments. A fracture of a dentate block of the alveolar process should be treated longer with more rigid arch bars or splints than mentioned for other isolated conditions in this chapter. Such a fixation should be maintained for 6 weeks.

In high-energy trauma the mandible is sometimes forced towards the maxilla with a force that splits both the teeth and alveolar process (**Fig 1.5.7-3a–b**). Such injuries may require extraction of a large number of teeth. Due to the crush type injury, large amounts of alveolar bone may have to be removed. Care should be taken to preserve any bone that might have a chance to survive. The success of future reconstruction efforts will be greatly improved if as much of the original bone structure as possible can be saved.

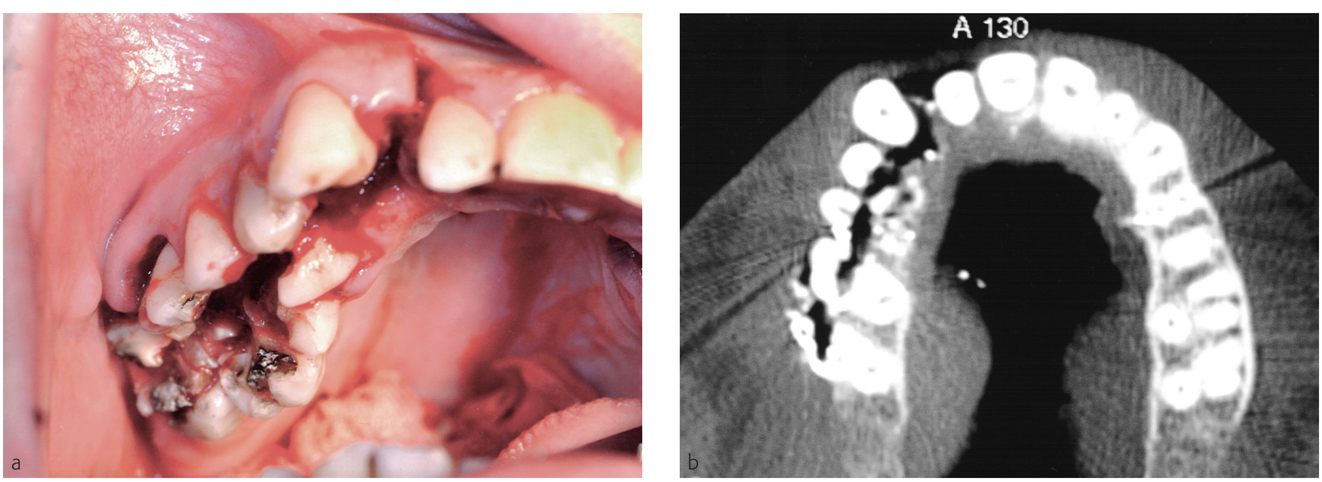


Fig 1.5.7-3a–b
a High-energy trauma sustained in a fall from high altitude. The mandible has hit the maxilla and the upper and lower dentition each have impacted the other. Severe axial fractures of teeth were sustained in combination with corresponding fractures of supporting alveolar bone.
b CT scan of the injury.

Author Anders Westermark

6 Primary dentition

In general, trauma in the primary dentition seldom should have sophisticated treatment. Extraction is the treatment of choice for most fractured or luxated teeth in the primary dentition. Replantation of avulsed primary teeth should be avoided due to the risk of damage to underlying permanent teeth and the poor prognosis of replanted teeth. Intrusion injuries most often can be left untreated, since most primary teeth will have the potential to reerupt spontaneously.

Author Anders Westermark

1.5.8 Teeth in the fracture line

The fate and consequences of teeth involved in the fracture line have been debated for a long time. It is almost exclusively a matter of concern in mandibular fractures. The controversy is whether they should be extracted or preserved and what the risk of infection will be to the fracture.

Fear of infection was the main reason to extract a tooth in the fracture line. This fear has to a large extent been inherited from the past, especially in the pre-antibiotic era. In those days, it was more or less mandatory to remove a tooth from the fracture line. Otherwise it was presumed that the communication from the oral cavity through a disrupted periodontal membrane into the fracture line would create an infection resulting in delayed healing, non-union, or even osteomyelitis. Other sources of infection from a tooth in the fracture line might include the devitalized tooth, which could be secondarily infected, and then infect the fracture. Today, with rigid fracture stabilization and antibiotics available, many teeth in fracture lines are preserved and not extracted during primary fracture care.

Although many scientific studies have offered information on the issue, the controversy persists. In one study, Ellis studied 402 patients with fractures in the mandibular angle. Teeth were removed in 75% of the fractures that contained teeth. Postoperative complications occurred in 19% of the sample, versus 19.5% when the tooth was retained. Fractures not containing teeth had postoperative infection rate of 15.8% compared to 19.1% for those which had teeth in the fracture. The differences, however, were not significant. Similar findings have been demonstrated by others.

Thus, we find ourselves without strong scientific evidence to support either side of the controversy. Other factors must also be considered. The patient's general oral hygiene and cooperation always influence the decision. The site of the fracture may be important. The mandibular angle is more prone to fracture infection than other locations in the mandible. An impacted third molar with little prospect of normal eruption should be removed at the time of open fracture treatment if it would not make the fracture treatment more complex. In any area, needless to say, the presence of periapical, periradicular, or pericoronal infection around a tooth in the fracture is an indication for removal. The same goes for badly fractured teeth, or teeth dislocated from their sockets. On the other hand, a healthy tooth, surrounded by healthy periodontal membrane and good gingival conditions, should be retained.

Sometimes, but not always, a tooth in the line of fracture may make the fracture reduction easier. If such a tooth needs to be removed, it may still be advisable to delay extraction until the fracture has been stabilized by internal fixation. Surgical removal of an impacted tooth may lead to a reduced bone buttress, and as a consequence may make a stronger and more rigid internal fixation necessary or may reduce the remaining bone's potential for healing.

Finally, the prognosis for teeth left in the line of mandibular fractures needs to be discussed. Kahnberg and Ridell studied 185 teeth in the line of mandibular fractures. Clinical and radiological findings revealed complete recovery in 59% of those teeth. Obviously 41% did not do so well. Therefore, if teeth are left in mandibular fracture lines, they should be followed both clinically and radiologically, with emphasis on both marginal and periapical conditions.

All in all, the management of teeth in mandibular fracture lines should continue to be an individual clinical judgement, taking case by case and considering all aspects of the injury.

Authors Gerson Mast, Michael Ehrenfeld, Joachim Prein

1.5.9 Implant removal and stress protection

Along with the development and first clinical use of modern internal fixation materials, which started with metallic implants first made of stainless steel and cobalt-chromium-molybdenium (vitallium), later of titanium, questions about the necessity for implant removals were raised. These questions are closely related to the biologic behavior of those materials in the human body, namely corrosion resistance, behavior in presence of infection, and the potential to create other adverse phenomena such as allergies. In addition, questions about the long-term performance of relatively stiff implants were discussed, because obviously there is no need for an implant to be in place after a fracture has healed. Above that, an implant may have long-term adverse effects on bone stability, because the presence of the implant may prevent the bone from returning to maximum strength under a given physiological situation. A considerable amount of scientific and clinical research was invested over the years with the result that all materials mentioned above interfere with the biologic environment to some extent. However, the interpretation of those results and their clinical relevance is still controversially discussed. In addition, implant removal always means an additional surgical intervention with associated risks resulting from surgery and/or anaesthesia, and with additional costs. The intention of scientists was to find a biocompatible material without the need for removal, ideally a biodegradable implant that would completely disappear after a fracture has healed.

Early experiences with corrosion of internal fixation devices made from stainless steel and reports about allergic reactions have driven the practice of implant removal. The development and worldwide distribution of pure titanium implants for craniomaxillofacial applications, which have shown biocompatibility without evidence of any adverse side reactions, and which are widely used as permanent implants for dental rehabilitation, has overcome the necessity for implant removal as a principle technique. Therefore, every decision for the removal of a nonresorbable implant should have a clear individual indication depending on the material and also on the clinical situation.

1 Removal before completion of fracture healing

Indications to remove and replace implants during fracture healing are mainly problems caused by fractured plates, malpositioned plates, or loose hardware (like loose screws) with or without consecutive infection. Infection alone with osteosynthesis material adequately in place is not an indication for implant removal. Fracture healing in an infected area is possible, but only if there is no interfragmentary motion and adequate stability, usually under the condition of load-bearing fixation.

2 Removal after fracture healing

Absolute indications to remove metallic implants after a fracture has healed are mostly related to fractured or loose plates and screws, problems with infection, and/or penetration of the hardware through the soft-tissue envelope.

Relative indications for implant removal are potential interferences of implants with additional surgical interventions, such as sinus operations following midface fractures, bone augmentation procedures, or dental rehabilitation, for instance placement of dental implants.

