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FEATURES SECTION

Current Products and Practice

Bone anchorage devices in orthodontics

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Bone anchorage is a promising new field in orthodontics and already a wide variety of bone anchorage devices (BADs) are available commercially. This review aims to assist clinicians by outlining the principles of bone anchorage and the salient features of the available systems, especially those that may influence the choice of a specific BAD for anchorage reinforcement.

Key words: Orthodontic anchorage, orthodontic implants, mini-implants, mini-screws, mini-plates

Refereed paper

Introduction

Orthodontic anchorage control is a fundamental part of orthodontic treatment planning and subsequent treatment delivery. On one hand, research has focussed on the efficient movement of teeth to minimize anchorage loss by improvements in orthodontic materials, bracket designs (e.g. self-ligating brackets or Tip-Edge^{TM}) and friction-less treatment protocols (e.g. segmented arch technique). Alternatively, the methods used to reinforce orthodontic anchorage traditionally involve the use of extra-oral (headgear, protraction headgear) and intra-oral (transpalatal arch, quadhelix, etc.) appliances. However, it is recognized that these conventional anchorage systems are limited by multiple factors such as patient compliance, the relative number of dental anchorage units and periodontal support, allergy, iatrogenic injuries and unfavourable reactionary tooth movements.

In recent years, numerous publications have introduced novel ways of reinforcing anchorage using a variety of devices temporarily anchored in bone. Orthodontic bone anchorage (OBA) is indicated when a large amount of tooth movement (e.g. labial segment retraction or mesial/distal movement of multiple posterior teeth) is required or dental anchorage is insufficient because of absent teeth or periodontal loss. Such devices may also be useful in asymmetric tooth movements, intrusive mechanics, intermaxillary fixation/traction and orthopaedic traction and appear to be rapidly gaining acceptance in routine orthodontic practice. In an effort to improve and distinguish their products, manufacturers have produced systems with innovative design features and differing clinical protocols.

Given that there is no clear consensus on nomenclature, these devices are referred to by a confusing array of names including mini-implants,[1] micro-implants,[2] microscrew implants,[3] miniscrews[4] or temporary anchorage devices (TADs).[5] Whilst some of these synonyms refer to similar devices, the terminologies used are either vague or inaccurate. For example, the word 'micro' is not ideal, since it infers that a device has extremely small dimensions. The term 'mini-implant' does not represent all of the systems currently available, and 'TAD' is non-specific since all supplementary anchorage devices are temporary and bone anchorage is not clearly denoted. Since the distinguishing feature common to all of these devices is that they provide anchorage through either a mechanical interlocking or biochemical integration with bone, we suggest that they are best referred to as orthodontic bone anchorage devices (BADs).

In view of the rapidly evolving and complex nature of this topic, this paper aims to assist the orthodontist by reviewing the various design features of currently available BADs, and outlining principles of bone anchorage and the clinically relevant factors that influence the choice of a specific BAD.

Types of bone anchorage

There are three distinctly different approaches to bone anchorage in terms of the devices' backgrounds and

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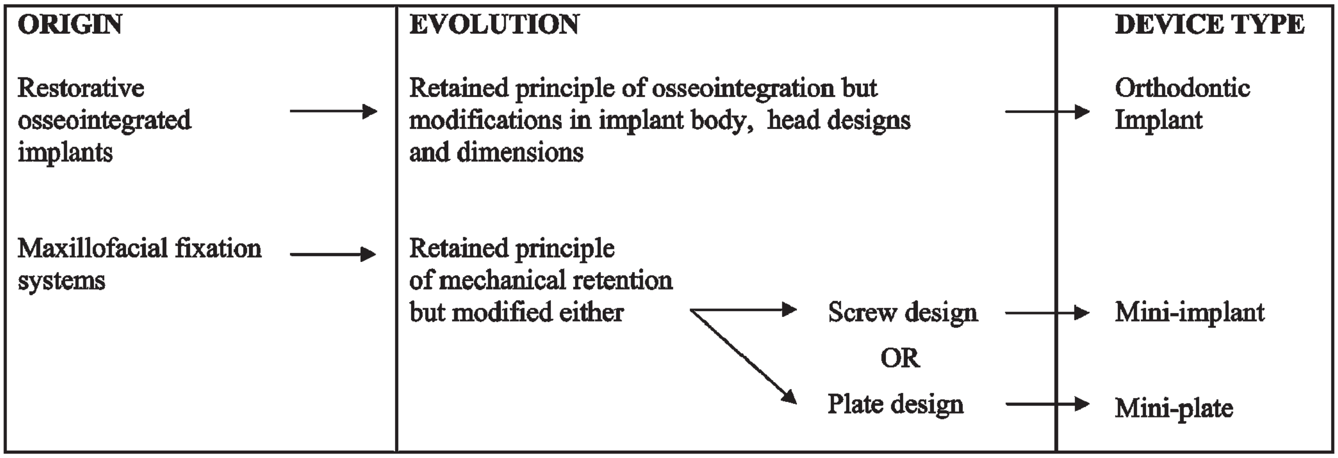


Figure 1 Classification of bone anchorage devices based on their evolution and characteristics

characteristics (Figure 1). Broadly speaking, BADs can either be osseointegrated or mechanically retentive depending on their bone-endosseous surface interface and design features. The latter group can be subdivided according to whether the screw (mini-implant) or plate (mini-plate) components are the principal design elements.

Orthodontic implants

The first widely available means of bone anchorage evolved from Branemark's[6] work on the concept of osseointegration and use of titanium implants to replace missing teeth. These endosseous implants have features to promote both functional and structural integration (osseointegration) at the implant–bone interface, and require an unloaded latency period of up to 6 months.[6] In 1984, Roberts *et al.*[7] investigated the tissue response to orthodontic forces applied to restorative implants and concluded that continuously loaded implants remained stable with 100 g force after a 6-week healing period. In a follow-up study on dog mandibles, osseointegration was found in 94% of the implants and it was concluded that less than 10% of endosseous surface area contact with bone was needed to resist forces of up to 300 g for 13 weeks.[8] Subsequently, several manufacturers modified restorative implant designs to produce customized orthodontic fixtures. Clinical studies on the use of osseointegrated implants for orthodontic anchorage have reported a success rate of 86–100%.[9–13] The retromolar implants,[14] Onplant™, Straumann Orthosystem™ and Mid-plant system™ are examples of osseointegrated BADs.

