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Implant Anchorage in Orthodontic Practice: The Straumann Orthosystem

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The modern era of dental implantology was ushered in by the pioneering work of Brånemark and his coworkers [1–6]. Their research demonstrated the relationship between bone and implant that now is known as osseointegration. They described osseointegration in histologic terms as the direct contact of living bone with the implant surface at the light microscopic level [7,8]. Schroeder and colleagues [9–12] further characterized this interface and termed the union of bone and titanium "functional ankylosis." Because of the work of these pioneers, dental implants have become a predictable means of tooth replacement.

Implants also have been used to provide orthodontic anchorage [13]. One such system is the Straumann Orthosystem implant (Institut Straumann, Waldenburg, Switzerland) [14–16]. This system consists of a small implant that is placed surgically in the midline of the anterior hard palate and allowed to integrate, after which it is attached to a transpalatal arch (TPA). The arch is bonded to two contralateral teeth (usually premolars) that provide anchorage for tooth movement. Upon completion of active tooth movement, the implant is removed surgically. This article provides an overview of this implant system and its application, including the anatomy of the bony palate and contiguous structures.

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Orthodontic anchorage

Control of anchorage is critical to the successful completion of most orthodontic treatment plans. Anchorage, in an orthodontic context, is defined as resistance to reaction forces that usually is provided by other teeth but sometimes is provided by the palate, head or neck, or implants in bone [17]. Examples of the first two categories involving teeth and palate include the TPA, stopped archwires, the Nance appliance, and intraoral elastics. Extraoral sources such as the back of the head and neck are also employed through headgear, but suboptimal patient compliance [18,19] and facial injuries have been reported [20,21].

All these conventional forms of anchorage have been used for the better part of the last 100 years. They offer varying degrees of successful anchorage, and they each have evolved with the on-going pursuit of absolute anchorage. Absolute anchorage, defined as 100% resistance against reactive forces, is required less often but is essential in certain cases; it has remained elusive. Osseointegrated implants are quickly living up to their potential to provide such anchorage [22–24].

Several types of implants have been used to provide orthodontic anchorage. Roberts and colleagues [25] used a two-stage endosseous implant in the retromolar region of the mandible to move two molars 10 mm mesially into an atrophic ridge. The implant remained stable for 3 years and was removed after completion of orthodontic treatment. The bone-to-implant contact was found to be 80%. A high rate of remodeling was verified through bone labeling.

Block and Hoffman [26] designed a hydroxyapatite-coated disc (the Onplant), which is 10 mm in diameter and 3 mm thick [26]. It is designed to be placed subperiosteally on the posterior portion of the palate where the vertical bone height is limited. Surgical placement is technically difficult, however, and a second-stage surgical uncovering is required.

In 1999, Melsen and colleagues [27] developed a 6-mm titanium implant for early loading called the "Aarhus implant." It was designed to be placed in multiple locations, (eg. between the roots of teeth). The mini-implant, 6 mm long and 1.2 mm in diameter, was developed to intrude teeth. A titanium plate is attached to the implant and acts as a hook for orthodontic attachment [28]. Mini-screws, unlike endosseous implants, do not attain true osseointegration and therefore are unable to provide the absolute anchorage offered by the Straumann Orthosystem implant and similar devices. The mini-implant achieves primary stability only through mechanical retention, which is less stable than osseointegration. Mini-screws have been shown to extrude and tip forward in the path of orthodontic loading [29].

The Straumann Orthosystem implant is a self-tapping, threaded titanium fixture with a diameter of 3.3 mm and insertion depths of 4 or 6 mm [14]. The surface of the intrabony portion of the implant has been grit-blasted and acid-etched to enhance osseointegration [30]. The implant has a smooth

transmucosal neck and normally is placed in the anterior mid-palatal region using a one-stage surgical technique (Fig. 1). After a healing period of approximately 12 weeks, the implant is connected to two contralateral teeth (usually premolars) by means of a TPA. These teeth then serve as the anchorage units. Considerations in placement of the Orthosystem implant include the avoidance of contiguous anatomic structures such as the nasal cavity, the degree of ossification of the palatal suture, and the quality and quantity of bone in the proposed implant site, all of which are discussed in this article.

Bone reaction to orthodontic implants

Implant stability and adjacent bone reaction have been evaluated both histologically and clinically after orthodontic loading. Trisi and colleagues [31] evaluated retromolar and palatal implants after orthodontic treatment was completed. All the implants were osseointegrated and stable after 12 months of loading. They also reported that treatment time was shortened and that the rate of remodeling was still elevated 18 months after placement. Wehrbein and colleagues [32] and Roberts and colleagues [25] also observed increased remodeling of bone adjacent to orthodontic implants. Melsen and colleagues [27] analyzed peri-implant bone reactions after orthodontic loading. The loading affected both the bone density and turnover, but the extent of osseointegration was independent of implant loading. Wehrbein and colleagues [33] analyzed bone-to-implant contact of retromolar and palatal implants. As in the studies previously cited, the implants were stable and well integrated.