In children, removal of metallic implants is still recommended. Expanding and growing bones have a tendency to overgrow metallic implants, which leads to a relative change in position of an implant, which finally may be incorporated into the bone or even appear on the opposite side. This phenomenon has falsely been called "plate migration," which is a misnomer because there is no active movement (migration) of the implant, but a passive translation. Nevertheless, in craniofacial surgery this translation may lead to an intracranial displacement of metallic fixation devices. Some surgeons believe that leaving implants in the midface and the mandible may have a negative impact on further growth, even if there are controversial reports about growth problems following trauma care in children.

Additional relative indications arise from individual patient's concerns, such as palpable plates, visible plates through layers of overlaying skin, sensitivity to the cold, or uncharacteristic and unspecified disturbances.

However, the vast majority of nonresorbable pure titanium fixation devices do not cause any problems during or after fracture healing. Therefore, there is usually no objective indication for their removal.

3 Stress protection

Plates for internal fixation reduce the load in the fracture site to prevent interfragmentary motion and support fracture healing. The terms "stress protection" or "stress shielding" were first used in long-bone healing to describe unfavorable structural changes in the form of porosis under the respective plates in the fractured areas after healing. This effect was believed to be the result of the stress (load) reduction caused by the plates. Meanwhile it became evident that cortical porosis in long bones was mainly the result of impaired periosteal blood supply due to pressure of the plates against the bone surface. Low contact plate profiles helped to overcome this problem. In the craniomaxillofacial area the overwhelming majority of data published show that there is no good evidence for a negative effect of so-called stress protection neither in the mandible nor in the midface. Experimental findings, supported by clinical observations, show that there are no signs for osteoporosis or bone atrophy in patients with nonresorbable implants of any available size in place. Prevention of "stress protection" today is not a valid argument for implant removal.

4 Implants and secondary trauma

The structure and biomechanical properties of the facial skeleton help to protect the functional units, like eye balls and brain, in case of injury. Internally placed fixation devices, which are left in place after bone healing, can change the biomechanical behavior of the part of the facial skeleton where they are located. It is being discussed, if this change of biomechanical behavior can lead to atypical and perhaps more complex fracture patterns in the case of secondary trauma, which may present higher risks for injuries of functional units. However, a secondary trauma with secondary fractures in an identical area is very rare and there are no relevant data available up to now to support the thesis that more complex fracture patterns may be observed in these cases.

5 Adverse side effects from titanium implants

The majority of approved metallic implants for trauma and reconstruction today are made of pure titanium. The human body is saturated with titanium, no additional soluable titanium can thus become active. Titanium implants, as used in the craniomaxillofacial area, are fully biocompatible and no adverse health effects are known up to now.

6 Effects on medical imaging and radiotherapy

X-rays and computed tomography (CT)

The attenuation and backscatter of diagnostic medical x-rays is a function of the energy of the x-ray, thickness and density of the object, and atomic numbers of constituents. Stainless steel and cobalt-chrome-molybdenium alloys, which have densities twice that of titanium, decrease x-ray penetration by three orders of magnitude more than titanium, and four orders of magnitude more than calcium. Thus, compared to stainless steel, the degree of artifact creation with titanium implants is not relevant in almost all clinical situations.

Magnetic resonance imaging (MRI)

MRI is based on the response of substances to static and dynamic magnetic fields of significant magnitudes. Basic concerns arising with metallic objects in a magnetic field are the introduction of artifacts in the diagnostic image, movements of the implant within the magnetic field, or production of heat or electrical current at the implant site. Ferromagnetic materials are of greatest concern. Different from stainless steel, the capacity of ferromagnetism of titanium is very low. Therefore it causes only minimal imaging artifacts or backscatter.

Radiation therapy

Due to the backscatter phenomena the distribution of radiation around plates and screws is of concern, when postoperative radiation is required. Compared to diagnostic x-rays, external beam radiation therapy has much greater penetration and different absorption characteristics. Reports showed elevated doses by 10–15% with titanium at the plate-tissue interface, and 15–25% with stainless steel due to backscatter effects. Recent studies did not find a significant increase of radiation doses in the vicinity of titanium implants. As a consequence a routine plate removal is not recommended prior to postoperative radiotherapy.

Increased associated risks with late implant removal at a higher age

An argument to promote early implant removal after fracture healing or reconstruction is the fact that late implant removal may become necessary after many years because of secondary changes, for instance plate exposure following alveolar crest atrophy. After an interval of many years the patient's general condition may have changed for the worse, thus creating an unnecessary risk scenario that would not have been present in early implant removal. However, indications for late implant removal are very rare, and there is no statistical evidence that an overall increased risk for complications in those cases presents a clinical problem which is statistically more significant than potential problems associated with routine early implant removal.

7 Summary

In summary, besides the above mentioned absolute indications no general recommendation for removal of metallic osteosynthesis material can be given. It must be noted that it is first of all the patient's decision, whether he or she wants to have the implants removed or not.

Author Gerson Mast

1.5.10 Techniques of mandibulomaxillary fixation (MMF)

Correct and precise intraoperative mandibulomaxillary fixation (MMF), often also called intermaxillary fixation (IMF), is a key for the successful establishment or preservation of the occlusal relationship of the upper and lower jaws in facial trauma, reconstructive and orthognathic surgery.

Historically, mandibulomaxillary immobilization has been documented for more than 2,000 years and a variety of different techniques and devices have been developed over time in close relation to the evolution of trauma care and material research. Especially during the last century, a multitude of new methods and refinements were established.

The discussion about the need for MMF in combination with open reduction and internal fixation in simple fracture patterns is controversial, but there is no doubt about its necessity in complex fractures.

In this context it must be noted that internal fixation techniques without or in combination with inadequate devices to fix the occlusion can lead to preventable failures, especially in the hands of inexperienced surgeons.

1 Basic considerations

The suitability of MMF devices depends on several criteria, such as stability, applicability in dentate and edentulous patients, children, and adults, short- and long-term immobilization, additional harm to the patient (pain, teeth, gingiva), risk for the surgeon (such as injuries), time of installation, costs, and others.

Main indications in trauma are:

- Temporary fragment stabilization in emergency cases before definitive treatment
- Intraoperative fixation in combination with internal fixation
- Use as tension band
- Long-term fixation in nonsurgical management
- Fixation of avulsed teeth and alveolar crest fragments.

MMF is also used for maintenance of the occlusion in mandibular reconstruction and for control of the interalveolar distance while reconstructing alveolar crests or the maxilla. In orthognathic surgery MMF is needed intraoperatively to secure the new jaw relationship before and during internal fixation. Postoperatively, the fixation device can be used to fix guiding elastics for functional training or in complications, eg, bad splits, as a support for an uneventful bone healing.

2 Mandibulomaxillary fixation options

A multitude of immobilization devices have been described. The majority is tooth-borne, such as wire ligatures, arch bars, cap splints, adhesive cast splints, brackets, and self-fixing plastic circumdental lugs/loops.

Others are fixed to the bone, such as dentures and splints, plates, pins, and screws.

According to the medical schools of different countries there are preferences for one or the other technique, mostly depending on tradition and not on science.

3 Tooth-borne devices

3.1 Wire fixation

Many different techniques for wire fixation exist. Ivy loops, Ernst ligatures, Stout intermaxillary loop wiring, and Obwegeser multiple loop wiring are only a few of the most popular.

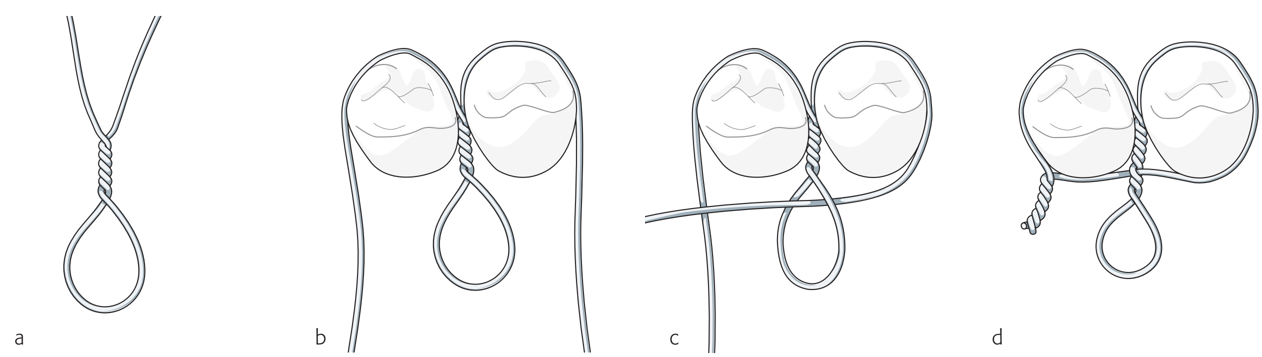
Wire fixation techniques for MMF have a somewhat reduced stability. Favorable features are the fast and simple procedures and the almost unrestricted, cost-effective availability. Unfavorable characteristics are the lack of stability, no adequate tension banding in combination with internal fixation, trauma to the gingiva, and the risk for extrusion of teeth. Therefore, wire fixation is mainly indicated in emergency cases for short-term immobilization in a full or partial dentition prior to surgery, and in selected cases with simple fracture patterns for intraoperative fixation. Several important aspects must be mentioned before starting:

- In the case of severe malocclusion it may be impossible to use wire ligatures.
- Loose teeth should not be included into the ligatures.
- The ligatures of the upper and lower jaw must be in an opposite, symmetric position for correct immobilization.
- Medical professionals are confronted with the risk of contamination from prick accidents.