Mini-implants and mini-plate systems

Orthodontic mini-implant and mini-plate systems are derived from maxillofacial fixation techniques and rely on mechanical retention for anchorage (Figure 1). Since these devices use osseous physical engagement for stability, they are less technique sensitive than osseointegrated implants, amenable to immediate orthodontic loading and are easily removed.[15–17] Osseointegration is neither expected nor desired (in terms of screw removal), although animal studies have demonstrated that a limited and variable level (10–58%) of osseointegration can occur.[15] In 1983, Creekmore and Eklund[18] reported the use of a vitallium screw, resembling a bone-plating screw, placed in the anterior nasal spine region. This was loaded after 10 days for successful intrusion of the adjacent upper incisors. Subsequent modifications to the design of fixation screws have made them more suitable for use in orthodontics and led to the introduction of customized mini-implant kits. In the late 1990s, both Kanomi *et al.*[1] and Costa *et al.*[19] described mini-implants specifically designed for orthodontic use. The Aarhus™, Spider screw™, Dual Top™, Absoanchor™ and IMTEC™ are current examples of mini-implant BADs.

Over the same period, alterations to the design of maxillofacial fixation plates have led to the introduction of mini-plate systems. In 1985, Jenner *et al.*[20] reported a clinical case where maxillofacial bone plates were used for orthodontic anchorage. In 1998, Umemori *et al.*[21] used L-shaped Leibinger™ mini-plates in the mandible to intrude molars for anterior open bite correction. They termed this approach the 'The Skeletal Anchorage System' (SAS) and suggested that, when compared with osseointegrated implants, these mini-plates provide stable anchorage with immediate loading. Since then other mini-plate design variations have been introduced, e.g. Bollard Mini Plate implant™ and C-tube implant™ (Figure 2). Clinical studies on these

Figure 2 A mini-plate device. This Bollard example has a two-holed baseplate with a neck extension and cylindrical tube head

non-integrating devices have reported success rates of 86–93% for mini-implants[22,23] and 93% for mini-plates.[24]

Key design features of BADs

There are several features common to all osseointegrated implants and mini-implants (Figure 3) and therefore these are described collectively (Table 1). Mini-plate design features however will be described separately.

Material specifications

Although manufacturers do not give detailed material specifications, most BADs are made of pure titanium or titanium alloy (Ti–6Al–4V). Titanium has proven properties of biocompatibility, is lightweight, has excellent resistance to stress, fracture and corrosion, and it is generally considered to be the material of choice. Surgical grade stainless steel has also been used for Leone mini-implants™ and in several systems to fabricate supra-implant attachments (e.g. the Orthosystem implant and IMTEC mini-implant). During their manufacture implants undergo a variety of surface alterations to promote osseointegration, e.g. the sand-blasted and acid-etched (SLA) endosseous surface of the Orthosystem.[11] Mini-implants on the other hand are manufactured with a smooth endosseous surface or additional surface treatments (e.g. TOMAS™ system) to actively discourage osseointegration and therefore simplify their removal.

Dimensions

Orthodontic implants and mini-implants are available in a range of body lengths and diameters. For orthodontic implants both physical stability and osseointegration depend on adequate bone-fixture surface contact, which in turn is a balance between the fixture's diameter and length.[25] If the length is small the diameter must be large and vice versa. In practice, an implant's primary stability is related to its intra-osseous length, whilst the threads help to dissipate stress within the trabecular bone. Subsequently, the implant's shape and surface characteristics are important influences on osseointegration, as the load tolerance is proportional to the available osseointegrated surface area. Such orthodontic implants are usually cylindrical in shape (Figure 3) with a relatively short body length (4–7 mm) and large diameter (3–5 mm) as compared with mini-implants. These dimensions provide a large surface area in a limited depth of bone, making them suitable for mid-palatal, retro-molar and edentulous sites.

Conversely, mini-implants have long, narrow conical shapes (Figure 3) and are available in 6–15 mm intra-osseous lengths and in 1.2–2.3 mm diameters. An *in vitro* laboratory study has compared the mechanical properties of three types of mini-implants (Leone, M.A.S.™ and Dentos™) on a non-biological bone substitute, and the authors concluded that mini-implants should be at least 1.5 mm in diameter in order to resist fracture.[26] A clinical study of the factors associated with mini-implant stability assessed fixtures with 1–2.3 mm diameters and 6, 11 and 14 mm body lengths. It was found that implant mobility was associated with 1 mm body diameter, but it was not statistically associated with body length.[23] Hence, in terms of a mini-implant's primary stability, the diameter is more important than body length for mechanical interlocking in bone. If excess resistance is encountered during the placement of a mini-implant, it is preferable to first create a pilot hole using a drill whose diameter is less than the fixture body. For example, insertion of a