It is well documented that osteoblast behavior may be affected significantly by different implant surfaces [30]. It is somewhat difficult to compare these studies, because differing implant systems and surfaces were used. Nonetheless, it seems clear that implants generally are capable of providing sufficient anchorage for orthodontic purposes, and the bone reaction to these forces seems to be favorable.

Fig. 1. Straumann Orthosystem implant.

Bone quality and quantity

Placement of implants in the bony palate has the potential to cause morbidity resulting from the proximity of structures such as the incisive canal and floor of the nasal cavity. Henriksen and colleagues [34] evaluated the bone in the midline of the anterior hard palate to determine whether there was sufficient bone for placement of 4-mm and 6-mm Orthosystem implants. Lateral cephalometric radiographs were taken of 25 dried skulls, and bone thickness was measured at a point described by the intersection of the midsagittal plane and a plane passing buccolingually through the first premolar teeth. Before the cephalometric exposure, the incisive canal was filled with gutta percha to make the canal radiopaque. Measurements were taken from the inferior aspect of the hard palate to the inferior border of the incisive canal. The mean mid-palatal vertical thickness, including the incisive canal, was found to be 8.6 mm. The mean dimension from the inferior aspect of the hard palate to the inferior border of the incisive canal, however, was only 4.3 mm. This measurement represents the amount of bone available for implant placement. These investigators found that only 50% of the skulls had 4 mm of bone at this site. The remainder of the skulls had less than 4 mm of bone in the mid-palatal region, thus precluding the placement of Orthosystem implants.

Wehrbein and colleagues [35] performed a clinical and radiographic examination of palatal bone in 12 subjects to determine the available bone in the mid-palatal region. Their findings suggest the mid-palatal region provides sufficient vertical support for palatal placement of Orthosystem implants of either 4- or 6-mm length. They reported that the vertical bone height is 2 mm greater than indicated by the cephalometric evaluation. Crismani and colleagues [36] reported similar results in a cadaver study. Specifically, they reported that the cephalometric image underestimated the superior extent of the bony palate by a mean value of 0.8 mm as compared with direct measurement. In the study by Wehrbein and colleagues [35], five patients showed radiographic evidence of implants protruding into the nasal cavity, but no perforations were found on clinical examination. Again, this finding is similar to data reported by Crismani and colleagues [36]. All studies cited in this section involved small numbers of subjects or specimens, so caution should be exercised in interpreting these data. It seems obvious that care must be taken during implant placement to avoid postsurgical morbidity [37].

Anatomy of the bony palate

The anterior portion of the hard palate is formed by the palatine processes of the maxillae, which meet in the midline to form the median palatine suture. The degree of ossification of the median palatine suture varies greatly, as discussed later. The bony palate is thicker in the anterior region but becomes progressively thinner posteriorly. The inferior surface of the

palatine process is uneven and somewhat concave, which has some clinical implications. The superior surface of the palatine process forms most of the nasal floor and is smooth and concave.

The incisive fossa is located in the midline directly behind the central incisors and contains the terminal branches of the nasopalatine nerve and septal branches of the sphenopalatine artery. The nasopalatine nerve provides sensory innervation to the palatal mucosa from canine to canine. The terminal branch of the greater palatine artery contributes to the blood supply of the anterior mucosa of the palate but rarely is of surgical significance [38]. The medial border of the palatine process is thicker in the anterior region. The nasal crest (crista nasalis) is formed by the union of the palatine processes and forms a ridge with which the vomer articulates. The Orthosystem implant is inserted into this area (assuming mid-sagittal placement).

Perforations of the nasal cavity

It is conceivable that placement of an implant in the bony palate could result in perforation of the nasal cavity. Wehrbein and colleagues [35] have suggested that the thick nasal mucosa will prevent open communication with the sinus if a slight perforation through the bony floor occurs subsequent to implant placement. Crismani and colleagues [36] reported that bone perforations of up to 1.3 mm did not result in perforation of the nasal mucosa [36]. A PubMed search using the keywords ''nasal,'' ''perforation,'' and ''implant'' in the title/abstract field found seven articles. Only two dealt with violation of the nasal cavity by palatal implants, and these were the previously cited works by Wehrbein and colleagues [35] and Crismani and colleagues [36]. There were no actual reports of adverse sequelae arising from these or similar implants.

