Interdisciplinary collaboration: an approach to optimize outcomes for patients with compromised dental esthetics

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Introduction

Over the past 20 years, the knowledge base of the dental profession in terms of both the art and science of practice has significantly expanded. The amount of information and the application of treatment for patients are often overwhelming. Despite the convenient access to knowledge in the modern world, it has become increasingly difficult for single clinicians to address all the needs of their patients.

Within dentistry, the benefit of collaboration between dental professionals to treat patients through an interdisciplinary approach is not a new concept.[1-5] Moreover, it is usually rewarding for the clinician and can produce optimal results for the patient. Today, a broader approach to patient care is recognized. As research progresses in dental therapy, and more is known about the oral–systemic connection and tissue engineering, interdisciplinary collaboration is paramount for the continued development of both dentistry and medicine.[6-8]

Certainly, challenges often arise when working as part of a team, and research and clinical experience have revealed some of these challenges.[9-11] Therefore, the need to understand how best to learn from each other and to share knowledge is fundamental to a successful interdisciplinary relationship. With this greater understanding, the elements of communication, commitment, mutual trust, and respect allow for greater acceptance of the responsibilities of each discipline.[1,7,12]

In this article, information is presented that is valuable to all members of the dental team so they can effectively participate in collaborative treatment. Certain esthetic dilemmas may be simple, while others are more complex. Some of the significant treatment challenges include malproportioned, injured or nonrestorable teeth; ectopically positioned or missing teeth; and altered periodontal attachment or ridge form. The shared interdisciplinary process of planning, design, communication, coordination, and execution of treatment for the esthetically compromised dental patient is reviewed in this article.

Fig 1

Fig 2

Space and alveolar ridge deficiencies

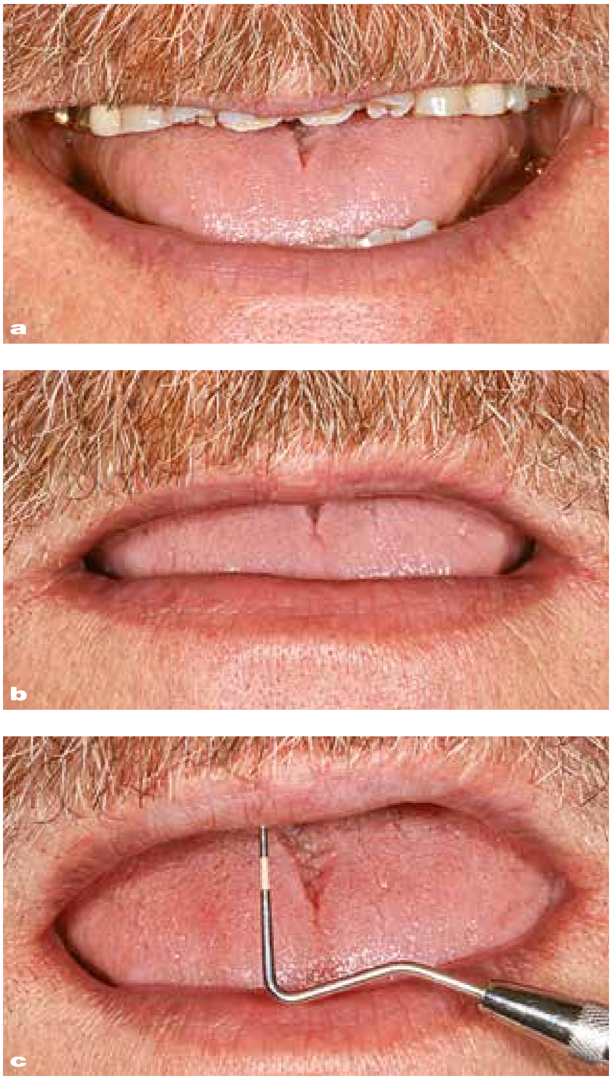
Esthetic compromise may be present in several different ways. However, it typically occurs in the dentition that has some degree of clinical "deficiency". Occasionally, patients may present with both hard and soft tissue deficiencies due to disease, trauma or missing teeth.[13] In addition to tissue deficiencies, patients frequently have insufficient spacing for the placement of implants or the replacement of teeth.[14,15] If these areas are not evaluated and addressed during the treatment-planning phase, the final result will be compromised. Consequently, the mismanagement of these parameters may result in malproportioned teeth, lack of proper soft tissue symmetry, and/or aberrant relationships between the papilla height and the contact length.[16,17] Poor planning may also create challenges for proper implant placement, leading to difficulties in managing the occlusion and potential speech problems.

The following discussion addresses the role of interdisciplinary treatment in the evaluation and management of patients with a variety of clinical "deficiencies". The topics covered include space appropriation for teeth and implants, and considerations for deficient ridges when planning tooth replacement for both adults and growing patients.

1. Space appropriation

Appropriate position of teeth

There are a number of different circumstances that can impact the ideal positioning of teeth. The most common tooth-position problem is crowding, and treatment to resolve this issue is usually predictable. Teeth are aligned orthodontically according to their mesiodistal widths and as long as there is not a clinically significant tooth-size discrepancy, the esthetics and occlusion can be established well.[18] Unfortunately, space appropriation becomes more challenging when faced with clinical findings that include multiple missing teeth, retained deciduous teeth, or malproportioned teeth[19,20] (Fig 1). Therefore, it is imperative for the orthodontist to work with the restorative dentist when determining



Figs 3a to 3c

ideal spacing and appropriate tooth position in these patients. It is also important to begin the treatment-planning process by determining the correct "esthetic" position of the teeth as it relates to the patient's face. After this has been established, attention can be focused on positioning the teeth for proper function. This process is called "Facially Generated Treatment Planning" (FGTP), and has been discussed in depth by Spear.[21] This basic concept of FGTP is derived from how teeth are ideally positioned in a complete denture setup.

Developing a treatment plan based on the position of the teeth relative to the face minimizes challenges that arise when trying to create a plan utilizing only mounted diagnostic models and radiographs. A perfect example of this is the patient with a worn dentition (Fig 2). Many patients who experience significant incisal edge wear also develop compensatory eruption, which maintains the initial incisal edge level relative to the face. In this scenario, treatment alternatives may include osseous crown lengthening or orthodontic intrusion to move the crestal bone and gingival levels apically into a more esthetic position. Both of these options ultimately produce a final, restored incisal edge position that is similar to the pretreatment incisal edge level. Other patients with more generalized tooth wear may experience a greater loss of vertical dimension requiring more extensive crown lengthening to re-establish a favourable lower facial height. To be able to choose the appropriate treatment plan, it is important to always first identify the desired position of the maxillary central incisors. It is difficult to set any other teeth first because we have no reference for where they should be positioned. In order to do this, the clinician will evaluate the relationship of the teeth to the lips in repose and during full smile, to the position and curvature of the lower lip, and

Fig 4

Figs 5a to 5c

to the horizon or interpupillary line[22,23] (Figs 3a to 3c). After the central incisor position is selected, the positioning of the laterals, canines, premolars, and molars becomes more predicatable. Following this step-by-step process provides guidelines for treatment planning with predictable esthetic outcomes and no compromises at the end of treatment (Fig 4).