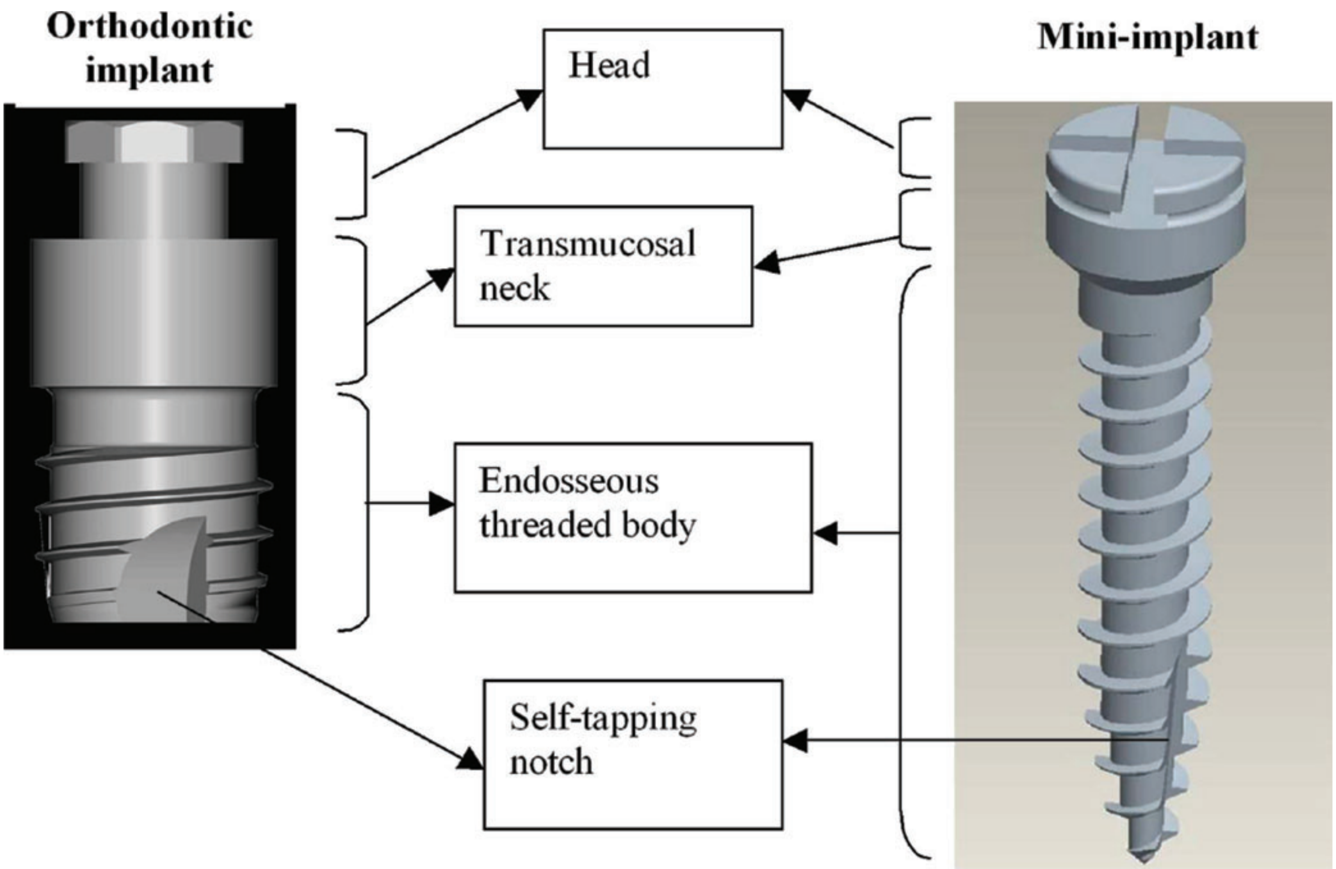


Figure 3 Typical design features of orthodontic implants and mini-implants. Whilst the diagrams are not exactly to scale, the different proportions (length/diameter) of the fixtures are evident

1.5 mm diameter mini-implant may warrant the use of a 1.1 mm diameter drill in the maxilla and 1.3 mm in the mandible, due to the differential bone density.

The C-Orthodontic micro-implant developed by Chung *et al.*[27] may be best termed as a hybrid mini-implant, rather than a 'micro-implant'. Its relatively narrow dimensions (1.8 mm diameter and length up to 10.5 mm) enable interproximal site insertion and loading is recommended after a healing period of 6–8 weeks. The authors claim that its endosseous surface encourages osseointegration even when subjected to early loading (2 weeks), but have not provided clear evidence to support this.

Body and thread designs

Orthodontic implants and most mini-implants are commonly described as being self-tapping. Self-tapping body designs often have a special groove in their tip, which cuts or taps the bone during insertion. This feature usually requires a pilot hole to be drilled first and the groove at the tip then creates the thread pattern in bone as the fixture is inserted. Orthodontic implants have broadly similar self-tapping designs to improve the transfer of compressive forces to the adjacent bone, minimize micro-motion and increase the bone-implant surface area. For example, the Straumann Orthosystem relies on the physical shape of its threads to provide primary stability from the time of insertion until osseointegration subsequently occurs.[11] Conversely, mini-implants have been manufactured with a wide variety of thread designs and body shapes. As with maxillofacial fixation screws, the first mini-implants were tapped into pre-drilled holes. More recently, we have seen the release of self-drilling mini-implants, which can be screwed directly into bone using a driver at an appropriate torque level.[15] This simplifies the insertion stage by avoidance of pre-drilling although some manufacturers indicate that their mini-implants behave in a self-drilling fashion in the maxilla, but may require pre-drilling in the mandible (e.g. IMTEC, Orlus). Kim *et al.*[28] compared the stability of mini-implants in beagle jaws inserted using pre-drilling and drill-free methods. They concluded that both methods showed some evidence of osseointegration under early orthodontic loading and that all of the mini-implants were sufficiently stable for anchorage purposes. However, the drill-free fixtures showed less mobility and more histomorphometric bone-metal contact. This may be because drill-free insertion produces little bone debris and less thermal damage.[29]

Head designs

Orthodontic implants usually feature two-piece designs with specific healing abutments and intra-oral attachments. A healing cap or cover screw is usually placed during the latency phase and then replaced by specialized fixtures, which enable connection of orthodontic auxiliaries such as a transpalatal arch (TPA) for indirect anchorage.[30] The majority of available mini-implants feature various one-piece designs (Table 1). The C-Orthodontic system has a two-piece design, where the head is screwed on to the endosseous base either at insertion or after an apparent osseointegration period of 6–8 weeks.[27] The IMTEC mini-implant system also has a detachable head abutment. Mini-implant head designs may have hooks, ball ends or grooves to connect orthodontic traction auxiliaries or rectangular/round slots. These slots have broadly similar dimensions to an orthodontic bracket and can be used to directly engage arch wires. The transmucosal neck is that part of the implant or mini-implant, which emerges through the soft tissue superficial to the cortical plate. A smooth polished transmucosal neck of appropriate height is essential to prevent plaque accumulation and harbouring of micro-organisms, and also provide sufficient clearance for the fixture head.

Mini-plate systems

Orthodontic mini-plate systems are broadly similar to maxillofacial plating systems (Figure 2) in terms of their holed baseplates and fixation screws, but have specifically modified ends to engage orthodontic auxiliaries. They are manufactured from titanium and are supplied in kits containing both mini-plates and fixation screws. The designs may vary in shape and size (Table 1), but are usually available as two- to five-holed mini-plates with transmucosal neck extensions. These plates are about 1.5 mm in thickness and can be bent or trimmed to adapt them to the cortical plate contour at the insertion site. They are secured with mono-cortical fixation screws of 5–7 mm lengths and 1.2–2.3 mm diameters. The intra-oral end is usually a cylindrical tube with holes through which orthodontic wires may be passed. A locking mechanism is integrated into the cylindrical tube, such that it can be tightened to stabilize the orthodontic wire or auxiliary (e.g. Bollard System). The Leibinger SAS kit and C-system contain both self-tapping and self-drilling screws for mini-plate fixation.

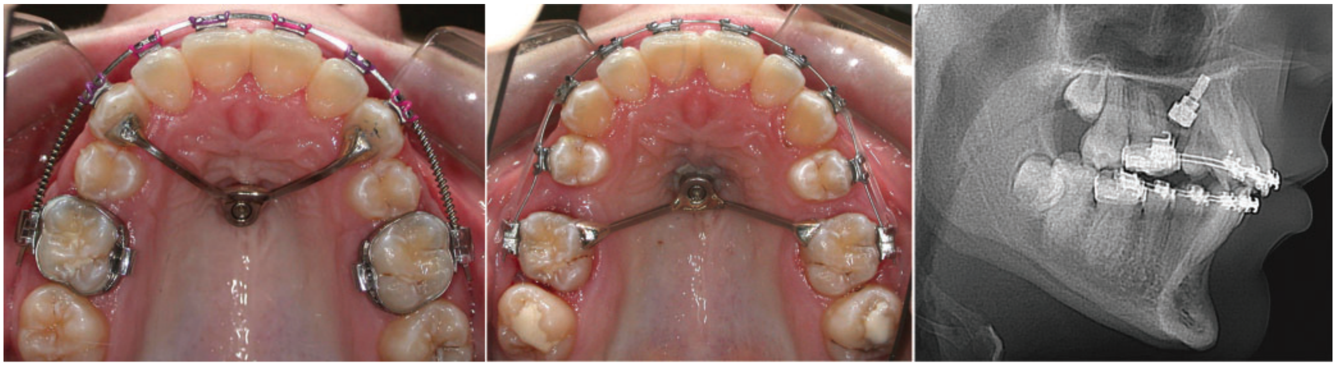
Clinical aspects that influence the choice of a BAD