Two of the most popular and technically similar techniques, the use of Ivy loops and Ernst ligatures, are briefly described here.

Ivy loops

Positioning and insertion of the ligatures: Bending a wire to halves, a small loop is created in the middle part by twisting it around the shaft of a clamp. The two free wire ends are interdentally placed from the buccal side between two stable teeth. The wire ends are wrapped around each neighboring tooth and fed back through the next dental interspace. The posterior wire is passed through the original loop and then tightened by twisting the anterior and posterior wire ends together. The same procedure is performed for the other dental arch, directly opposite the first Ivy loop. The loops may each be tightened further over the wire to decrease the loop size and length. MMF is finally achieved by passing and tightening a second wire through two opposing Ivy loops or by placing elastic bands over the loops if preferred (**Fig 1.5.10-1a–e**).



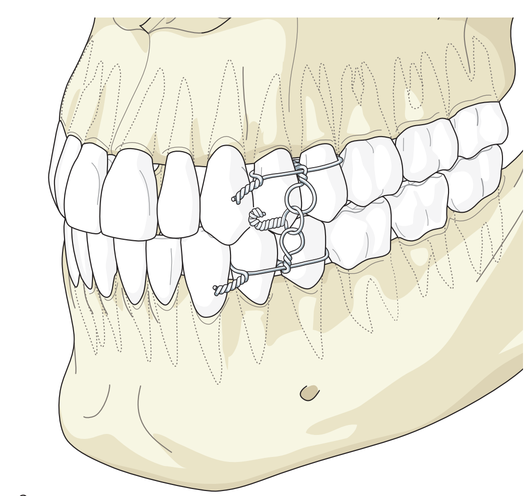


Fig 1.5.10-1a–e Ivy loops.
a A small loop is created with a 0.4 mm wire.
b After passing both free ends through the space between the premolars, the wire ends are then passed around those premolars and fed back through the next dental interspace.
c The distal wire is passed through the original loop.
d The wire ends are then twisted together and the excess is cut off. The same procedure is performed in the opposite dental arch.
e Finally, mandibulomaxillary fixation is achieved by passing a wire through the two opposing Ivy loops, which is then tightened.

Ernst ligatures

Positioning and insertion of the ligatures: An Ernst ligature is applied to two neighboring teeth, preferably the premolars.

One wire end is passed from the buccal side through the interdental space between the canine and premolar. The other end is passed between the second premolar and molar. Both ends are then fed back from the palatal/lingual to the buccal side via the interdental space between the premolars 4 and 5. One wire end must pass below, the other on top of the horizontal portion of the wire on the buccal side. By twisting with the twister, the wire is then tightened.

Ligatures are placed in all four sections of the dental arches in a symmetric position. MMF is achieved by twisting the wire ends of two opposite ligatures together, after assuring proper occlusion (**Fig 1.5.10-2a–b**). Care must be taken not to break the wires at this point as restarting the procedure would be necessary. The wire ends are then cut and bent towards the dental surface to protect the oral mucosa.

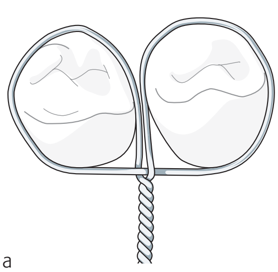
3.2 Arch bars

Arch bars are tooth-borne devices for MMF of dentate patients. They can be used:

- For temporary fragment stabilization in emergency cases before definitive treatment
- As tension band in combination with rigid internal fixation
- As long-term fixation for nonsurgical fracture management
- For fixation of avulsed teeth and alveolar crest fractures

Because of this extensive applicability, arch bars are still considered the gold standard for MMF. Advantages are the stability, the simplicity of the procedure, and the possibility to fix loose teeth. Disadvantages are the painful and time-consuming application, the damage to the gingiva associated with several types of arch bars, and the high potential for prick accidents with risk of inoculation of infected material.

Different types of arch bars are in use. They come as custom-made or commercially manufactured medical tools. Custom-made arch bars allow precise placement of the bar to prevent damage to the surrounding soft tissues, if applied properly. Time for insertion is short. The disadvantage is the need for an experienced dental technician who is not always available, especially in emergency cases.



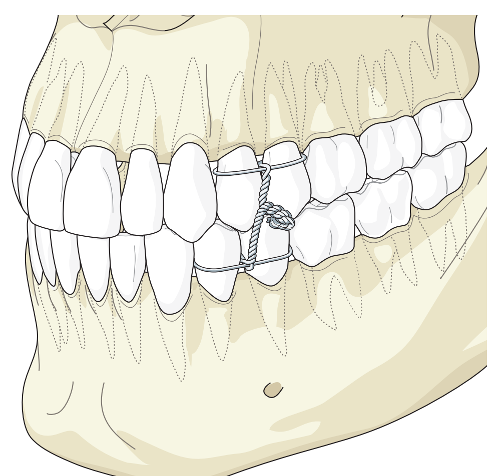


Fig 1.5.10-2a–b Ernst ligature.
a A 0.3 or 0.4 mm wire is placed between and around the premolars. The two ends are twisted together.
b After placement of two opposite ligatures in the premolar area of both jaws, these ligatures are twisted together.

Commercially manufactured arch bars, for example, are Schuchardt, Erich, and Dautreys arch bars. Arch bars are available in aluminum, stainless steel, and nowadays also titanium, as well as various alloys.

Before arch bars are applied the occlusion must be checked. The goal is to achieve full interdigitation of the teeth with regular contacts. In case of severe malocclusion, such as a deep bite deformity, it may be impossible to use bars. To have calculable tension vectors between the placed mandibulomaxillary wire loops or elastics, there should be a symmetrical positioning of the hooks in the upper and lower jaw. This is essential for functional training with elastics. If arch bars are used for long-term immobilization, the teeth should be fluoridated before insertion to prevent demineralization in the contact zone between tooth surface and bar. Two of the most common prefabricated types of arch bars, Schuchardt and Erich, are briefly described.

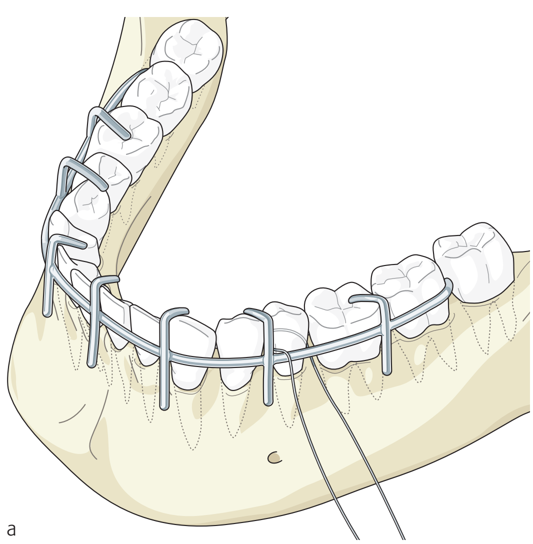
Schuchardt arch bars

The prefabricated arch bars must be adjusted in shape and length to the individual situation. The arch bars should not damage the gingiva. Therefore, Schuchardt arch bars are available with occlusal stops to prevent migration of the bar to the gingiva. In a full dentition the amount of occlusal stops can be reduced to one on each side and one in the front.

Before fixation, the bars are adapted closely to the teeth. If maximum stability is needed, eg, for long-term fixation in multiple fractures, the bar is cut behind the second molar. If reduced stabilty is adequate, eg, for temporary fixation in condylar neck fractures, the bar can be trimmed behind the second premolar. For maximum stability, the bar is fixed to each healthy tooth (**Fig 1.5.10-3a–c**).