There have, however, been reports of complications arising from perforation of the nasal floor by endosseous implants. One such report involved a 69 year-old woman who developed rhino-sinusitis as a result of two implants perforating the nasal floor [39]. The authors suggest that this condition was caused by changes in the nasal airflow and mucosal irritation and inflammation secondary to the implants. The apical portions of the implants were resected, and the rhino-sinusitis condition resolved. The patient's age may have been a factor, because Lantsov and colleagues [40] found that older patients have impaired circulation of the nasal mucous membrane caused by inadequate microcirculation.

Brånemark and colleagues [41] reported on 139 implants placed in dogs so as to perforate the nasal cavity or maxillary sinus. Twenty-three nasal-perforating implants (NPI) and 25 sinus-perforating implants (SPI) were observed for periods ranging from 2 to 5 years. The success rates were 96% and 88%, respectively. Forty-seven NPI and 44 SPI were observed for 5 to 10 years. The success rates were 72% and 70%, respectively, percentages

that fall below the criteria for implant success (80% at 10 years) [42]. These findings indicate that long-term stability and success of implants perforating the nasal cavity or sinus may be compromised.

An important caveat applies to these findings, however. Brånemark and colleagues [41] did not remove the implants, as would be done with the Orthosystem implant. The act of explantation involves the use of a small trephine, and it seems possible that removal of the implant could contribute to the formation of a patent nasal-oral fistula (whereas the orifice might be occluded functionally while the implant is in situ).

Although not entirely analogous, implants have been placed intentionally in the anterior nasal floor to secure nasal prostheses. Although these implants differ from palatal orthodontic implants, the results may have some relevance to the current discussion. Nishimura and colleagues [43] placed 19 anterior nasal implants for implant-retained nasal prostheses. Seventeen implants were 3 to 4 mm in length, and two were 7 mm in length. The patients were followed for 6 to 74 months. The success rate was 88.1% (15/17). Two implants failed; one failed to osseointegrate in irradiated bone, and the other exhibited inflamed and irritated tissue surrounding the abutment that did not resolve with nonsurgical therapy. These finding are consistent with a previous study in which 16 anterior nasal floor implants were placed and had a success rate of 89.5% (14/16) [44].

In summary, it is not possible to calculate the relative risk of perforation based on the current literature, nor is it possible to determine the likely sequelae of such an event. A useful concept is the number needed to harm, that is, the number of procedures that would be performed before a patient was harmed. This useful concept has become increasingly important in the discipline of evidence-based health care, and tables of such values are being developed for a variety of medical procedures. Such information is not yet available for palatal implant placement, although the authors' clinical experience (and that of others) suggests that significant morbidity is uncommon with the use of this system.

Suture ossification

The degree of ossification of the median palatine suture also is of potential interest when planning implant placement [37]. Persson and Thilander [45] examined histologically the palatal suture closure in 24 specimens from subjects ranging in age from 18 to 35 years. The authors reported that palatal suture ossification did not show any significant degree of closure until the third decade of life. Ossification was found to start earlier in the posterior than in the anterior segment of the suture and to progress faster in the oral than in the nasal aspect of the palate. Schlegel and colleagues [37] examined ossification of the mid-palatal suture anatomy at various ages. They removed trephined bone cores from the mid-palatal suture at

the first premolar site in 41 cadavers of persons aged 12 to 53 years at death. The investigators' findings indicate that closure of the median palatal suture is rare in individuals younger than 23 years of age. Furthermore, the authors propose implant placement posterior to a plane bisecting the first premolars, because the suture often is more ossified as one proceeds posteriorly. The authors suggest that the risk of failure is small because the implant will be in contact with bone around most of its circumference because of the small size of the sutural gap.

Melsen [46] performed a histologic study of 60 specimens from persons 0 to 18 years of age. The author investigated the morphologic development of the median palatine suture in three stages. During the infantile stage, the suture is broad and Y shaped. The suture becomes longer and winding in the juvenile stage. In the third, or adolescent, period the suture becomes increasingly tortuous and interdigitated. Revelo and Fishman [47] compared the mid-palatal suture using occlusal films with the skeletal maturity indicator (SMI). As the SMI stages proceeded through adolescence, the degree of fusion increased. The anterior portion of the suture had less fusion than the posterior aspect of the suture. By the end of adolescence (SMI 11), only 50% of the total mid-palatal suture was fused.