Appropriate spacing of teeth

The orthodontist plays a key role in helping to establish proper space requirements for patients with missing teeth or retained deciduous teeth (Figs 5a to 5c and Fig 6). However, in this example, two questions arise: Given the obvious difference in tooth dimensions between the deciduous and permanent teeth, how does the orthodontist know where to position the teeth in order to provide adequate room for replacement of the

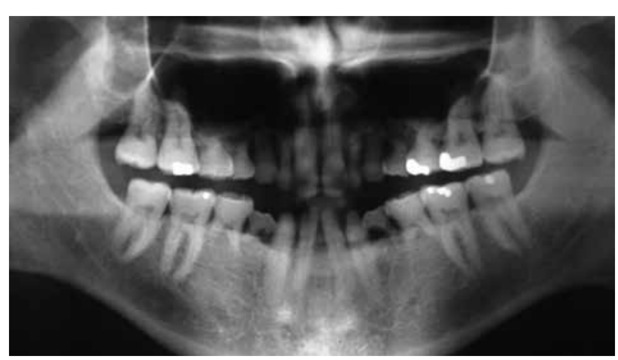


Fig 6

deciduous teeth? Also, since the alveolar ridges were never developed by the eruption of permanent teeth, what is the most appropriate way to manage these deficient ridges?

The most common mistake that most orthodontists make when trying to appropriate space for patients with multiple missing teeth is doing it without any input from their fellow interdisciplinary team members. For a predictable outcome when planning treatment for these patients, it is imperative that the orthodontist be aware of the desired final restorative and surgical objectives. Actually, the restorative dentist has the most influence over final tooth position, while the orthodontist educates the team on which tooth movements are biomechanically realistic and when auxiliary implant anchorage may be necessary to achieve those initial restorative and surgical goals. The surgeon and restorative dentist understand the importance of ideal implant location and appropriate tooth dimension, respectively, as they relate to function and esthetics. Therefore, orthodontic space appropriation should be determined based on a collaborative effort by the interdisciplinary team.

Conversely, the orthodontist has primary control over space appropriation in patients with single missing anterior teeth. It is thus rarely necessary in these situations for the orthodontist to solicit input from the restorative dentist and surgeon unless the patient exhibits abnormally small teeth. The literature outlines four specific ways to appropriate space for the single missing anterior tooth.[24-26] The first method is utilization of the golden proportion. However, since this perceived value has no true relation to the actual measured widths of the teeth, it has no value to the orthodontist when creating the proper spacing. The second alternative to determine ideal spacing is to use the contralateral tooth as a guide. However, it is not suitable for patients whose contralateral tooth is missing or malformed. A third option utilizes the Bolton analysis to mathematically compare the widths of the maxillary and mandibular anterior teeth.[18] The Bolton ratio is 0.78 and a mathematical equation can be used to achieve the unknown

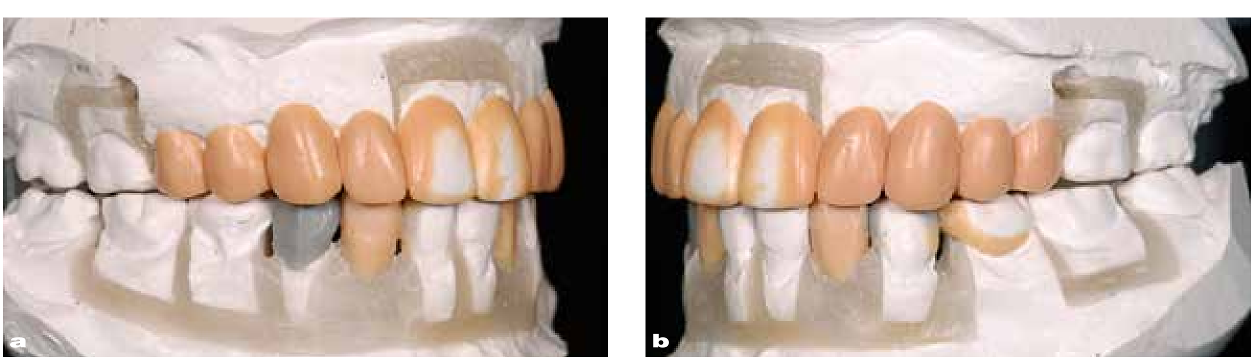
Figs 7a and 7b

width(s). Finally, the most predictable guide for determining appropriate spacing is to construct an orthodontic setup/diagnostic wax setup. This setup is used to determine the position of the teeth necessary for optimal esthetics and proper development of the lateral and protrusive functional pathways.