Isolated avulsed teeth in combination with jaw fractures can be stabilized. For long-term immobilization, tension banding, or fixation of avulsed teeth, Schuchardt did recommend the use of methamethacrylate. Methamethacrylate is placed in a thin layer on the vestibular surface of bar and wires (**Fig 1.5.10-3d–e**). The objectives are to protect the wires and bars against loosening under function, to keep the wires and bars in the desired position preventing migration onto the gingiva, and to cover all sharp wire ends for protection of the surrounding soft tissues. For short-term MMF, the arch bars are typically used without methamethacrylate.

After removal of the occlusal stops, the occlusion is established and rubber or 0.5 mm wire loops are inserted in a symmetrical fashion. Stable immobilization of the jaws in maximum intercuspidation is achieved (**Fig 1.5.10-3f**).



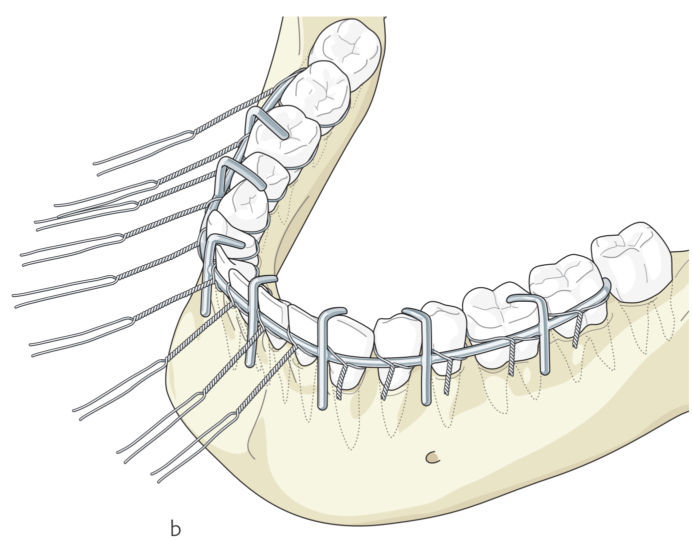


Fig 1.5.10-3a–f Schuchardt arch bars.
a The prefabricated Schuchardt arch bar is adjusted and cut in length to the individual situation. The occlusal stops prevent migration onto the gingiva. A first loop with a 0.3 mm wire is placed around the left second premolar, one end above and the other below the arch bar.
b After passing the wires around each tooth, they are twisted and cut to length.

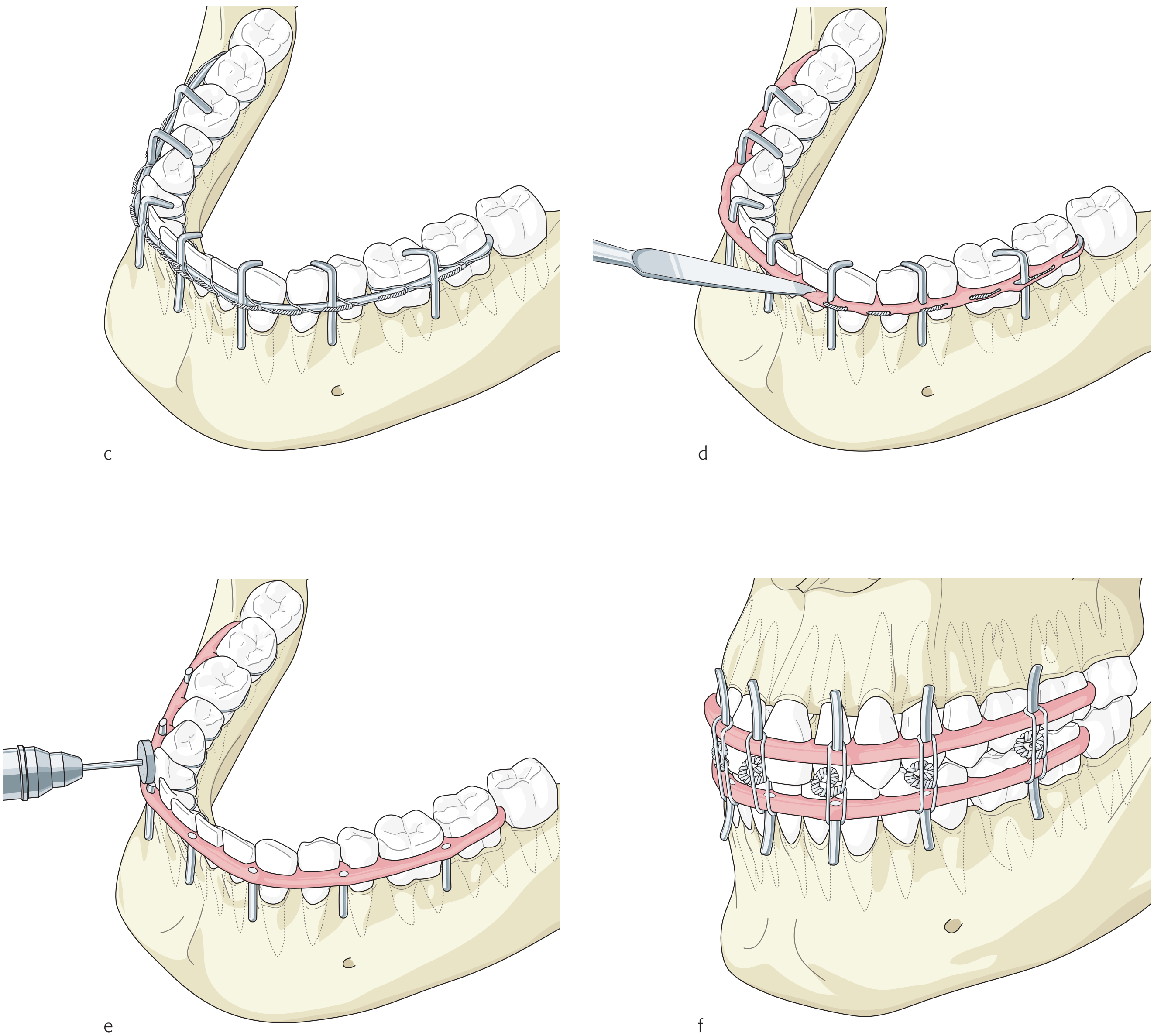


Fig 1.5.10-3a–f (cont) Schuchardt arch bars.
c All wire ends are placed onto the arch bar.
d Methamethacrylate is placed in a thin layer onto the bar and covers the wires.
e After removal of the occlusal stops, the ends are smoothed with a grindstone.
f Intermaxillary fixation is achieved either with a 0.5 mm wire or elastics.

Erich arch bars

Erich arch bars belong to the most popular devices for MMF. Usually made of a relatively soft alloy, they do not have occlusal stops. Fixation to the teeth is similar to the fixation of Schuchardt arch bars (**Fig 1.5.10-4**).

3.3 Brackets

These tooth-borne devices are directly bonded to the tooth surface. Usually used for orthodontic treatment, they can also be applied for MMF. They are commonly used in orthognathic surgery and in selected trauma cases with full permanent dentition and healthy teeth. Advantages are the noninvasive application and the simplicity of the procedure. Disadvantages are the need for access to the technology in emergencies, the problem of keeping the tooth surfaces dry for bonding, the costs, and the risk for extrusion of single teeth when used for long-term fixation.

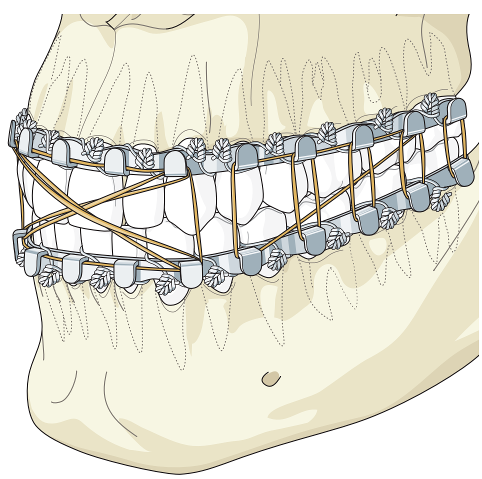


Fig 1.5.10-4 MMF with Erich arch bars. Like Schuchardt arch bars, Erich arch bars are fixed to each healthy tooth with 0.3 mm wire loops. Intermaxillary fixation is achieved with elastics that are placed onto the hooks of the bars.

4 Bone-borne devices

Recently bone-borne devices have gained increasing popularity for mandibulomaxillary immobilization. Besides screw anchored hooks, screw anchored 2 or 3-hole plates ("hanger plates"), and transmucosally fixed conventional osteosynthesis screws as retentions for MMF, today specific kits with specialized IMF screws are commercially available. Most of these screws are self-drilling and self-tapping with screw heads that offer a special geometry to serve as retention for wires or elastics.