Thorough treatment planning is essential for the successful use of BADs to both minimize morbidity and ensure a predictable outcome. The patient's anchorage requirements, age, potential insertion site morphology and available bone (quantity and quality) are important factors. Anchorage specific steps include informed consent, selection of a suitable BAD, planning for accurate positioning, the surgical insertion procedure and biomechanical principles of force application. In addition to study models, a working model assists the orthodontist to plan treatment, identify insertion areas and prescribe a surgical stent. A panoramic radiograph, peri-apical radiographs, and a lateral cephalograph assist in the evaluation of available bone depth and the proximity of adjacent anatomical structures, and to confirm the positional details post-operatively. Some authors have suggested the use of CT scans to assess the bone morphology at potential sites for both orthodontic implants[12] and mini-implants,[31] but this is difficult to justify in routine clinical practice.

Anatomical site considerations

The most common sites for orthodontic implants are the mid-palatal region,[11] para-median area of palate,[12] and retromolar edentulous areas.[14] For the anterior palate, bone depth can be assessed on a lateral cephalograph such that the antero-posterior location and inclination of the implant are planned to optimize the available bone depth.[32] This allows for implants of up to 6 mm lengths to be placed in this region (Figure 4). Implants can also be inserted in para-median positions, i.e. 6–9 mm posterior to the incisive foramen and 3–6 mm laterally.[12] This may be a valid option in young patients with a patent mid-palatal suture, although appropriate surgical and radiological planning is essential. If there are any doubts over the degree of obliteration of the mid-palatal suture the implant should be placed just posterior to the first premolars where ossification is usually more complete.[33]

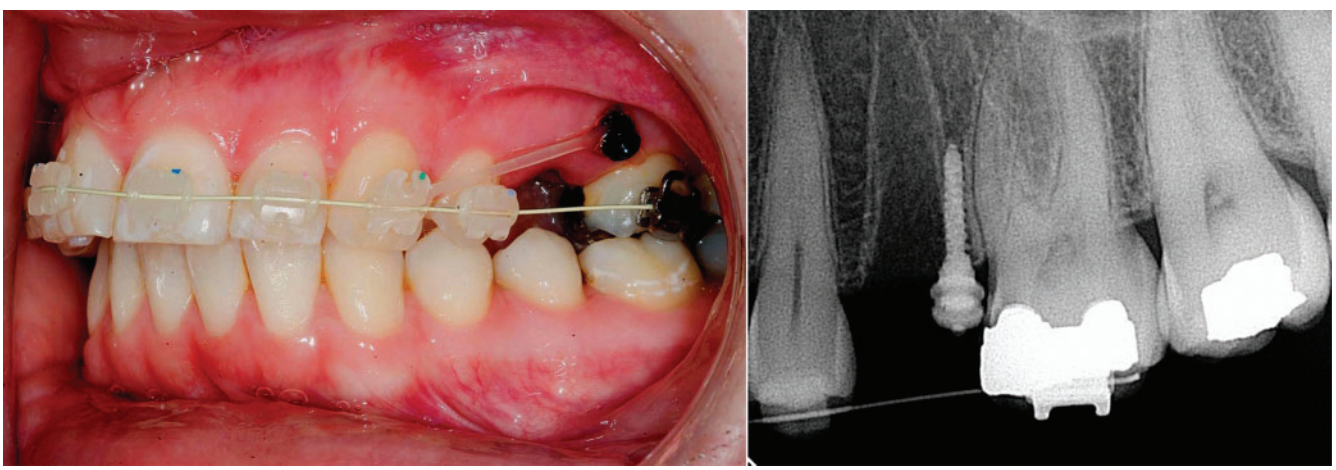
Mini-implants (including the C-Orthodontic device) are much more versatile in terms of their potential anatomical sites because of their small diameters. Typical insertion sites are maxillary and mandibular buccal interproximal areas (Figure 5), the maxillary



(a) (b) (c)

Figure 4 (a) Mid-treatment photograph where an Orthosystem palatal implant anchors the canine teeth via a transpalatal arch, whilst the molars are distalized. (b) Following the molar distalization phase the TPA has been bonded to the first molars. This then provides anchorage for retraction of the anterior teeth. (c) Lateral cephalograph of this patient showing the 6 mm intraosseous length implant (and healing cap) in the standard anterior palate site and angulated at 25° to the vertical plane

sub-nasal spine region, mandibular symphysis, para-median and mid-palate, retro-molar, infra-zygomatic and maxillary tuberosity areas. A volumetric CT study of 20 patients to assess the hard and soft tissue depths required for mini-implant insertion, indicated that 10 mm length screws could be placed in the symphysis and retro-molar regions and 4 mm lengths were preferable in the mid-palate area, incisive and canine fossae.[34] In another study Poggio *et al.*[35] assessed the interproximal alveolar sites in terms of the vertical insertion levels for mini-implants using 25 volumetric tomographic images of the maxilla and mandible.[35] Mesio-distal and bucco-lingual distances were evaluated 2, 5, 8 and 11 mm from the alveolar crest. The results suggested that in both the maxilla and mandible, insertion in the buccal inter-premolar areas 5–11 mm from the alveolar crest would avoid damage to roots. The mean mesio-distal width of interproximal bone available was 3.5 mm in maxilla and 4.9 mm in mandible in this vertical range. In the maxilla maximum bone width was



(a) (b)

Figure 5 (a) An Aarhus mini-implant inserted in the buccal interproximal region mesial to the first molar and at an angulation of approximately 45° to the vertical axis. This has been loaded immediately with a traction auxiliary to distalize the canine and first premolar. (b) A post-insertion radiograph confirms the position of the mini-implant in the interproximal bone between the second premolar socket and the first molar roots

(a) (b)

Figure 6 (a) A 3D surgical stent for Orthosystem palatal implants. The stent's guide cylinder provides physical guidance for the surgical instruments yet allows access for external irrigation. (b) A 3D surgical stent used for the insertion of an Aarhus mini-implant. The guide cylinder physically directs the screwdriver at the prescribed location and angulations

available on the palatal aspect of the alveolus; however, in the molar region insertion more than 8 mm from the alveolar crest should be avoided because of proximity to the maxillary sinus. In the interproximal sites, the authors suggested that mini-implants should be angled at 30–40° to the vertical axis of teeth to enable insertion of longer ones in the available three-dimensional (3D) bone trough. Although not always necessary, if initial alignment is completed first then there may be more sites available for mini-implant placement through intentional separation of the adjacent roots during this treatment phase.[36]

Even when correctly inserted, it is important to be aware that mini-implants do not remain absolutely stationary, as was demonstrated in a clinical study of 16 patients with mini-implants inserted in the zygomatic buttress.[37] When loaded over a period, these fixtures were displaced by −1 to 1.5 mm in the direction of the applied force. Interestingly, a histological animal study has assessed root repair after injury from mini-implant insertion and found that complete root repair occurred within 12 weeks of fixture removal.[38] Finally, in long-term edentulous areas, implant and mini-implant placement should be carefully planned due to likely alveolar resorption and lowering of the maxillary sinus floor.