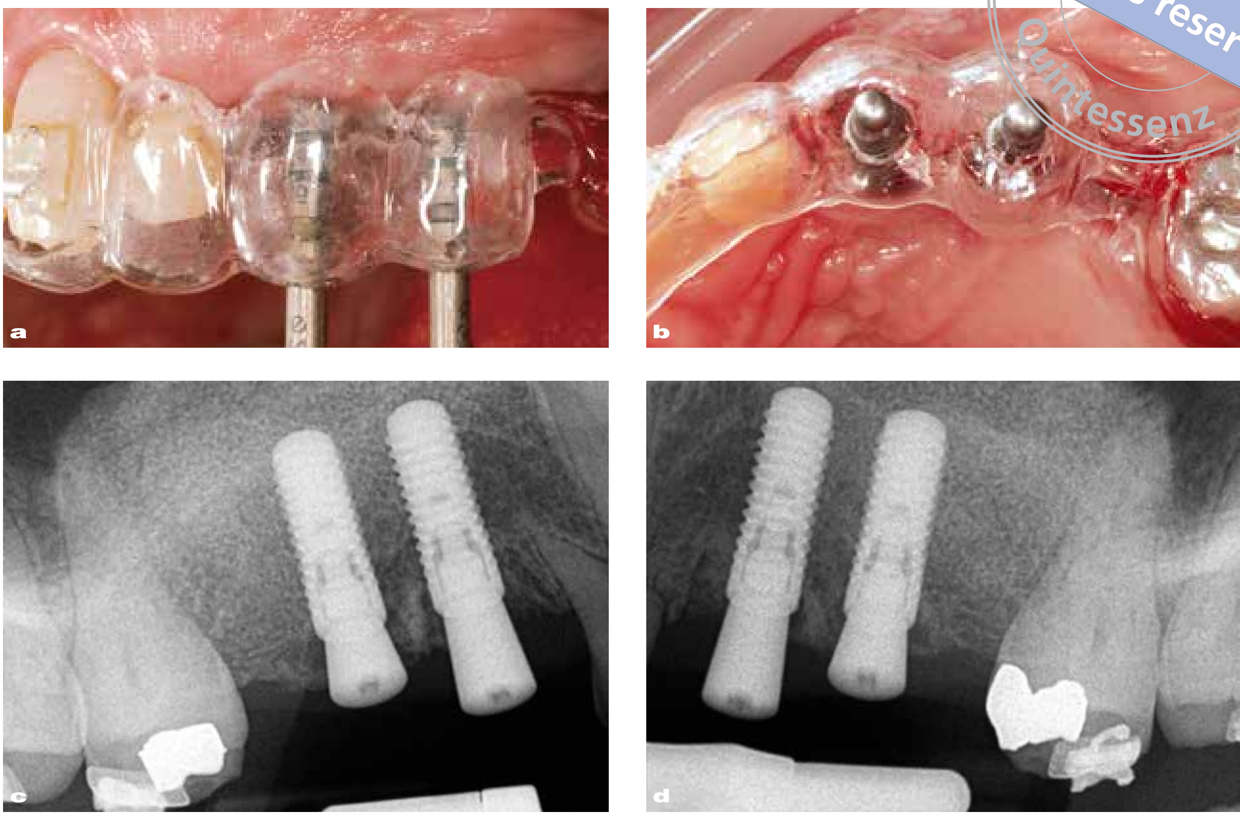
Case example

As discussed above, it was important to begin by determining the correct esthetic and functional position of the maxillary central incisors relative to the face (Figs 7a and 7b). After evaluating those parameters, it was determined that the shortening the incisal edge and increasing the width would enhance the esthetic appearance of the central incisors.

Once the position and shape of the maxillary central incisors were established, diagnostic waxing was used to determine correct size and position for the lateral incisors, canines, and premolars. This, in turn, helped to confirm the position of the natural first molars, which were not in need of restoration. The position of the mandibular incisors is based in part on esthetics and in part on function. Generally, the amount of overbite or vertical overlap of the incisors is related to the cusp-fossa relationship of the posterior teeth. The deeper the cusp-fossa relationship, the greater the overbite must be to ensure proper disclusion of the posterior teeth. The posterior teeth for this patient had a relatively flat topography, which meant that less incisor overlap was required for function. The benefit of maintaining a shallower anterior guidance is to observe force distribution during lateral disclusion. For this patient, maxillary implants were used to guide the lateral disclusion; therefore, it is important to understand the impact that the disclusion angle has on the functional success of the restoration. For every 10 degree increase/decrease in the angle of disclusion, there is a 32% increase/decrease in torsional stress at the abutment level.[27] Therefore, to help provide some proprioception during lateral disclusion, it was decided that the mandibular canines should be orthodontically moved distally into a more ideal canine position. The intention



Figs 8a and 8b



Figs 9a to 9d

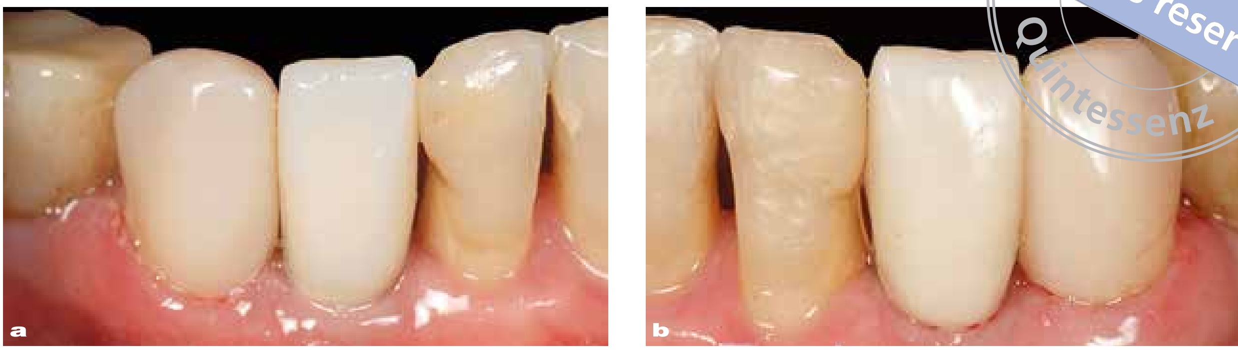
was to produce a lateral disclusion not completely derived by two implants opposing each other. It is also important to understand that, at this point, the diagnostic setup is simply an estimate of anterior/posterior tooth position that requires confirmation by way of a thorough clinical examination (Figs 8a and 8b).

Following completion of the diagnostic setup/wax-up, the orthodontic phase of treatment can begin. One common challenge in managing these types of patients is translating the diagnostically derived tooth position back to the mouth. There are, in fact, several ways this can be accomplished. If the diagnostic work-up was digitally created (ie, Invisalign), then the communication of tooth position can be accomplished through the aligners. Another method can be to correct the tooth size intraorally by changing crown shape with composite or by placing provisional restorations. A third alternative can be to orthodontically estimate the correct tooth position and then periodically re-evaluate the position with progress models and a subsequent diagnostic wax-up. All three techniques can be used successfully, and occasionally it may be necessary to utilize more than one option for the same patient.