The increasing popularity is due to fast insertion, low risk for prick accidents for surgeons, missing traction on teeth, eg, in orthognathic surgery, and ease of removal. The strong commercial promotion focuses on these advantages but it must also be realized that there are considerable optional disadvantages reported like tooth root injuries, damage to the soft tissues (mucosa and nerves), undesired displacement of fragments by outward rotation, screw fractures, and loosening. Postoperative functional training with elastics becomes more difficult because of missing adequate retention points for directional guidance.

Typical indications are short-term intraoperative immobilizations especially for treatment of simple fracture patterns in orthognathic and reconstructive surgery.

The use of plates, pins, and screws is limited in severely comminuted and displaced fractures, in unstable segmented fractures, in fractures of the alveolar process, and in children, if tooth buds are still in place.

Important aspects before applying bone-borne devices are:

- Checking the position of the tooth roots, the infraorbital and mandibular nerve
- Positioning the screws or pins in a symmetrical fashion from jaw to jaw if possible
- Avoiding interference with the surgical approach and internal fixation devices

4.1 IMF screws

Intermaxillary fixation (IMF) screws are made from stainless steal. They are self-drilling and self-tapping. The screw head is elongated and contains two holes in a cruciform orientation for wire placement.

Screw insertion can be performed directly through the mucosa. Care has to be taken that the screw head does not compress the gingiva when fully seated. Various IMF screw placement patterns exist and are dictated by the fracture location. The areas for screw application are limited by the tooth roots and the position of the infraorbital and inferior alveolar nerve. The recommended placement of IMF screws is superior to the maxillary and inferior to the mandibular tooth roots, and either lateral or medial to the long axis of the canine roots.

For MMF 0.4 mm wires are inserted through the IMF screw holes. Wire ligatures can also be wrapped around the screw head grooves. Before tightening the wires, the correct occlusion has to be established. For additional stability, wiring in an X-pattern can be applied. Alternatively, elastics can be inserted (**Fig 1.5.10-5**).

Looking at the results according to the originally recommended technique some problems have been reported. A lack of stability can occur due to the long distance between the IMF screws which is bridged with nonrigid wires.

In addition, tightening of the anterior wires may create a posterior open bite. To overcome this problem additional IMF screws or Ernst ligatures on the posterior dentition may be used. Overtightening of the wires may lead to an outward rotation of a fragment because of the position of the screws and the long lever arm. Further problems are the burying of screw heads in the soft tissues, especially in the anterior mandibular vestibulum, and interference of the wire loops with the upper incisor edges or canine facets.

With research and experience in the field of screw placement close to and between teeth mainly coming from miniscrew application in orthognathics, new screw types have been developed which can also be used for MMF techniques.

4.2 Plates

In dentate patients so-called "hanger plates" can be used for short-term MMF. For this, 2 or 3-hole pieces are cut from a 2.0 adaptation plate. These pieces are bent in a slightly angular shape or as little hooks. After using a 1.5 mm drill the 2-hole plates are monocortically fixed with 2.0 mm screws of 6 mm length in the planned position. After establishing the occlusion, MMF is performed with wires or elastics running through the plate holes or around the hooks (**Fig 1.5.10-6**). Compared to IMF screws there is less risk of damage to the tooth roots and nerves, especially in the lateral aspect of the mandible.

In edentulous patients plates can be used as "interarch plates" to fix and save the vertical dimension between the jaws (**Fig 1.5.10-7**).

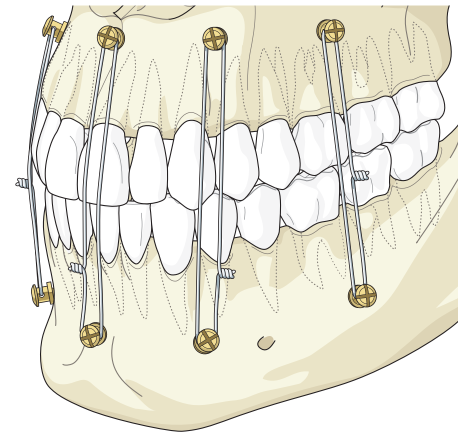


Fig 1.5.10-5 MMF with special IMF screws placed opposite of each other in both jaws. 0.4 mm wires are inserted through the IMF screws holes.

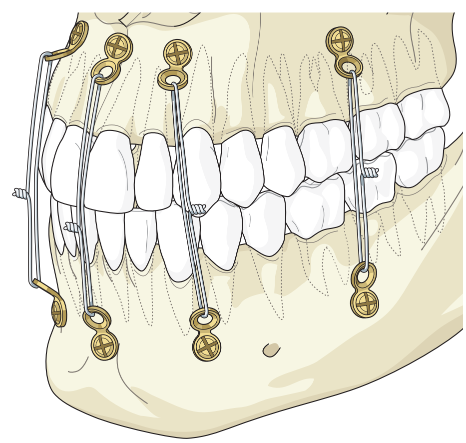


Fig 1.5.10-6 MMF with 2-hole 2.0 adaptation plates.

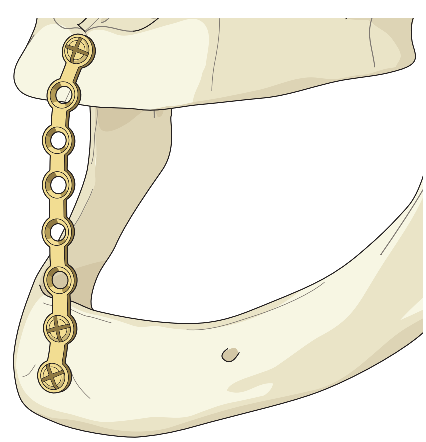


Fig 1.5.10-7 MMF in an edentulous patient, with an adaptation plate fixing the vertical dimension between the jaws.

4.3 Spino-mental fixation

This bone-borne technique is a simple method of MMF in dentate or denture wearing patients especially with subcondylar fractures. Under local anesthesia S-shaped steel wire hooks are placed below the nasal spine and slightly above the mental protuberance in the symphyseal region and fixed with miniscrews. MMF is achieved using wire ligatures or elastics. Similar to the problems related to IMF screws the burying of the hooks in the anterior mandibular vestibulum and the interference of the wire loops with the upper incisor edges can occur (**Fig 1.5.10-8**).

5 Dentures or Gunning-type splints

MMF in edentulous or partially edentulous patients can be achieved with the help of dentures. If those are not available acrylic splints may be fabricated.

General aspects such as age and condition of the patient must be considered. Especially in elderly patients the immobilization period, which is often painful, should be restricted to a minimum and long-term use should be avoided whenever possible.

For MMF retention elements can be applied to the dentures or splints. This can be achieved by fixing arch bars, metal hooks, or screws on the dentures or splints. Alternatively, bone-borne IMF screws can also be used for MMF in cases with sufficient bone stock.

Nutrition must be assured by reducing the retromolar acrylic part of the dental prosthesis or by creating a "feeding hole" in the incisor region of the prosthesis or splint. The correct mandibulomaxillary relationship must be established either by an appropriate occlusal intercuspidation of the dentures or by positioning stops on the occlusal surfaces of the Gunning-type splints.

The dentures or splints can be fixed with suspension wires to the bone, such as transalveolar, zygomaticomaxillary, or circumferential mandibular wiring, or, more easily, with screws. The maxillary prosthesis or splint should be fixed in the compact anterior part of the hard palate. The lower denture can easily be fixed in the symphyseal area because of the dense bone in this region. One or two screws are usually sufficient (**Fig 1.5.10-9**).

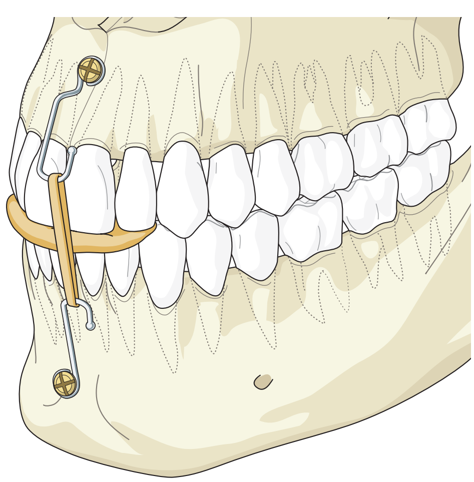


Fig 1.5.10-8 MMF with S-shaped steel wire hooks. A partial acrylic splinting is used to separate the elastics from the front teeth.

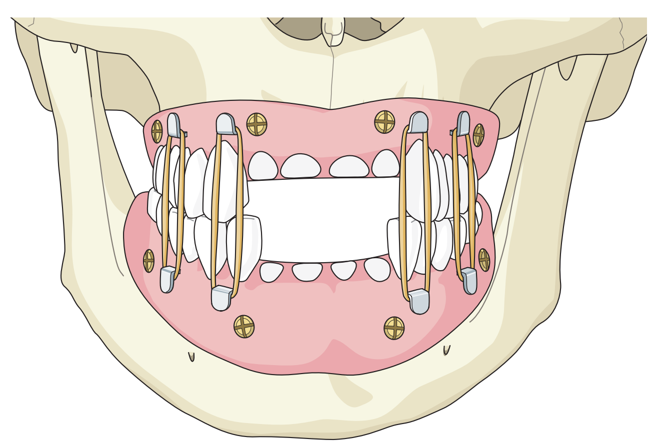


Fig 1.5.10-9 MMF with Gunning splints. The patient's dentures are fixed with screws to the jaws, the incisors are removed to create a feeding hole.