Wehrbein and Yildizhan [48] examined autopsied tissue blocks from 10 specimens from persons between 18 and 38 years of age at death to determine the correlation between the appearance of the median palatal suture on occlusal radiographs and histologic assessment of the degree of ossification. The degree to which patency of the suture can be assessed is determined by the coincidence of the central x-ray beam with the sutural space. In the group in which the suture was radiographically visible (group 1), the sutural space was parallel with the central beam. In the group in which the suture was not visible suture (group 2), the sutural space was not aligned with the path of the central beam. Group 1 also had a smaller amount of interdigitation than group 2. In group 2 the vomer was located immediately superior to the suture and was aligned with the space. The amount of obliteration and suture width was not a major factor in determining whether the visible suture was open. Based on these findings, it would seem that the degree of ossification of the median palatal suture cannot be predicted by occlusal radiography.

Bernhart and colleagues [49] proposed placement of orthodontic implants paramedial to the median palatal suture. Twenty-two patients were included in the study. CT was used to determine the vertical bone volume in the anterior palatal region. The results indicated the best location for implant placement was 6 to 9 mm posterior to the incisive foramen and 3 to 6 mm paramedial to the palatal suture. Implant placement 3 to 6 mm lateral to the median palatal suture coincides with Henriksen and colleagues' [34] findings that the width of the incisive canal is 2.5 mm. Bernhart and colleagues [49] placed short implants lateral to the palatal suture for orthodontic anchorage. Twenty-one patients were included in the study. None of the

implants failed during healing, although three implants failed during orthodontic loading. Two of these failures occurred shortly after loading was initiated; the third implant loosened 8.5 months after loading.

The absolute anchorage provided by palatal orthodontic implants has proven to be useful in orthodontic treatment and is well accepted by patients [50], but placement of these implants requires a certain quantity and quality of bone. Insufficient bone thickness conceivably could result in perforation of the nasal cavity.

Clinical protocol

A preoperative lateral cephalometric film is obtained, and the bony dimensions of the palate are estimated. Wehrbein and colleagues [35] have reported the radiographic bony thickness to be approximately 2 mm less than the actual bony thickness, but this report should be confirmed by other studies. The authors previously have reported that the first premolar site is ideal from the standpoint of adequate bone thickness [51,52]. Placement often is planned in a location slightly lateral to the mid-sagittal suture. The anterior hard palate is anesthetized. Specifically, nasopalatine and greater palatine blocks are usually administered.

A special mucosal trephine is used to remove the palatal mucosa at the proposed osteotomy site (Fig. 2), and the palatal bone is perforated with a small round bur. After removal of the mucosa with the trephine, the site should be inspected to ensure all soft tissue remnants are removed so that the implant will be fully seated against the bone with no intervening soft tissue. If the palatal surface is uneven or rough, it sometimes is desirable to smooth it with a rotary instrument, but care must be taken not to remove too much bone. It is the authors' clinical impression that early clinical stability is enhanced when the implant can be firmly seated so that the flat area abuts the bone over a broad area.

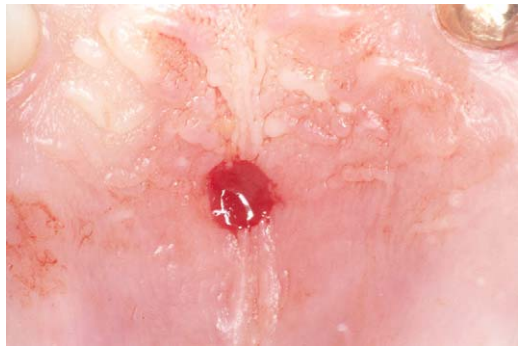

Fig. 2. Hole in mucosa created with trephine.

A profile drill is used to create the osteotomy site. The drill has a flat stop to limit depth of penetration. It is most important to align the drill so that the centerline of the hole is perpendicular to the bony surface. This precaution helps ensure that the flat of the implant rests firmly on the bone. If the hole is drilled at an angle to the surface, only one edge of the rim will rest on bone, and the implant will be much less stable. The self-tapping implant is connected to the insertion device, placed into the osteotomy site, and screwed in by hand until completely seated. Great care should be exercised to stop turning the implant once the flat surface is seated against the bone. Further turning of the implant at this point will cause the threads to be stripped or reamed and will result in instability. The manufacturer suggests that either a healing cap or a small screw be placed on the implant body. The authors use the small screw because it is less noticeable to the patient.

A lateral cephalometric radiograph is obtained postoperatively. The work of Wehrbein and colleagues [35] suggests that it is difficult to predict clinical perforations of the nasal mucosa, although Daniel's [52] findings contradict this assertion. Unfortunately, both studies involved small sample sizes, and more conclusive recommendations must be based on larger studies.