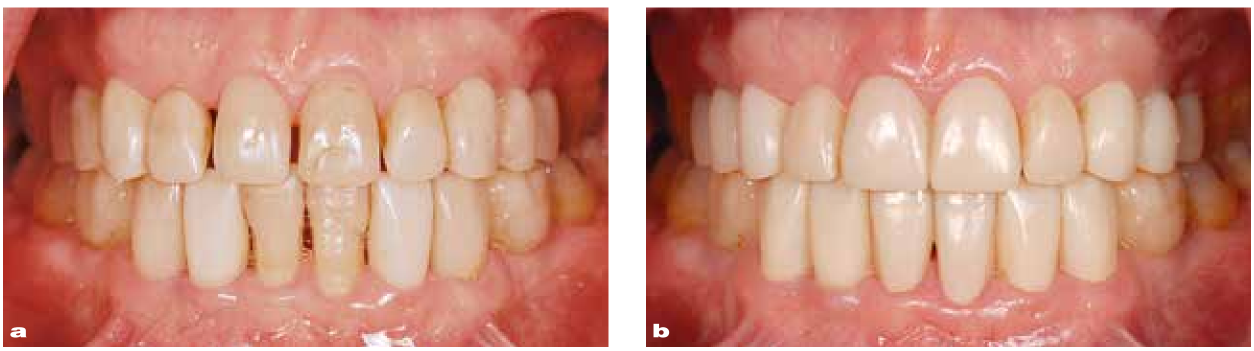
For the patient shown in Figure 9, the first surgical phase of treatment consisted of extracting the primary molars, placing two mandibular molar implants, and sinus bone grafting. Following integration, these implants were provisionally restored so that they could be used as anchorage to retract the natural canines into a more ideal canine position. The second stage of surgery consisted of placing implants in the maxillary canine and first premolar sites. The ideal location for these implants was communicated to the surgeon by way of a surgical guide fabricated from a diagnostic wax-up completed on an orthodontic progress model (Figs 9a to 9d). It is important to also note that implants were not placed in the second premolar position at that time due to insufficient space. Once the canine and first premolar implants were provisionally restored, orthodontic appliances were bonded to the provisional crowns and the molars were distalized to create adequate space for implant replacement of the second premolars. The third and fourth surgical phases allowed for implant placement in the mandibular anterior and maxillary second premolar positions (Fig 10). All tooth movements and implant positions were ultimately determined by the initial diagnostic setup/wax-up (Figs 11a and 11b). However, since the diagnostic work-up is only an estimate, it is often necessary to make progress models during orthodontic treatment in order to confirm final tooth position. For example, the mesiodistal spacing in the mandibular lateral incisor sites appeared too large. In this case, refining tooth form by bonding composite resin to the canines and provisionally restoring the lateral implants provided guidelines for tooth position as the orthodontics was finalized (Figs 12a and 12b). Finally, the maxillary and mandibular central incisors were provisionally restored following completion of orthodontics (Figs 13a and 13b). By following the steps that have been reviewed, the final restorative treatment becomes predictable (Figs 14a to 15b).

Fig 10

Figs 11a and 11b

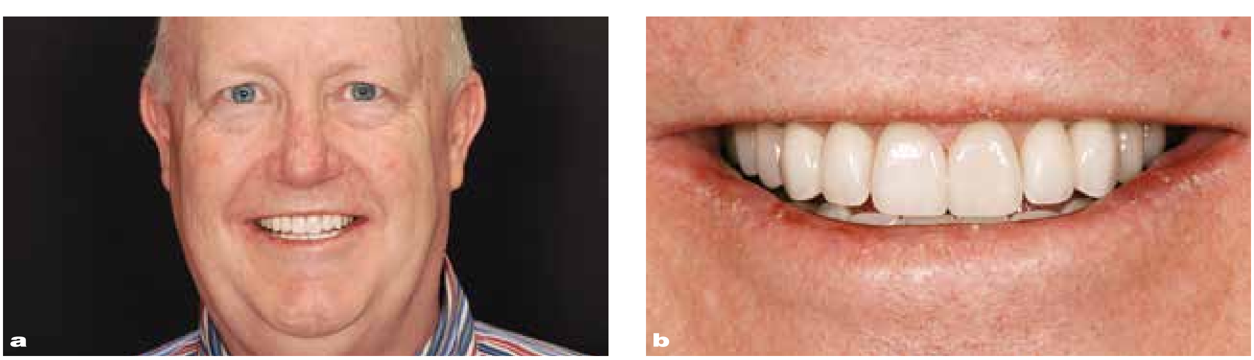


Figs 12a and 12b



Figs 13a and 13b

Figs 14a to 14c



Figs 15a and 15b

Class	Restorative environment	Proximity limitations (mm)	Vertical soft tissue limitations (mm)
1	Tooth-tooth	1.0	5.0
2	Tooth-pontic	NA	6.5
3	Pontic-pontic	NA	6.0
4	Tooth-implant	1.5	4.5
5	Implant-pontic	NA	5.5
6	Implant-implant	3.0	3.5

Fig 16 Adapted from: Salama H, et al. The interproximal height of bone: a guidepost to predictable aesthetic strategies and soft tissue contours in anterior tooth replacement. Pract Periodontics Aesthet Dent 1998;10:1131–1141.

2. Alveolar ridge form

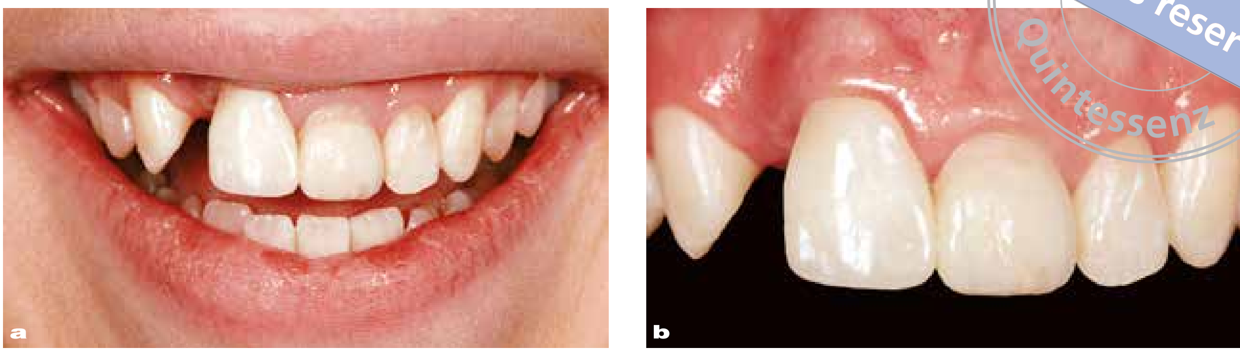
Ridge dimension (horizontal) – restorative considerations

When an edentulous site is present, it is important for the restorative dentist to understand the limitations of alveolar bone regeneration and how they may influence the restorative treatment-planning process.[28] It is also critical to understand the relationship between the underlying bone and soft tissue. As has been shown by Salama et al, there are limitations to the amount of soft tissue height that can predictably be maintained above the crest of bone[29] (Fig 16). The chart in Figure 16, adapted from the Salama et al article,[29] shows the height of soft tissue will vary, depending on the clinical situation and the treatment option. The most difficult clinical scenario for the team to resolve is the presence of two adjacent edentulous sites in the esthetic zone. Achieving ideal papillae height in these patients is not only unpredictable but also directly impacted by the challenge the surgeon faces when attempting to augment the vertical bone height. Therefore, placing adjacent implants in the esthetic zone is generally avoided in favor of treatment options that enable the soft tissue height to be more predictably maintained.