Recommended sites for the placement of mini-plates are the zygomatic process of the maxilla,[39] mandibular body distal to the first molars[21] and the maxillary buccal plate above the premolar/molar roots.[40] Whilst mini-plates may be placed in bony areas remote from the dental roots and important anatomical structures, their disadvantages include the large scale subperiosteal flap surgery necessary to access these remote sites and the associated patient morbidity. Their transmucosal part is adapted such that it emerges through the soft tissue at an appropriate position and level for orthodontic auxiliaries to be attached. One mini-plate, the C-plate is suitable for subperiosteal placement in the mid-palatal region and has a cross-shaped exposed part for application of forces in multiple directions.

Surgical stents

The insertion techniques for all BADs should attempt to maximize the available bone volume, whilst avoiding adjacent anatomical structures such as dental roots, naso-maxillary cavities and neurovascular tissues. Clinical experience with palatal implants has shown that accurate 3D positioning is a critical factor in this respect.[41,32] Several authors have recommended the use of removable stents for orthodontic implants to transfer the pre-surgical prescription to the surgical stage,[42–44] but only one stent design provides direct 3D physical guidance for the surgical instruments during insertion (Figure 6a).[45]

Some authors and manufacturers currently recommend an indirect planning technique for mini-implants, where a brass separating wire or a custom-made wire guide is placed between adjacent teeth and over the insertion site, or added to an adjacent fixed appliance bracket. These markers are then radiographed *in situ* in order to relate them to the planned insertion site and adjacent dental roots.[2,46,47] Arguably, such wire markers only provide limited and indirect topographical and angulation information, but no inclination guidance for mini-implant insertion. To overcome this problem, 3D removable stents have been described for mini-implants (Figure 6b).[48–50] Although the fabrication of a stent involves additional lab support the advantages of ease and accuracy of mini-implant placement, and reduced chairside time and patient morbidity may outweigh the disadvantages. This is especially true when different clinicians are responsible for planning and placement, or for those inexperienced in insertion techniques.

Implantation/explantation

Several studies on endosseous implants have demonstrated that pre-operative prophylactic antibacterial measures reduce post-operative infection and hence early failure rates.[51] A single dose of pre-operative antibiotics is generally recommended before placement of orthodontic implants, but the consensus is that this is not required for mini-implants other than for general medical reasons.[52] Instead, a chlorhexidine mouthwash or swab may be used immediately pre-operatively to reduce the bacterial load.[53]

Most BADs can be inserted as a chairside procedure under local anaesthesia, although some patients may prefer general anaesthesia for implant and mini-plate procedures. A generous surgical access flap is clearly required for mini-plate systems and a localized subperiosteal flap is recommended by some mini-implant manufacturers. Conversely, some mini-implants may be screwed directly through the attached mucosa, or a soft tissue punch may be used to prevent mucosal tearing and provide a clean-cut tissue margin around the transmucosal neck. The soft tissue thickness at the insertion site influences the choice of fixture, such that a longer transmucosal neck should be used in areas with thick soft tissues. The pilot hole (if required) should be drilled as per the manufacturer's recommendations, at a slow speed with adequate cooling using saline irrigation to minimize heat generation (below 47°C) and associated bone necrosis. The fixture may be seated either with digital pressure using a screwdriver (with or without a torque wrench), or a slow speed handpiece depending on operator choice, access and the manufacturer's recommendations.

The implant placement torque (IPT) is a measure of resistance to fixture insertion and its relationship to mini-implant success rates was studied in 41 patients (124 mini-implants).[54] The results showed that the IPT was higher in the mandible than the maxilla, and that the failure rate in the mandible increased when high torque values were encountered during insertion. The authors attributed such failures to excessive stress created in the dense peri-implant bone as indicated by the high IPT values resulting in local ischaemia and bone necrosis. Therefore, it appears that a low IPT may indicate bone deficiency and poor initial stability, whilst a very high torque may be associated with bone degeneration. The authors recommended IPT values within the range of 5–10 Ncm when 1.6 mm diameter mini-implants are used and suggested the use of a relatively larger pilot drill for the mandible than the maxilla. Although the conclusions of this study are limited to pre-drilled mini-implants, it is likely that the general IPT principles also apply to self-drilling ones.

Written and verbal post-operative instructions should include details on oral hygiene measures and analgesia, and will vary depending on the BAD and site selection. Regular chlorhexidine mouthwashes for 1–2 weeks are typically recommended. Clinical studies have shown that inflammation of peri-implant tissue is a contributory risk factor for early failure in both orthodontic implants[55] and mini-implants.[23,56] Post-operatively, there should be no signs of pain (including tooth sensitivity), peri-implant inflammation or implant mobility, although clinical experience indicates that mini-implants may still be rotated, whilst remaining resistant to translatory movements.

Explantation of orthodontic implants can be done under local anaesthesia using the manufacturer's specific explanation tools. For example, Orthosystem implants are removed by rotary dissection with an explantation trephine at 750 revolutions per minute. The implant bed is left to granulate and good mucosal coverage occurs within a week.[32] Mini-plates require a second episode with full surgical flap access for their removal. Conversely, mini-implants are easily removed by unscrewing them using their screwdriver or handpiece adapter and the consensus is that 90% of such episodes do not even require local anaesthesia.[52]

Force application on BADs

Straumann recommend that Orthosystem implants are kept unloaded during the initial 12 weeks healing (latency) phase, although there are reports in the literature of this ranging from 2 to 16 weeks.[9,10,11,13] In a histomorphometric animal study, osseointegrated implants were subjected to continuous forces of 100–300 g.[57] This appeared to favourably influence the turnover and density of peri-implant bone, whilst the degree of osseointegration was independent of the amount of loading within this range. A similar experimental study showed that when a continuous uniform force or a static load (e.g. an orthodontic force) is applied, the marginal peri-implant bone is denser than that around implants loaded with a fluctuating (e.g. masticatory) force.[58] Several clinical studies have shown that loaded osseointegrated implants are stable over force levels in the range of 80–600 g.[8,11,13]

Mini-implants are usually described as being loaded immediately[15] or after a healing period of 2 weeks.[37] They apparently withstand forces ranging between 50–250 g[19,22,23] and are stable when horizontal or vertical forces are applied provided that these forces cause minimal rotational moments.[19] A study of factors associated with the stability of mini-implants, concluded that the main risk factors for premature loosening were a small diameter, peri-implant inflammation and patients with high mandibular plane angles (who appeared to have thinner buccal cortical bone), but not force levels.[23]