After placement, the implant is allowed to integrate for 12 weeks. The manufacturer recommends that the implant not be brushed for 7 days, although the authors generally have patients avoid brushing it for 2 weeks. During that time, chlorhexidine rinses are prescribed for use two or three times daily. The patient is seen for a variable number of postoperative visits. At postoperative week 10, success is judged by a lack of inflammation in the peri-implant mucosa, lack of patient symptoms referable to the implant, and a high-pitched sound on percussion (Fig. 3). An impression can be taken at week 10, but the implant should not be functionally loaded (ie, the TPA attached) until week 12 (Fig. 4).

Ten weeks after implant placement, an alginate impression is taken of the implant with an impression coping in place of the healing cap. An implant analogue is inserted into the impression cap, and the impression is poured in yellow stone. The resulting cast is sent to the laboratory for fabrication of

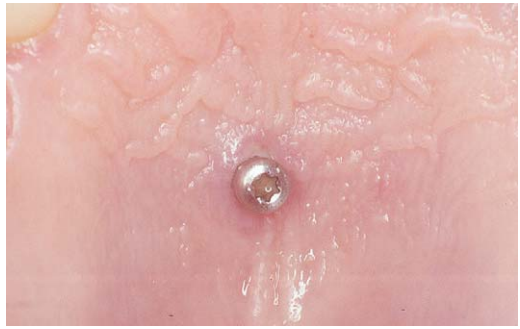

Fig. 3. Implant in situ, 10 weeks postoperatively.

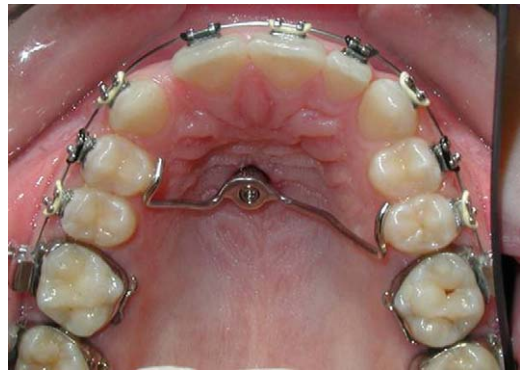

Fig. 4. Implant in situ, with transpalatal arch attached.

a TPA that will be secured to the implant and bonded to the teeth chosen to serve as anchorage units.

Upon completion of active tooth movement, explantation of the implant is performed using a purpose-built trephine. Before explantation, the TPA or screw is removed, and a special metal rod is placed on the implant to guide the trephine. The trephine is used at low speed and with copious irrigation to a depth of about two thirds of the insertion depth. It usually can be removed with a gentle rotational force with a pair of extraction forceps. After explantation, the wound is allowed to heal by secondary intention. The authors' postoperative protocol calls for the use of chlorhexidine rinses for 2 weeks postoperatively.

The authors believe that early mechanical stability (in the time between placement and osseointegration) is an important factor in ensuring the predictability of this particular implant. The stability during this period derives from the mechanical friction-fit of the implant within bone. With conventional tooth-replacement implants that have a sandblasted and acid-etched surface, this period can be quite short [53–55]. The orthodontic implant is much smaller in diameter and insertion depth, however, and its thread dimensions are smaller. These factors (plus its vulnerable location on the palate) may make it especially susceptible to micromotion [56]. Every precaution should be taken during placement to ensure that the implant is as stable as possible. These precautions include careful osteotomy preparation combined with careful insertion of the implant during placement.

Summary

Conventional means of achieving orthodontic anchorage have a number of shortcomings. To some extent, these shortcomings can be overcome through the use of orthodontic anchorage. The Straumann Orthosystem implant system offers a method for achieving absolute anchorage. Surgical

placement of these implants involves the potential for violating certain contiguous structures such as the floor of the nasal cavity. Knowledge of the anatomy of the area and careful planning are essential to avoid postoperative morbidity. The use of a preoperative lateral cephalometric radiograph is recommended, although other imaging modalities may offer advantages over this modality and may someday supplant it.

Care must be taken during osteotomy preparation and insertion of the implant to avoid introducing mechanical instability. It may be wise to use the 4-mm implant (in lieu of the 6-mm version) whenever possible. Placement of the implants should, in most cases, be limited to the region contiguous with a line bisecting the contralateral first premolars. Although the influence of ossification of the suture on implant integration is not established definitely, it may be prudent to place the implant slightly lateral to the suture (especially in younger individuals). The clinical experience of the Divisions of Periodontology and Orthodontics at the University of Kentucky suggests that these implants may be a valuable adjunct to conventional orthodontic tooth movement. Care in planning and execution has resulted in a high degree of success with minimal morbidity.

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