A deficiency in ridge form may arise as a result of factors such as disease, missing teeth, and trauma. Prior to the restoration or replacement of missing teeth, it is necessary to evaluate the parameters that will lead to an esthetic result.[31] In patients requiring multiple tooth replacement, specific factors such as the span of the edentulous space, periodontal attachment levels on adjacent teeth, alveolar ridge form, and soft tissue profile and thickness will influence the predictability of the different treatment options and ultimately the final esthetic outcome. Therefore, creating an ideal recipient site in both the horizontal and vertical dimensions prior to the replacement of missing teeth allows for ideal implant placement and a predictable esthetic outcome.[32]

Case example

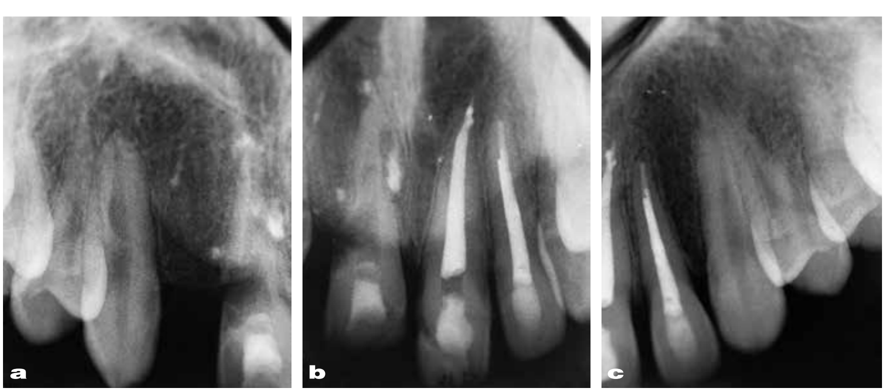
A 17-year-old female patient presented with a dental history that included trauma to the maxillary anterior teeth at the age of 10, which resulted in the avulsion



Figs 17a and 17b

of the maxillary right central and lateral incisors (Figs 17a and 17b). Although the teeth were replanted, the lateral incisor subsequently fractured and was extracted at age 15. As can be viewed in the radiograph, the maxillary right central incisor is ankylosed and undergoing replacement resorption (Figs 18a to 18c). When this crown fractures, it will create two adjacent edentulous sites. When comparing the current papilla height on the distal of the central incisor to the contralateral papilla, an approximately 6 mm difference in height is evident. Presently, the central incisor is providing a supracrestal gingival attachment. As a result, this discrepancy will increase once the central incisor fails. Therefore, it is important to develop a treatment plan that will be predictable and provide an excellent esthetic result. The three typical treatment plans that would be considered for this clinical situation are the following:

1. Augmentation of the ridge and the placement of two implants – the maxillary right central and lateral incisor sites.
2. Augmentation of the ridge and the placement of one implant – the maxillary right central incisor site and cantilever the lateral incisor.



Figs 18a to 18c

Fig 19

Fig 20

3. Augmentation of the ridge with soft tissue and the placement of a 4-unit tooth-supported fixed partial denture (FPD).

When evaluating the current and projected hard and soft tissue levels and comparing them with the soft tissue height limitations published by Salama et al, it becomes evident that matching papillae height to the contralateral side is extremely challenging.[29] As mentioned above, the simplest and most esthetic implant tooth replacement is the single tooth site bordered by healthy adjacent teeth with normal periodontal attachment. Therefore, the most predictable and esthetic treatment plan would be to create two single tooth implant sites by orthodontically moving the canine into the lateral incisor position. This would not only develop the deficient ridge in the lateral incisor site, it would also create bone and provide a supracrestal attachment on the mesial and distal for a more ideal soft tissue profile that matches the contralateral side (Fig 19). The ankylosed central incisor was utilized as orthodontic anchorage to move the canine mesially and was not extracted until after the canine was moved into the lateral incisor position. The edentulous sites were then augmented, the implants placed, and facial crown lengthening completed on the

Figs 21a and 21b

maxillary left central incisor to reposition the gingival margin (Fig 20). Following integration of the maxillary right canine and central incisor implants, provisional crown restorations were placed. Direct composite was bonded to the right lateral and left central incisors (Figs 21a and 21b). In this patient, a significant improvement in a vertical soft tissue position was achieved through horizontal tooth movement, one that would have been extremely difficult to accomplish with adjacent edentulous sites.

Ridge dimension (horizontal) – surgical considerations

The clinical scenario that yields the most predictable and esthetic implant tooth replacement is the single tooth site bordered by healthy adjacent teeth with normal periodontal attachment. Whether it is an orthodontic patient with congenitally missing teeth or a restorative patient with a history of trauma or failed treatment, the approach is similar.

In order to achieve an esthetic outcome, there are certain biologic parameters that need to be understood. Dental implant therapy has been criticized as being unesthetic.[33,34] Outcomes have been noted showing facial tissue recession and interproximal papillae loss. This was certainly more common in the early years when implant therapy was transitioning from the fully edentulous patient to the partially edentulous patient. Fortunately, the biologic limitations of implant placement are better understood today.[35-37] Bone remodeling around the platform of an implant is a normal process after abutment connection. This remodeling occurs 360 degrees around the implant in both the vertical and horizontal directions. Therefore, the dimensions of the alveolar ridge and recipient site are of particular importance.

It has been shown that a dental implant should not be closer than 1.5 mm to a natural tooth.[38] The resultant circumferential bone remodeling can cause periodontal attachment loss on an adjacent tooth with subsequent loss of papillary height. Since there is no connective tissue fiber insertion to an implant, the form and height of the papillae are dependent on a healthy attachment to the tooth. Therefore, the orthodontist must be aware of this limitation when creating space to allow for implant replacement of missing teeth.

Similarly, on the facial, a lack of bone or bone remodeling can lead to gingival margin recession and flattening of the tissue form. Although modern restorative materials can help to overcome some of the "shadowing" of the tissues that often results with soft tissue changes, the long-term esthetic result may not be predictable. Recent esthetic assessments have noted that esthetic implant-supported crowns have a convex facial–gingival contour, along with a similar tissue color and texture as that of the adjacent teeth.[40,41] To achieve this contour, it is important to plan for appropriate augmentation. In fact, a narrow alveolar ridge often requires augmentation for both implant and soft tissue support. Various methods have been developed and studied, including the use of autogenous bone block grafts, guided bone regeneration, and ridge split techniques. Recently, a systematic review of studies reporting lateral ridge augmentation outcomes was completed,[43] which showed that all methods appear to be successful when it comes to the survival of implants. The guided bone regeneration technique has the most long-term documentation and appears to be the most common procedure performed for lateral ridge augmentation.[43,44] Other important details, such as the differences in bone remodeling that each technique will have on the esthetic outcome, are unknown because this type of comparative study has not been done.