6 Important aspects of prolonged or long-term MMF

If long-term MMF is planned, several important aspects should be respected. The patient must be provided with a wire cutter or scissors to cut elastics or wires in cases of emergency, to prevent airway problems following emesis, fainting, or epileptic attack, and he/she or escort should be instructed in its use to allow for urgent removal if necessary.

Good oral hygiene is mandatory during immobilization periods. For this goal a water pick device is helpful. The use of fluoride gels prevents demineralization and reduces the risk for caries.

During the immobilization period body weight should be controlled. Nutrition counselling and the use of soft diets should be part of the treatment.

At least weekly follow-up appointments are recommended to check the stability of the occlusal relationship. Fatigue of wires, bruxism, or the removal of the wires or elastics by the patient may reduce stability and can lead to preventable complications, eg, malocclusion, nonunion, and infection.

7 Summary

Mandibulomaxillary fixation (MMF) can be achieved with many different devices depending on the local and general conditions of the patient, the medical needs in trauma, orthognathic and ablative or reconstructive surgery, the availability of technologies and technical support. All methods show advantages and drawbacks.

In dentate or partially dentate patients, arch bars are still the gold standard to establish the occlusion. They have proven their usefulness in short- and long-term immobilization. Any surgeon dealing with craniofacial surgery should be able to use them properly. Devices with reduced long-term stability should not be used for long-term immobilization.

In emergency and selected cases wire ligatures, plates, screws, and pins can be an alternative to arch bars. The growing interest in bone-borne fixation devices actually leads to increased activities to create better devices.

In edentulous patients dentures or splints are helpful tools for MMF, though long-term use should be avoided. In selected cases interarch plating can be an alternative.

1.6 References and suggested reading

Chapter 1.1.5

Bhandari M, Zlowodzki M, Cole PA (2004) From eminence-based practice to evidence-based practice: a paradigm shift. *Minnesota Med;* 87(4):51–54.

Fletcher R, Fletcher S (2004) *Clinical Epidemiology: the Essentials.* Fourth edition. Baltimore: Lippincott Williams & Wilkins, 10–11.

Hanson B (2006) Designing, conducting, and reporting clinical research: a step by step approach. *Injury;* 37(7):583–594.

Suk M, Norvell D, Hanson B, et al (2008) Evidence based orthopaedic surgery: what is evidence without the outcomes? *J Am Acad Orthop Surg;* 16(3):123–129.

Chapter 1.1.6

Audigé L, Bhandari M, Hanson B, et al (2005) A concept for the validation of fracture classifications. *J Orthop Trauma;* 19(6):401–406.

Audigé L, Bhandari M, Kellam J (2004) How reliable are reliability studies of fracture classifications? A systematic review of their methodologies. *Acta Orthop Scand;* 75(2):184–194.

Bächli H, Leiggener C, Gawelin P, et al (2009) Skull base and maxillofacial fractures: two centre study with correlation of clinical findings with a comprehensive craniofacial classification system. *J Craniomaxillofac Surg;* 37(6):305–311.

Bagheri SC, Dierks EJ, Kademani D, et al (2006) Application of a facial injury severity scale in craniomaxillofacial trauma. *J Oral Maxillofac Surg;* 64(3):408–414.

Buitrago-Téllez CH, Audigé L, Strong B, et al (2008) A comprehensive classification of mandibular fractures: a preliminary agreement validation study. *Int J Oral Maxillofac Surg;* 37:1080–1088.

Buitrago-Téllez CH, Schilli W, Bohnert M, et al (2002) A comprehensive classification of craniofacial fractures: postmortem and clinical studies with two- and three-dimensional computed tomography. *Injury;* 33(8):651–668.

Carinci F, Zollino I, Brunelli G, et al (2006) Orbital fractures: a new classification and staging of 190 patients. *J Craniofac Surg;* 17(6):1040–1044.

Chen CH, Wang TY, Tsay PK, et al (2008) A 162-case review of palatal fracture: management strategy from a 10-year experience. *Plast Reconstr Surg;* 121:2065–2073.

Clark N, Birely B, Manson PN, et al (1996) High-energy ballistic and avulsive facial injuries: classification, patterns, and an algorithm for primary reconstruction. *Plastic Reconstr Surg;* 98(4) Suppl 1:583–601.

Cooter RD, David DJ (1989) Computer-based coding of fractures in the craniofacial region. *Br J Plast Surg;* 42(1):17–26.

David DJ (1999) Facial fracture classification: current thoughts and applications. *J Craniomaxillofac Trauma;* 5(4):31–36;discussion 37–38.

Donat TL, Endress C, Mathog RH (1998) Facial Fracture classification according to skeletal support mechanisms. *Arch Otolaryngol Head Neck Surg;* 124(10):1306–1314.

Guérin A (1866) [Fractures of the upper maxilla.] *Arch Gén Méd;* 6 ,Série 8. French.

Hammer B (1995) *Orbital fractures. Diagnosis, operative treatment,secondary corrections.* Seattle Toronto Bern: Hofgrefe & Huber.

Jackson IT (1989) Classification and treatment of orbitozygomatic and orbitoethmoid fractures. The place of bone grafting and plate fixation. *Clin Plast Surg;* 16(1):77–91.

Jaquiéry C, Aeppli P, Cornelius CP, et al (2007) Reconstruction of orbital wall defects: critical review of 72 patients. *Int J Oral Maxillofac Surg;* 36(3):193–199.

Joos U, Meyer U, Tkotz T, et al (1999) Use of a mandibular fracture score to predict the development of complications. *J Oral Maxillofac Surg;* 57(1):2–5. Discussion 5–7.

Le Fort R (1901) [Experimental study of fractures of the upper jaw. Part I, Part II, Part III.] *Rev Chir (Paris) 23, 208–227, 360–379, 479–507.* French.

Loukota RA, Eckelt U, De Bont L, et al (2005) Subclassification of fractures of the condylar process of the mandible. *Br J Oral Maxillofac Surg;* 43:72–3.

Loukota RA, Neff A, Rasse M (2010) Nomenclature/classification of fractures of the mandibular head. *Br J Oral Maxillofac Surg;* 48(6):477–478.

Madhusudan G, Sharma RK, Khandelwal N, et al (2006) Nomenclature of frontobasal trauma: a new clinicoradiographic classification. *Plast Reconstr Surg;* 117(7):2382–2388.

Markowitz BL, Manson PN, Sargent L, et al (1991) Management of the medial canthal tendon in nasoethmoid orbital fractures: the importance of the central fragment in classification and treatment. *Plast Reconstr Surg;* 87(5):843–853.

Marsh JL, Slongo TF, Agel J, et al (2007) Fracture and dislocation classification compendium–2007: Orthopaedic Trauma Association classification, database and outcomes committee *J Orthop Trauma;* 21 Suppl 10:1–133.

Müller ME, Nazarin S, Koch P, et al (1990) *The comprehensive classification of fractures of long bones.* Berlin Heidelberg New York: Springer-Verlag.

Nolasco FP, Mathog RH (1995) Medial orbital wall fractures: classification and clinical profile. *Otolaryngol Head Neck Surg;* 112(4):549–556.

Rafferty MA, Mc Conn Walsh R, Walsh MA (2006) A comparison of temporal bone fracture classification systems. *Clin Otolaryngol;* 31(4):287–291.

Roth FS, Kokoska MS, Awwad EE, et al (2005) The identification of mandible fractures by helical computed tomography and panorex tomography. *J Craniofac.Surg;* 16(3):394–399.

Spiessl B (1989) Internal Fixation of the mandible. *A manual of AO/ASIF Principles. Heidelberg New York: Springer-Verlag.*

Spiessl B, Schroll K (1972) [Fractures of the condylar process and condylar head]. *Nigst H (ed), Spezielle Frakturen- und Luxationslehre, Band I/1: Gesichtsschädel.* Stuttgart New York: Georg Thieme Verlag, 136–152. German.

Tessier P (1972) The classic reprint: experimental study of fractures of the upper jaw. I and II. *Rene Le Fort, M.D., Lille, France. Plast Reconstr Surg ;* 50(5):497–506.

Tessier P (1972) The classic reprint: experimental study of fractures of the upper jaw. III. *René Le Fort, M.D., Lille, France. Plast Reconstr Surg;* 50(5):600–605.