In terms of orthodontic mechanics, either direct or indirect traction may be applied to BADs. For instance, palatal implants usually provide indirect anchorage via a TPA connected to anchor teeth (Figure 4). The TPA can be either soldered to the implant cap or secured with a clamping cap or resin bonding (e.g. Mid-plant system, Straumann Orthosystem). It is important to plan the fabrication of the TPA with the implant position and dental attachments (molar bands or bonding bases) in mind so that a conflict in the paths of insertion is avoided.[32] One should also allow for possible deformation of the TPA, as occurred in a prospective study of Orthosystem palatal implants.[30] This resulted in 0.9 mm of anchorage loss and consequently a stiffer 1.2 mm^2 rectangular TPA was recommended.[59]

Conversely, mini-implants usually provide direct anchorage whereby traction is applied to the fixture's head (Figure 5a). Occasionally, a mini-implant can be reinforced by combining it with an abutment via a rigid rectangular wire, e.g. to a bracket on the tooth that forms the anchorage unit. A FEM study of mini-implants has shown that the use of an abutment may significantly reduce the stress concentrated in the peri-implant bone.[60] Clinically, this could increase the anchorage value and flexibility of applying forces in different vectors. In some scenarios, it is possible to apply a combination of force applications depending on the type of tooth movement required, e.g. simultaneous intrusion and retraction of anteriors, distalization of buccal segments with vertical control, uprighting of terminal molars with cantilever attachments. Recent clinical reports also describe the innovative use of BADs in atypical fixed appliance situations, e.g. with the Pendulum appliance and Distal jet for molar distalization,[61] alignment of ectopic canines,[3] unilateral molar intrusion[62] and inter-maxillary traction.[63,64]

Conclusions

BADs have evolved as viable alternatives to traditional anchorage methods and offer significant advantages in terms of low compliance, efficient, multi-purpose and reliable anchorage. Comparison of the three groups of BADs indicates that once integrated, orthodontic implants provide a reliable method for 'absolute anchorage' and most studies have shown high success rates.[9,10,13,30] However, they have disadvantages of relatively high costs, invasive placement and removal, elaborate planning and laboratory support, a limited range of anatomical sites for insertion and the requirement for a latency period before clinical loading.

Although, mini-plates can be placed in remote sites independent of the alveolar ridge, this means that surgical access can prove difficult. This is their main disadvantage along with the associated increase in patient morbidity, the degree of invasiveness and relatively high costs. However, they do have advantages of being amenable to immediate loading and versatility in terms of the application of forces in different vectors.

Arguably, mini-implants will be more widely used than the other two BAD groups because of their ease of insertion and removal, wide range of insertion sites, low cost, lower patient morbidity and discomfort, and early/immediate loading. They are also considered more clinician-friendly, since orthodontists can easily insert them as a routine procedure. Although, mini-implants have been shown to displace under loading,[37] they can be safely placed in most interproximal areas. Their main limitations are dependence on adequate bone quality/depth for stability, adjacent soft tissue inflammation and a small risk of fracture during insertion or removal. On balance, it appears that as techniques evolve further, mini-implants may be the BAD of choice in most clinical scenarios requiring maximum anchorage reinforcement, whereas implants and mini-plates may be reserved for those cases requiring the use of remote anchorage sites due to over-riding anatomical considerations.

Table 1 Bone anchorage devices: commercially available products and their features.

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
I. ORTHODONTIC IMPLANTS				
1. C-Orthodontic Micro-implant www.cimplant.com	Titanium Self-tapping two-piece cylindrical osseointegrated orthodontic implant Body features Sand blasted and acid-etched (SLA) surface, except the most superficial 2 mm Diameter – 1.8 mm Endosseous lengths – 6.5, 7.5, 8.5 mm Head features Transmucosal screwable attachment Diameter – 2.5 mm Heights – 5.35, 6.35, 7.35 mm 0.8 mm hole located 1, 2 or 3 mm from the top of the body and a separate groove for elastics	Driver handles – short & long C-implant holder Pilot drills – 1.3, 1.5 mm diameters	Interproximal alveolar sites	Pilot drill speed at 1000–1500 rpm at 10–15 Ncm pressure.[27] The two component system reduces risk of neck fracture during implantation.[27] Immediate loading possible in dense bone but otherwise after 6–8 weeks.[27] Applied forces may range from 50–200 g.
2. Mid-plant System www.hdc-italy.com	Titanium Self-tapping two-piece cylindrical osseointegrated orthodontic implant Body features Treated with titanium plasma spray (TPS) or bone-lock etching (BLE) to promote osseointegration Lengths – 4.5, 5, 6, 7 mm Diameters – 3.75 or 4 mm (latter is an emergency screw) Head features Transmucosal screwable head attachment (Orthodontic Implant Connection-ORIC) Diameter – 5.5 mm Heights – 2.5, 4, 6, 8 mm ORIC E.A. – a fan shaped transmucosal, screwable head attachment	No details available on the surgical kit	Median and paramedian palate region	Unloaded healing phase of approximately 12 weeks. Indirect anchorage

Table 1 (Continued).

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
3. Straumann Orthosystem Implant www.straumann.com	Titanium Self-tapping one-piece cylindrical osseointegrated orthodontic implant Body features Sandblasted, acid-etched (SLA) surface Endosseous length – 4.2 mm Endosseous diameters – 4.1, 4.8 mm Head features Transmucosal neck height – 1.8 mm Plastic healing cap available for initial coverage – 4.8 mm diameter and 3.5 mm height Stainless steel Post Cap – 3.5 mm and 5.5 mm heights used for TPA attachment.	Mucosa trephine Pilot drills with depth markings and 2.2, 2.8, 3.5, 4.2 mm diameters Implant depth gauge Screwdriver and rachet Explantation trephine 1.2 mm diameter TPA wire	Median and paramedian palate Retromolar area Edentulous ridge	Antibiotic prophylaxis. Surgical stent for accurate placement.[32,45] Mid-palate site suitable in adults and adolescents after mid-palatal suture closure. Less than 750 rpm pilot drill speed and constant saline irrigation. Unloaded healing phase of approximately 12 weeks. Indirect anchorage. Removed by rotary dissection with explantation trephine.
II. MINI-IMPLANTS				
1. Aarhus mini-implants www.aarhus-mini-implant.com	Titanium alloy (Ti-6Al-4V) Self-drilling conical body Body features Endosseous lengths – 5.4, 5.7, 5.8, 6.7, 7.4, 7.7, 7.8, 8.7 mm Endosseous diameters – 1.5, 2 mm Head features Diameter – 3 mm Two head designs: either bracket-like top with rectangular slots (for archwire insertion) or circumferentially grooved head (to retain auxiliaries) Transmucosal neck heights – 1.5, 2.5 mm	Starter and professional kits available Octagonal headed screwdriver or handpiece adapter	Mid-palate Infra-zygomatic and sub-ANS maxillary sites Interproximal alveolar sites Mandibular symphysis	Transmucosal insertion. Stent fabrication recommended.[50] Immediate loading.
2. ACR system www.BioMK.com	Ti-6Al-4V and stainless steel Self-drilling conical body	Individual kits for each commercial type		Transmucosal insertion. Self-drilling.