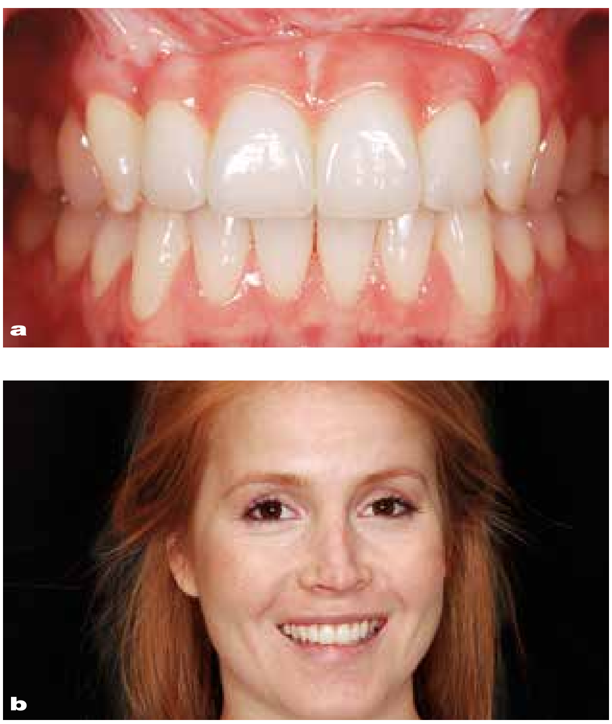
Subsequently, it is necessary for alveolar ridge augmentation procedures to regenerate bone not only for implant support but also for "contour augmentation" in order to provide a stable soft tissue framework for the implant restoration.[42] Investigations into the stability of these techniques continue, along with the benefits of adding soft tissue grafting together with implant placement.[45-48]

Ridge dimension (horizontal) – orthodontic considerations

As explained above, the most esthetic implant restoration is one that has two healthy teeth with normal periodontal attachment on either side. In addition, smaller edentulous sites provide adjacent teeth with a normal interproximal periodontal attachment that can be used as a guide and scaffold for ridge augmentation procedures. When confronted with multiple missing teeth, it is often beneficial for the interdisciplinary team to recommend orthodontic treatment in order to move teeth in a horizontal direction. Redistributing the space and creating single tooth implant sites can overcome the esthetic limitations of consecutively placed implants. Using orthodontic tooth movement to reduce larger partially edentulous sites has several advantages. It improves periodontal attachment levels, helps to avoid consecutive implant placement, develops better pontic sites, and helps the surgeon with the bone augmentation procedure. When considering this type of lateral tooth movement, it is also important to understand what happens biologically to the alveolar ridge. Although the following research has focused on the alveolar response to movement of premolars and molars into narrower edentulous ridges, the principles discussed can also be applied to the alveolus in the anterior maxilla.

A common question faced by every orthodontist is whether or not to extract an ankylosed primary molar that has no permanent successor. If the decision to extract the tooth is made before significant eruption of the adjacent teeth has occurred, then the periosteal pull between the erupting adjacent teeth will stimulate bone deposition.[49] However, occasionally, the decision to extract the ankylosed and submerged deciduous second molar is made too late, resulting in a narrow alveolar ridge with a vertical defect. If nothing is done at the time of surgery to try to maintain the buccolingual volume of bone, it is typical to see a 30% loss in ridge width in the first 7 years following extraction.[50] One option to gain adequate ridge width and height for implant placement in this site is to perform a bone graft. Another possibility exists if the patient is willing to undergo orthodontic therapy. In this latter scenario, it may be advantageous to move the first premolar laterally into the second premolar position, thereby creating space for the single-tooth implant in the first premolar location. When faced with

Fig 22



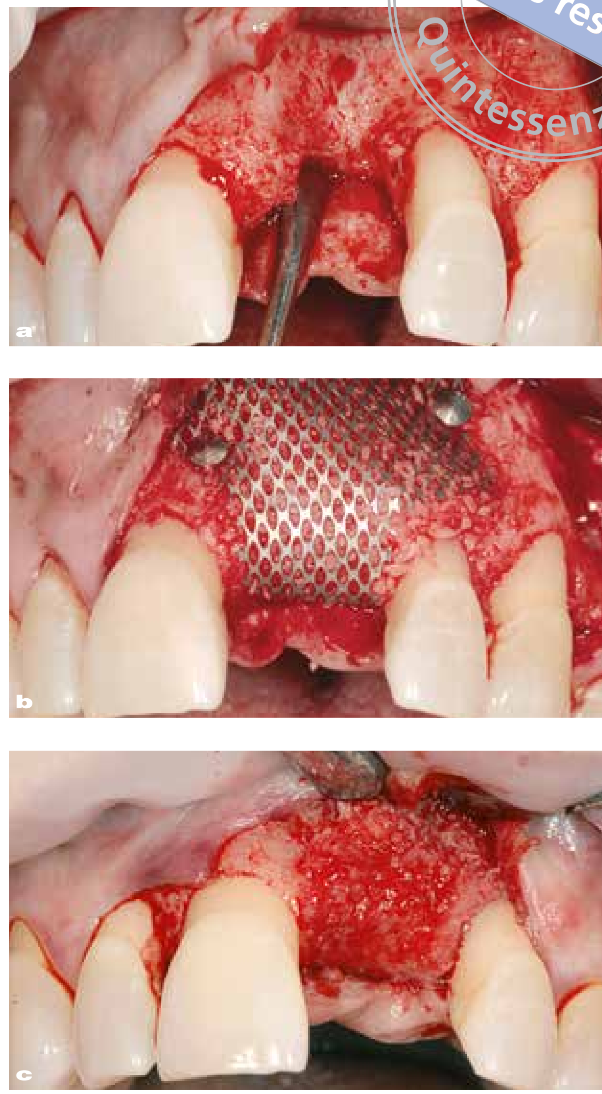
Figs 23a and 23b

this decision, clinicians are often fearful that there is insufficient alveolar ridge width in which to move the permanent first premolar. However, previous studies have shown that a wider tooth root can be moved through a narrow alveolar ridge without compromising the eventual bone support around the repositioned tooth root.[51,52] In fact, Hom showed that the average increase in ridge w[illegible] molar is moved into a narrower ridg[illegible] 1.2 mm.[49] More recently, in a case series of six patients, it was reported that ridge width increased an average of 1.6 mm when larger second premolars were moved into narrower, edentulous first premolar sites.[53]

Another question often associated with this treatment option is stability of the new bone formation. In 2013, Eliášová and colleagues conducted a study that evaluated 71 congenitally missing mandibular second premolar sites following orthodontic movement of the mandibular first premolar into the second premolar site. Their objective was to determine the stability of this orthodontically created ridge width 5 years after the completion of orthodontic treatment. They found that the increased ridge width was relatively stable, decreasing an average of 4.2% over 5 years.[54] A previous study conducted by Nováčková and colleagues in 2011 investigated the stability of alveolar bone developed through orthodontic distalization of the permanent maxillary canine in patients with congenitally missing lateral incisors. They also found excellent stability in both the vertical and horizontal dimensions. In fact, there was only a 2% decrease in alveolar ridge width 5 years after orthodontic treatment.[55]