Wassmund M (1927) [Fractures and luxations of the facial skull]. Berlin: Meusser Verlag. German.

Zhang J, Zhang Y, El-Maaytah M, et al (2006) Maxillofacial Injury Severity Score: proposal of a new scoring system. *Int J Oral Maxillofac Surg;* 35(2):109–114.

Zingg M, Laedrach K, Chen J, et al (1992) Classification and treatment of zygomatic fractures: a review of 1025 cases. *J Oral Maxillofac Surg;* 50:778–790.

Chapter 1.2

Abé H, Hayashi K, Sato M (1996) Data Book on Mechanical Properties of Living Cells, Tissues, and Organs. *Tokyo: Springer Verlag.*

Ascenzi A, Bonucci E (1967) The tensile properties of single osteons. *Anat Rec;* 158(4):375–386.

Aubin JE (1998) Advances in the osteoblast lineage. *Biochem Cell Biol;* 76(6):899–910.

Belanger LF (1969) Osteocytic osteolysis. *Calcif Tissue Res;* 4(1):1–12.

Biltz RM, Pellegrino ED (1969) The chemical anatomy of bone. I. A comparative study of bone composition in sixteen vertebrates. *J Bone Joint Surg Am;* 51(3):456–466.

Kasperk C, Wergedal J, Strong D, et al (1995) Human bone cell phenotypes differ depending on their skeletal site of origin. *J Clin Endocrinol Metab;* 80(8):2511–2517.
Udagawa N, Takahashi N, Akatsu T, et al (1990) Origin of osteoclasts: mature monocytes and macrophages are capable of differentiating into osteoclasts under a suitable microenvironment prepared by bone marrow-derived stromal cells. *Proc Natl Acad Sci USA;* 87(18):7260–7264.
Yamada H (1970) *Strength of Biological Materials.* Baltimore: Williams & Wilkins.

Chapter 1.3.1

Bacon, Francis (1620) The new organon or true directions concerning the interpretation of nature. *English translation by Spedding J, Ellis R, Heath, D; "The Works."* Vol 8. Boston: Taggard and Tompson, 1863.
Beecher RM (1979) Stress Monkey's Strain Gage In-Vivo. Functional significance of the mandibular symphysis. *J Morphol;* 159(1):117–130.
Carter DR (1987) Mechanical loading history and skeletal biology. *J Biomech;* 20(11–12):1095–1109.
Carter DR, Beaupré GS, Giori NJ, et al (1998) Mechanobiology of skeletal regeneration. *Clin Orthop Relat Res;* 355 Suppl:41–55.
Daegling DJ (1989) Biomechanics of cross-sectional size and shape in the hominoid mandibular corpus. *Am J Phys Anthropol;* 80(1):91–106.
Daegling J, Hylander WL (2000) Experimental observation, theoretical models and biomechanical inference in the study of mandibular form. *Am J Phys Anthropol;* 112(4):541–551.
Daegling DJ, Hylander WL (1998) Biomechanics of torsion in the human mandible. *Am J Phys Anthropol;* 105(1):73–87.
Daegling DJ, Hylander WL (1997) Occlusal forces and mandibular bone strain: Is the primate jaw "overdesigned"? *J Hum Evol;* 33(6):705–717.
De Alba JA, Chaconas SJ, Caputo AA, et al (1982) Stress distribution under high-pull extra-oral chin cup traction. *Angle Orthod;* 52(1):69–78.
Endo B (1970) Analysis of stresses around the orbit due to masseter and temporalis muscles, respectively. *J Anthrop Soc Nippon;* 78:251–266.
Ferre JC, Barbin JY, Helary JL, Lumineau JP (1984) The mandible, an overhanging mechanically suspended structure. Considerations on the system of attachment and servo-command of the mandible. *Anat Clin;* 6(1):3–10.
Ferre JC, Legoux R, Helary JL, et al (1985) Study of the deformations of the isolated mandible under static constraints by simulation of a physicomathematical model. *Anat Clin;* 7(3):183–192.
Galileo Galilei Linceo (1638) Discourses and mathematical demonstrations. *English translation by Henry Crew and Alfonso de Salvio; "Two new sciences."* New York: The Macmillan Company, 1933.
Grant PG (1973) Biomechanical significance of the instantaneous center of rotation: The human temporomandibular joint. *J Biomech;* 6:109–113.
Hart RT, Hennebel VV, Thongpreda N, et al (1992) Modeling the biomechanics of the mandible: A three-dimensional finite element study. *J Biomech;* 25(3):261–286.
Haskell B, Day M, Tetz J (1986) Computer-aided modeling in the assessment of the biomechanical determinants of diverse skeletal patterns. *Am J Orthop;* 89:363–882.
Hylander WL (1984) Stress and strain in the mandibular symphysis of primates: A test of competing hypotheses. *Am J Phys Anthropol;* 64(1):1–46.
Ingber DE. Dike L, Hansen L, et al (1994) Cellular tensegrity: exploring how mechanical changes in the cytoskeleton regulate cell growth, migration, and tissue pattern during morphogenesis. *Int Rev Cytol;* 150:173–224.
Johansson T, Meyer P, Blickhan R (2000) Finite element model for the mechanical analysis of skeletal muscles. *J Theor Biol;* 206(1):131–149.
Koolstra JH, van Eijden TM, Weijs WA, et al (1988) A three-dimensional mathematical model of the human masticatory system predicting maximum possible bite forces. *J Biomech;* 21(7):563–576.
Korioth TW, Romilly DP, Hannam AG (1992) Three-dimensional finite element stress analysis of the dentate human mandible. *Am J Phys Anthropol;* 88(1):69–96.
Lanyon LE, Goodship AE, Pye CJ, et al (1982) Mechanically adaptive bone remodelling. *J Biomech;* 15(3):141–154.
Manson PN, Hoopes JE, Su CT (1980) Structural pillars of the facial skeleton: An approach to the management of Le Fort fractures. *Plast Reconstr Surg;* 66(1):54–62.
Nigg BM, Herzog W (1999) *Biomechanics of the Musculo-skeletal System.* Second edition. Chichester: John Wiley & Sons.
Pauwels F (1980) *Biomechanics of the locomotor apparatus.* Berlin, Heidelberg, New York: Springer Verlag.
Rahn B, Cordey J, Prein J, et al (1975) [Biomechanics of osteosynthesis in the mandible]. *Fortschr Kiefer Gesichtschir;* 19:37–42. German.
Roesler H (1987) The history of some fundamental concepts in bone mechanics. *J Biomech;* 20(11–12:1025–1034.
Rudderman RH, Mullen RL, Phillips JH (2005) The biophysics of mandibular fractures: an evolution toward understanding. *Plast Reconstr Surg;* 121(2):596–607.
Rudderman RH, Mullen RL (1992) Biomechanics of the Facial Skeleton. *Clin Plast Surg;* 19(1):11–30.
Standlee JP, Caputo AA, Ralph JP (1977) Stress trajectories within the mandible under occlusal loads. *J Dent Res;* 56(11):1297–1302.
Van Eijden TM, Brugman P, Weijs WA, et al (1990) Coactivation of jaw muscles: Recruitment order and level as a function of bite force direction and magnitude. *J Biomech;* 23(5):475–485.

Chapter 1.3.2

Allgöwer M (1956) *The Cellular Basis of Wound Repair.* Springfield, Illinois: Charles C Thomas.
Arnett TR, Gibbons DC, Utting JC, et al (2002) Hypoxia is a major stimulator of osteoclast formation and bone resorption. *J Cell Physiol;* 196(1):2–8.
Perren SM, Cordey J, Rahn BA, et al (1988) Early temporary porosis of bone induced by internal fixation implants: a reaction to necrosis, not to stress protection? *Clin Orthop Relat Res;* 232:139–151.
Rhinelander FW (1974) Tibial blood supply in relation to fracture healing. *Clin Orthop Relat Res;* 105:34–81.

Chapter 1.3.3

Ashhurst DE (1986) The Influence of mechanical conditions on the healing of experimental fractures in the rabit. A microscopical study. *Philos Trans R Soc Lond B Biol Sci;* 313:271–302.
Champy M, Lodde JP (1971) [Mandibular synthesis. Placement of the synthesis as a function of mandibular stress]. *Paris: Stomat.* French.
Danis R (1979) [The theory and practice of osteosynthesis.] *Paris: Masson.* French.
Gautier E, Cordey J, Lüthi U, et al (1983) [Bony remodeling after plating: biological or mechanical reasons?]. *Helv Chir Acta; 50:53–58.* German.
Gunst MA, Suter C, Rahn BA (1979) [Bone perfusion after plate osteosynthesis.] *Helv Chir Acta;* 46:171–175. German.
Hayes WC (1980) Basic biomechanics of compression plate fixation. *Uhthoff HK, Stahl E (eds) Current concepts of internal fixation of fractures.* Berlin Heidelberg New York: Springer, 49–62.
Matter P, Brennwald J, Perren SM (1974) [Biological reaction of bones to osteosynthesis plates]. *Helv Chir Acta;* Suppl 12:1. German.
Perren SM (1979) Physical and biological aspects of fracture healing with special reference to internal fixation. *Clin Orthop Relat Res;* (138):175–196.
Perren SM, Boitzy A (1978) Cellular differentiation and bone biomechanics during the consolidation of a fracture. *Anatom Clin;* 1:13.