Table 1 (Continued).

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
	Four commercial types available: **1. ACR mini-implant** Body features Endosseous lengths – 4.5, 5, 5.15, 6, 6.5, 7 mm Endosseous diameters – 1.15, 1.3, 1.45, 1.5 mm Transmucosal heights – 0.35, 1, 1.5, 2, 4 mm Head features Cap shaped head with circumferential groove **2. CAPlant** Body features Endosseous lengths – 4, 6 mm Endosseous diameters – 1.45, 1.75 mm Transmucosal height – 1 mm Head features Three superficial slots in a triangular design for archwire engagement. A screwable cap locks the wire in place. **3. Orthoplant** Body features Endosseous lengths – 4, 5 mm Endosseous diameters – 2, 2.2, 2.5 mm Transmucosal heights not specified Head features H-type – hook design with a round slot T-type – cap shaped head with circumferential groove **4. Mplant** Body features Endosseous length – 7.1 mm Endosseous diameters – 1.5 mm Transmucosal height – 1.5 mm Head features Cap shaped with head with circumferential groove	Screwdriver handle and tips for manual and handpiece insertion	Interproximal sites Retromandibular area Mid-palate Interproximal alveolar sites Acts as an 'emergency' mini-implant in the maxilla	Immediate loading
3. Dentos Abso-Anchor www.dentos.co.kr	Titanium Self-tapping/self-drilling conical body Body features	Pilot drills in 24, 25 and 31 mm lengths and 0.9, 1, 1.1 and 1.2 mm diameters	Mid-palate Interproximal alveolar sites	Transmucosal placement or full flap access. Pre-drilling is

Table 1 (Continued).

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
	Endosseous lengths – 5, 6, 7, 8, 10, 12 mm Endosseous diameters – 1.2 mm to 1.7 mm With tapered or cylindrical body shapes Head features 7 types of head designs each with a transverse hole: Small Head (SH) No Head (NH) Long Head (LH) Circle Head (CH) Fixation Head (FH) Bracket Head (BH) Bracket head Type Left hand (BH-L) Transmucosal neck diameters - 1.8 mm – SH/NH/LH/CH types 2.5 mm – FH/BH types	Screw Drivers – long, short, torque drivers and a handpiece adapter		recommended for most insertions (e.g. 1.2 mm diameter body to avoid fracture), but self-drilling insertion possible in thin cortical sites. Selection of design type is based on site of insertion – Small Head (SH), Circle Head (CH), Bracket Head (BH) – maxillary/mandibular attached gingiva including palate, No Head (NH) – maxillary/mandibular movable soft tissue, Long Head (LH) – mandibular attached gingiva and mucosal border area, Fixation Head (FH) – maxillary/ mandibular areas for intermaxillary fixation, palate including mid-palatal suture area. Immediate loading
4. Dual –Top Anchor System www.rmortho.com	Titanium alloy Self-tapping and self-drilling conical body	Head-specific driver shafts for the screwdriver and contra-angle handpiece	Mid-palate Interproximal alveolar sites Mandibular symphysis	Transmucosal insertion. Pre-drilling is recommended in

Table 1 (Continued).

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
	Body features Lengths – 6, 8, 10 mm Diameters – 1.4, 1.6, 2 mm Head features Four head designs: TOP H – hexagonal head with a round hole and circumferential groove for auxiliary attachment TOP JB – button-head with circumferential groove TOP G1 – 0.022-inch rectangular slots for archwire insertion TOP G2 – 0.022-inch rectangular slots for archwire and a round hole in the neck	Pilot Drill – details on sizes not available	Retromolar sites	dense cortical bone areas. Either self-drill with screw driver or use contra-angle handpiece at less than 30 rpm speed. Immediate loading.
5. IMTEC Cope Ortho-implant www.imtec.com	Titanium alloy (Ti-6Al-4V) Self-drilling conical body with bone compressive tip design Body features Lengths – 6, 8, 10 mm Diameters – 1.8 mm Head features Circular head with 0.75 mm hole and a circumferentially grooved neck. O-CAP – stainless steel cap may be fitted onto the head with an intermediate O-ring gasket Cap height 3 mm and diameter 4 mm The O-Cap helps to prevent mucosal overgrowth, has a groove for attachment of auxiliaries and is solderable to customize attachments	Mucosa marker 1.5 mm soft tissue punch 1.1 mm surgical drill Screw Driver	6 mm length -Interproximal alveolar bone mesial to 2nd premolar Maxillary sub-ANS region Mandibular symphysis 8 mm length– Interproximal alveolar bone distal to 2nd premolar, parasagittal mid-palate 10 mm length – Maxillary tuberosity, Zygomatic buttress, Retromolar area, Posterior palate	Transmucosal insertion in attached gingival areas and soft tissue punch in mobile areas. Self-drilling using a special taper in the apical 4 mm of the body rather than a self-tapping notch. This acts to compress, not cut bone, during insertion 10–20 seconds respite suggested between half to two complete revolutions to allow for bone expansion during placement. If a pilot hole is required, 1.1 mm drill at 500–800 rpm speed with irrigation recommended. Immediate loading.

Table 1 (Continued).

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
6. Leone mini orthodontic implants www.leone.it	Stainless steel Self-tapping body Body features Lengths – 6, 8, 10, 12 mm Diameters – 1.5, 2 mm Head features Hexagonal head shape with transverse hole and a circumferential groove (high head design only) Transmucosal neck heights – 1.75, 3 mm	Soft tissue punch Pilot drills of 12 mm length and 1.1, 1.3, 1.5 and 1.7 mm diameters Screwdriver and handpiece adapter	Interproximal alveolar sites	Circular mucosal punch or full flap access. Use pilot drill notches to assess depth of implant bed. Surgical stent recommended for accurate placement.[50] Allow soft tissues to heal for two weeks before loading.
7. LOMAS – Lin/Liou Orthodontic Mini Anchor System (Quattro) www.mondeal.ws	Titanium (Ti-6Al-4V) Self-tapping and self-drilling conical body Body features Endosseous lengths – 7, 9, 11 mm Endosseous diameters – 1.5, 2 mm Head features Bracket-like head with rectangular slots of either 0.018 or 0.022-inch dimensions Transmucosal neck height – 2 mm	Pilot drills – details on sizes not available Screwdriver and handpiece adapter	Interproximal alveolar sites	Supplied in sterile colour-coded packs. Self-drilling Transmucosal insertion. Immediate loading.
8. Neo-Anchor plus www.anchorplus.co.kr	Material specification not available Self-tapping conical body Body features Lengths – 6, 7, 8, 10, 12 mm Diameters – 1.4, 1.6 mm Three zones of thread patterns within each body: S-shaped threads in the coronal third, round/triangular threads in the middle third, and triangular threads with self-tapping notch in the apical third. Head features Cap shaped with round slot	Pilot drills - details on sizes not available Long and short screwdrivers	Interproximal alveolar sites	Transmucosal insertion or full flap access. Immediate loading.