Ridge dimension (vertical) – restorative considerations

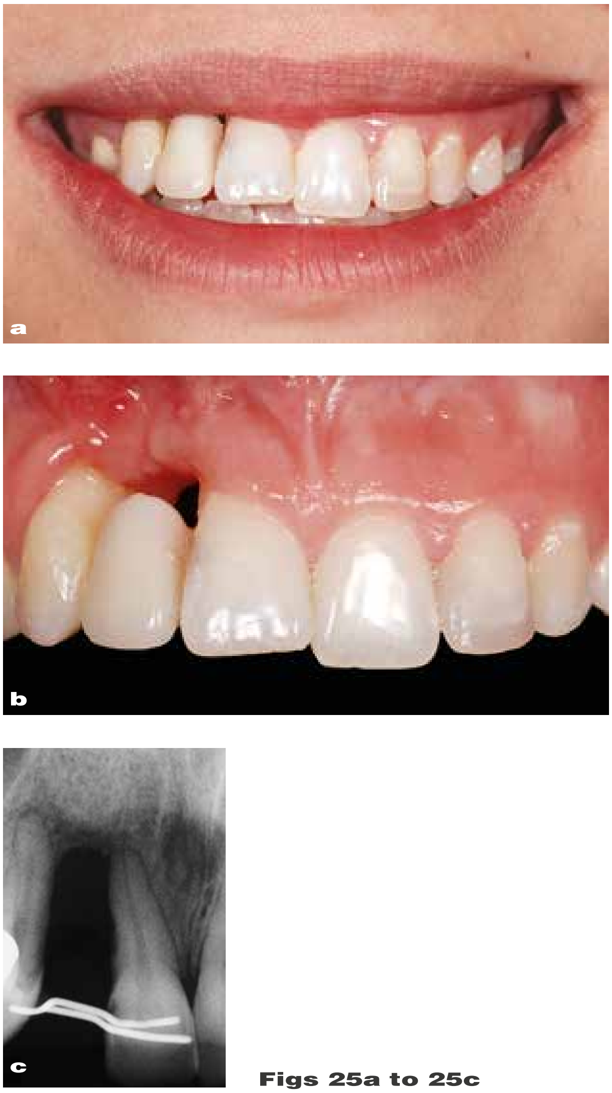
Several treatment options exist for replacing multiple missing anterior teeth, including implants, FPDs with pontics, implants with pontics, and implants or FPDs with pink ceramic/composite.[56-59] In order to determine the most appropriate alternative, it is helpful to know the soft tissue limitations for the various treatment options.[29,60] According to the measured values from Salama et al, it is more predictable to develop greater soft tissue height above the bone by restoring adjacent edentulous sites with pontics, as compared to restoring with adjacent implants (see Fig 16).[29] The only location where adjacent implants may be used without significantly impacting the esthetic result is when two central incisors are missing. Papillary height will still be deficient between the two implants compared to the natural teeth; however, it will be more acceptable because it is in the midline. Another option that is often extremely esthetic is prosthetic replacement of gingival tissue. For example, the patient in Figure 22 was treated with an implant-supported FPD with pink porcelain. The result is esthetic since the lip position during smile does not reveal the transition between the prosthesis and the patient's mucosal tissue. The result would not have been as esthetic if an alveolar ridge augmentation procedure had resulted in a ridge level that was still short of ideal. This would have created a situation where the junction between prosthesis and soft tissue would have been visible. Ultimately, understanding the requirements of the restorative recipient sites together with the surgical limitations allows the team to develop the best treatment plan for esthetic tooth replacement (Figs 23a and 23b).



Figs 24a to 24c

Ridge dimension (vertical) – surgical considerations

The patient with multiple missing teeth and a horizontally deficient alveolar ridge can usually be treated predictably in several ways. Lateral ridge augmentation (as reviewed above) can be performed successfully using various techniques. Additional contour with either guided bone regeneration (GBR) or soft tissue grafting can also benefit the restorative recipient sites, creating a convexity of tissue form for either pontics or implants.

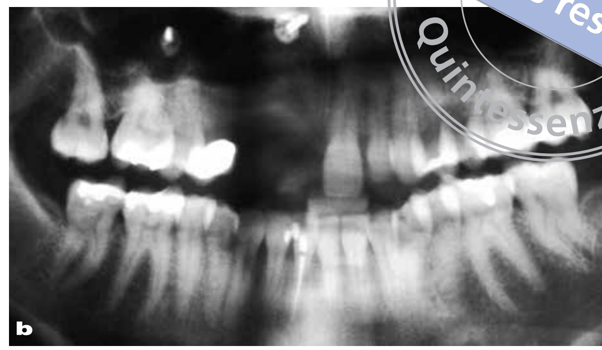


Figs 25a to 25c

The challenges increase as the ridge becomes deficient in the vertical dimension. A recent review of vertical ridge augmentation techniques and outcomes illustrated the limitations with these procedures.[61] Although there have been multiple approaches to this problem, the most commonly used techniques are GBR and distraction osteogenesis.[62]

Vertically guided bone regeneration requires the use of titanium-reinforced membranes or titanium mesh to space for bone regeneration, with placement of a bone graft material to act as a scaffold. Its application has been shown to be effective in bone regeneration, with varying amounts of vertical height and histologic evidence of bone formation.[63-66] One limitation with GBR for vertical ridge augmentation can be attributed to the use of osteoconductive graft products. An exciting and developing usage is that of growth factors to aid with bone formation. Platelet-derived growth factor (rhPDGF) enhanced matrices have demonstrated the potential to increase bone turnover and bone regeneration in both periodontal and dental implant sites.[67,68] In addition, bone morphogenetic protein-2 has been developed and used in orthopedic medicine and in dentistry as the first osteoinductive bone graft substitute, allowing surgeons to avoid complications associated with harvesting autogenous bone.[69] In dentistry, the introduction of BMP2 was initially investigated in patients requiring sinus augmentation and single tooth extraction sockets.[70,71] Since these initial studies, clinicians have started applying this approach to more challenging lateral and vertical augmentation procedures (Figs 24a to 24c).