Rahn BA (2002) Bone healing: histological and physiological concepts. *Summer-Smith G (ed), Bone in Clinical Orthopedics.* Stuttgart, New York: Georg Thieme Verlag.
Rahn BA (1987) Direct and indirect bone healing after operative fracture treatment. *Otolaryngol Clin North Am;* 20(3):425–440.
Rahn BA, Cordey J, Prein J, et al (1975) [Questions around biomechanics of osteosynthesis of the mandible]. *Fortschr Kiefer Gesichtschir;* 19:37–42. German.
Rahn BA, Galinaro P, Baltensperger A, et al (1971) Primary bone healing. An experimental study in the rabbit. *J Bone Joint Surg Am;* 53(4):783–786.
Rahn BA, Matter P, Mikuschka-Galgoczy, et al (1978) Relationship between radiological density, hardness, holding power of screws, and microscopic structure in human cortical bone. *Asmussen F, Joergensen K (eds), Biomechanics.* Baltimore: University Park Press.
Schenk R (1987) Cytodynamics and histodynamics of primary bone repair. *Lane JM (ed), Fracture healing.* New York: Churchill Livingstone.
Schenk RK (1992) Biology of fracture repair. *Browner BD, Jupiter JB, Levine AM, Trafton PG (eds), Skeletal trauma.* Philadelphia: Saunders, 31–75.
Schenk RK, Willenegger H (1963) [On the histological picture of socalled primary healing of pressure osteosynthesis in experimental osteotomies in the dog.] *Experientia;* 19:593–595. German.
Spiessl B (1989) *Internal fixation of the mandible: A manual of AO/ASIF principles*. Berlin, Heidelberg, New York: Springer Verlag.
Weber BG, Cech O (1973) [Pseudoarthrosis: Pathology, Biomechanics, Therapy, Results.] *Bern: Hans Huber Verlag.* German.

Chapter 1.4.1

Davies JE (1998) Mechanisms of endosseous integration. *Int J Prosthodontics;* 11(5):391–400.
Disegi JA (2000) Titanium alloys for fracture fixation implants. *Injury;* 31:S-D14–17.
Eisenbarth E, Velten D, Schenk-Meuser K, et al (2002). Interactions between cells and titanium surfaces. *Biomol Eng;* 19(2–6):243–249.
Hayes JS, Kahn IM, Archer CW, Richards RG (2010) The role of surface microtopography in the modulation of osteoblast differentiation. *Eur Cell Mater;* 20: 98–108.
Hayes JS, Richards RG (2010) The use of titanium and stainless steel in fracture fixation. *Expert Rev Med Devices;* 7(6):843–853. Review.
Hayes JS, Richards RG (2010) Surfaces to control tissue adhesion for osteosynthesis with metal implants: in vitro and in vivo studies to bring solutions to the patient. *Expert Rev Med Devices;* 7(1):131–142. Review.
Hayes JS, Seidenglanz U, Richards RG, et al (2010) Surface Polishing Positively Influences Ease of Plate and Screw Removal. *Eur Cell Mater;* 19:117–126.
Hayes JS, Vos DI, Richards RG, et al (2009) An in vivo evaluation of surface polishing of TAN intramedullary nails for ease of removal. *Eur Cell Mater;* 18:15–26.
Hierholzer S, Hierholzer G (1992) *Internal Fixation and Metal Alergy: Clinical Investigations, Immunology and Histology of the Implant Tissue Interface.* New York: Thieme Medical Publishers.
Moriarty TF, Campoccia D, Richards RG, et al (2010a) In vivo evaluation of the effect of intramedullary nail microtopography on the development of local infection in rabbits. *Int J Artif Organs;* 33:667–675.
Moriarty TF, Schlegel U, Richards RG, et al (2010b) Infection in Fracture Fixation: Can we influence infection rates through implant design? *J Mater Sci Mater Med;* 21(3):1031–1035.
Moriarty TF, Debefve L, Richards RG, et al (2009) Influence of material and microtopography on the development of local infection in vivo: Experimental investigation in rabbits. *Int J Artif Organs;* 32(9):663–670.
Pearce AI, Pearce SG, Schwieger K, et al (2008) Effect of surface topography on removal of cortical bone screws in a novel sheep model. *J Orthop Res;* 26(10):1377–1383.
Perren SM, Pohler O, Schneider E (2001) Titanium as an implant material for osteosynthesis applications. *Brunette DM, Tengvall P, Textor M, et al (eds), Titanium in Medicine.* Berlin: Springer-Verlag, 771–823.
Pohler OEM (2000) Unalloyed titanium for implants in bone surgery. *Injury;* 31:7–13.
Rogers SD, Howie DW, Graves SE, et al (1997) In vitro human monocyte response to wear particles of titanium alloy containing vanadium or niobium. *J Bone Joint Surg Br;* 79(2):311–315.
Steinemann SG (1997) Metal for craniomaxillofacial internal fixation implants and its physiological implications. *Greenberg AL, Prein J(eds), Principles of internal fixation using theAO/ASIF Technique.* Berlin New York Berlin Heidelberg: Springer-Verlag, 107–112.
Vinall, RL, Gasser, B, Richards, RG (1995) Investigation of cell compatibility of titanium test surfaces to fibroblasts. *Injury;* 26(Suppl 1): 21–27.

Chapter 1.4.2

Ashammakhi N, Gonzales A, Tormala P, et al (2004) New resorbable bone fixation: biomaterials in craniomaxillofacial surgery: present and future. *Eur J Plastic Surg;* 26:383–390.
Bergsma JE, de Bruijn WC, Rozema FR, et al (1995) Late degradation tissue response to poly(L-lactide) bone plates and screws. *Biomaterials;* 16(1):25–31.
Bessho K, Iizuka T, Murakami K (1997) A bioabsorbable poly-L-lactide miniplate and screw system for osteosynthesis in oral and maxillofacial surgery. *J Oral Maxillofac Surg;* 55(9):941–945.
Böstman O, Hirvensalo E, Vainionpää S, et al (1989) Ankle fractures treated using biodegradable internal fixation. *Clin Orthop Relat Res;* (238):195–203.
Böstman O, Hirvensalo E, Vainionpää S, et al (1990) Degradable polyglycolide rods for the internal fixation of displaced bimalleolar fractures. *Int Orthop;* 14(1):1–8.
Böstman O, Vainionpää S, Hirvensalo E, et al (1987) Biodegradable internal fixation for malleolar fractures: a prospective randomised trial. *J Bone Joint Surg Br;* 69(4):615–619.
Bos RR, Boering G, Rozema FR, et al (1987) Resorbable poly(L-lactide) plates and screws for the fixation of zygomatic fractures. *J Oral Maxillofac Surg;* 45(9):751–753.
Bos RR (2005) Treatment of pediatric facial fractures: the case for metallic fixation. *J Oral Maxillofac Surg;* 63(3):382–384.
Buijs GJ, Stegenga B, Bos RR (2006) Efficacy and safety of biodegradable osteofixation devices in oral and maxillofacial surgery: a systematic review. *J Dent Res;* 85(11):980–989.
Buijs GJ, van der Houwen EB, Stegenga B, et al (2009) Mechanical strength and stiffness of the biodegradable SonicWeld Rx osteofixation system. *J Oral Maxillofac Surg;* 67(4):782–787.
Buijs GJ, van der Houwen EB, Stegenga B, et al (2007a) Mechanical strength and stiffness of biodegradable and titanium osteofixation systems. *J Oral Maxillofac Surg;* 65(11):2148–2158.
Buijs GJ, van der Houwen EB, Stegenga B, et al (2007b) Torsion strength of biodegradable and titanium screws: a comparison. *J Oral Maxillofac Surg;* 65(11):2142–2147.
Callister WD Jr (1997) *Materials Science and Engineering: An Introduction.* New York: John Wiley & SonsI Inc.
Cheung LK, Chow LK, Chiu WK (2004) A randomized controlled trial of resorbable versus titanium fixation for orthognathic surgery. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod;* 98(4):386–397.
Cutright DE, Hunsuck EE, Beasley JD (1971) Fracture reduction using a biodegradable material, polylactic acid. *J Oral Surg;* 29(6):393–397.