Table 1 (Continued).

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
9. Orlus mini-implant www.ortholution.com	Material specification not available Self-drilling conical body Body features Three endosseous diameters – Mini, Regular and Wide (1.4, 1.6, 1.8 mm respectively) Endosseous lengths – 5, 6, 7 mm Head features Button shaped head with 0.022-inch circular groove Transmucosal neck heights – Regular – 1 mm Long – 2, 4 mm	Pilot drills in 4 mm length for both manual and handpiece use. Long and short driver tips	Interproximal alveolar sites Mid-palate Retromolar sites	Lateral cutting groove and trapezoidal threads to reduce bone stresses, with a cork-tip design for drill-free insertion. Pre-drilling, below 60 rpm is recommended in dense cortical bone. Immediate loading.
10. Orthodontic Anchorage Saver Implant (O.A.S.I.) www.lancerortho.com	Grade 5 Titanium Self-drilling conical body with double threaded, channel-tip design Body features Lengths – 5, 7, 9 mm Diameters – not specified Head features Button shaped head with a transverse hole Transmucosal neck heights – 2.5, 3.5 mm	Long and short screw driver Mini-implant drills in two lengths – 7, 9 mm	Interproximal alveolar sites	Transmucosal insertion. Requires pre-drilling of a small channel with the tap drill before insertion in self-drilling fashion. Loading within one week.
11. Spider Screw Anchorage System www.hdc-italy.com	Titanium Self-tapping and self-drilling cylindrical/ conical body Body features Available in 3 subtypes of body designs: 1. Regular Spider screw Cylindrical body design Lengths – 7, 9, 11 mm Diameter – 2 mm 2. Mini Spider screw Cylindrical body design Lengths – 6.5, 8, 10 mm Diameter – 1.5 mm 3. Mini Spider K1	Separate kits available for Regular, Mini and Mini K1 screws Pilot drills of 1.5, 1.8 mm diameters and 7, 9, 11 mm lengths. Manual screwdriver	Interproximal alveolar sites Edentulous areas with temporary prosthetic abutment	Fixtures supplied in sterile pre-packed envelopes. Transmucosal insertion or full flap access. Spider Screw Regular and Mini Spider screw require pre-drilling. Mini Spider K1 has a self-drilling design, but may require pre-drilling in dense bone areas.

Table 1 (Continued).

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
	Conical body design Lengths – 6.5, 8, 10 mm Diameter – 1.5 mm Head features Bracket like head with 0.022 × 0.028-inch internal/external rectangular slots and two internal round holes of 0.025-inch diameter Regular Spider Screw has three head designs: Regular, Low profile, Low profile flat Mini Spider Screw and Mini Spider K1 have two transmucosal neck lengths of 1.5 mm diameter and long/short necks for posterior areas and anterior areas respectively			Pilot hole drilling at 60–100 rpm speed with saline cooling.[46] Mini-implant inserted at 20–30 rpm speed.[46] Immediate loading. Regular Spider screw may have a resin core added for a temporary prosthetic abutment.
12. TOMAS – Temporary Orthodontic Mini Anchorage System www.dentaurum.com	Titanium Self-tapping or self-drilling (TOMAS – SD) conical body types Body features Endosseous lengths – 8, 10 mm Endosseous diameter – 1.2 mm Special body surface treatment to inhibit osseointegration Head features Head contains 0.022-inch archwire slots	Soft tissue punch TOMAS locator – a topographical wire guide Pilot drills – 8, 10 mm lengths and 1.1, 1.2 mm diameters Torque ratchet Screwdriver and handpiece adapter	Interproximal alveolar sites	Supplied in sterile colour-coded packs. Circular mucosal punch used before insertion. Self-drilling technique (TOMAS-SD) used in maxilla, but in mandible pilot drilling is recommended at 800 rpm speed with adequate cooling. Maximum torque 20 Ncm recommended at max 25 rpm insertion speed. Immediate loading.
III. MINI-PLATES				
1. Bollard Mini-plate System www.boneanchor.be	Titanium Anchor plates – left and right sided with three holes for maxilla and two holes for mandible Mono-cortical screws with 5 or 7 mm lengths and 2.3 mm diameter	Manual screwdriver and handpiece adapter Pilot drills for maxilla and mandible Emergency locking screw for the cylindrical head unit	Zygomatic buttress Nasal process of the maxilla Canine region of the mandible Molar region	Subperiosteal flap for surgical access. Mini-plates adapted to bone's external contour. Loading recommended two weeks post-op.

Table 1 (Continued).

Device Name/Manufacturer	Device Design	Surgical kit and Main Accessories	Typical Insertion Sites	Specific Clinical Features/Manufacturer's Recommendations
				Cylindrical fixation unit enables various auxiliary wires and force vectors to be used. Simultaneous placement and dental extractions not recommended in order to reduce plate infection risks.
2. C-tube and C-palatal Mini-plate www.martin-med.com	Titanium alloy Ti-6Al-4V Two designs C-tube – 2 holed mini-plate with a cylindrical tube which projects supramucosally as a buccal slot for archwires C-palatal plate – A cross-shaped three holed mini-plate for palatal sites, with a supramucosal head Mini-plates fixed with either self-tapping or self-drilling screws of 5, 7 mm lengths and 1.5 mm diameter	Driver handpiece adapter Plate bending pliers Burs and pilot drills	C-tube – buccal aspect of maxilla and mandible C-palatal plate – mid-palate area	Subperiosteal flap for surgical access. Mini-plates adapted to bone's external contour. Immediate loading.
3. Leibinger Orthodontic Skeletal Anchorage System www.stryker.com	Titanium Two plate designs: 1. Standard 2. Locking mechanism Straight or T-shaped plates with three or five holes are available in short and long lengths. Mini-plates fixed with self-tapping/self-drilling screws of lengths – 3, 4, 5, 6, 8, 12 mm and 1.7 or 1.9 mm diameters (latter is an emergency screw)	Plate bending pliers Manual screwdriver Pilot drills Locking screwdriver	Zygomatic buttress Canine region and nasal process of the maxilla Molar region in maxilla and mandible	Subperiosteal flap for surgical access. Mini-plates adapted to bone's external contour. Loading after 1–2 weeks healing period.

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