Vertical alveolar bone augmentation using distraction osteogenesis was first reported in the 1990s.[72] Since then, multiple studies have evaluated the potential to develop vertical bone growth, demonstrating that distraction osteogenesis can develop greater amounts of bone vertically than other techniques.[73,74] When the clinician plans treatment for a patient with a severe vertical defect (Figs 25a to 25c), consideration should



Figs 26a and 26b

Figs 27a and 27b

be given to techniques that will provide the most predictable and stable regenerated bone.[75] However, the complexity of this technique certainly has the potential for subsequent complications. One study reported that complications ranging from minor to more severe occurred in 75% of patients.[76] In addition, this technique is effective in growing bone in a vertical direction only.[77,78] As discussed above, esthetic implant restorations require facial convexity. Therefore, it is common to plan for additional horizontal ridge augmentation and soft tissue grafting to achieve this desired ridge form (Figs 29a and 29b). The three-dimensional reconstruction of the alveolar ridge is a prerequisite to achieving an optimal result at a site with a severe ridge deficiency that is visible in the esthetic zone (Figs 30a and 30b).

Ridge dimension (vertical) – orthodontic considerations

Due to the challenges of vertical ridge augmentation procedures, the dental team needs to look at additional options when confronted with patients who are missing multiple teeth. Guided orthodontic tooth eruption is one such option. The primary goal of this procedure is to develop bone in a vertical direction. This is done by orthodontically applying tension to the periodontal ligament (PDL). This stretching of the PDL fibers increases osteoblastic activity and ultimately

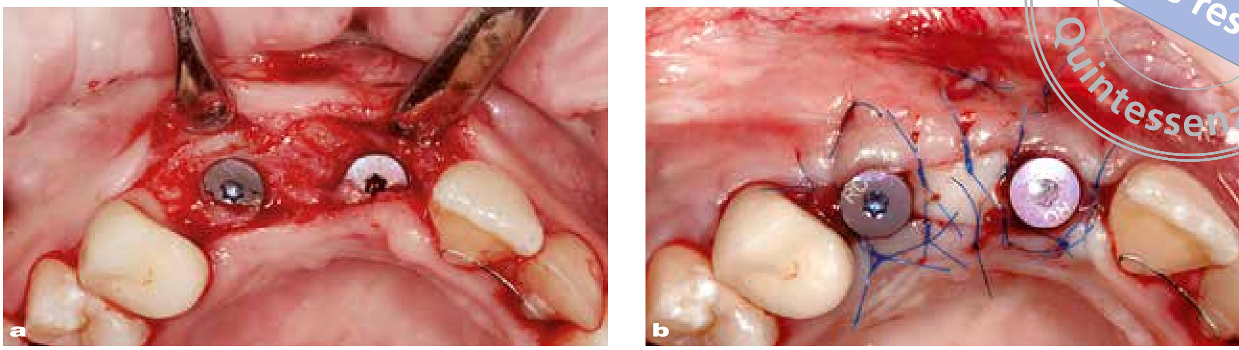
Fig 28

generates new bone formation.[79–81] As teeth are erupted, the soft tissue also moves coronally. The interproximal bone peaks can be developed to help support the soft tissue and/or provide scaffolding for bone augmentation procedures. Therefore, in a patient with interproximal bone loss and a resultant loss of papillae, extrusion can predictably correct the bone level and ultimately improve the papillae height. In fact, it is believed that lighter forces will result in a more predictable soft tissue change for this type of tooth movement.[82]

There are four additional factors that need to be considered when a tooth is undergoing orthodontic extrusion. The first is periodic reduction in length to prevent occlusal interferences from developing, unless there is no opposing tooth present. The second is that, following any extrusive movement, it is important to stabilize the tooth in its new position for a period of 6 months to allow time for the transseptal fibers to reorganize horizontally.[83] The third is the importance of reviewing with the patient the esthetic change that generally follows significant forced orthodontic eruption. As the gingival margi[illegible] coronally with the extruded tooth, the [illegible]thetic change that accompanies it may be an unexpected surprise for patients if they are not made aware of it before it happens. The fourth factor is that if a tooth is ultimately planned for extraction following extrusion, it is usually necessary to perform prophylactic endodontic therapy so that pulp exposure is not a concern as the tooth is reduced in length. Multiple authors have described the extrusion of hopeless teeth prior to extraction as a method of developing implant sites.[79,84] However, another way to orthodontically augment an alveolar ridge is to change the buccolingual inclination of the teeth as they are extruded. By increasing the buccal root torque as a hopeless maxillary incisor is extruded, a larger volume of buccal bone will be developed as the root moves coronally and labially.[85] The teeth that are considered for this type of tooth movement and ridge development typically have significant labial bone loss and a lack of PDL in this area. Therefore, it is the PDLs on the interproximal and lingua-palatal root surfaces that lay down bone as the tooth is orthodontically moved away from the periodontal defect.

Case example

This 19-year-old female in Figure 25a was congenitally missing a lateral incisor. After completion of orthodontic treatment, a dental implant was placed in the maxillary right lateral incisor site. Unfortunately, there were complications with the placement of the implant. Seven subsequent surgical procedures were performed in an attempt to repair and save the implant. This resulted in



Figs 29a and 29b

Figs 30a and 30b

the creation of a large hard and soft tissue defect with compromised adjacent teeth. Given the severity of the defect and the surgical challenge of regenerating bone in the vertical dimension, the dental team discussed numerous interdisciplinary treatment options. These ranged from a FPD with or without soft tissue augmentation, orthodontic eruption for extraction of the adjacent teeth, to extraction and placement of implants in the canine and central incisor sites with pink prosthetic tissue replacement. Along with the clinical findings, consideration was given to the patient's esthetic expectations and request that the use of prosthetic soft tissue replacement be avoided. Therefore, with these goals in mind, it was decided that distraction osteogenesis would produce the best possible chance of vertical bone regeneration to the level required for an esthetic result with a more natural soft tissue position.

The first step in the treatment process was to extract the maxillary right canine and central incisor and augment the ridge. The purpose of this augmentation was not to increase ridge height, but rather to create sufficient bone at the alveolar base for subsequent distraction. The bone augmentation procedure utilized a calvarial graft and was performed by craniofacial surgeon, Dr. Richard Hopper (Figs 26a and 26b). Following healing and integration of the graft, the distractor was placed. The patient was instructed to activate the distractor three times per day. Each activation resulted in 0.3 mm of vertical movement of the mobile segment of bone. After 2 weeks of active movement, the bone segment had been distracted approximately 12 mm (Figs 27a and 27b). During the distraction process, a clear retainer with a facial window was fabricated to replace the missing teeth and mitigate the esthetic impact for the patient (Fig 28). Although the distraction procedure achieved significant ridge height, subsequent bone grafting was still necessary prior to implant placement in order to enhance the horizontal ridge form. The implants were then placed and allowed to integrate for 3 months, during which time orthodontic treatment was completed to improve the general tooth position. The implant exposure was used as an additional opportunity to augment the soft tissue and improve ridge contour (see Figs 29a and 29b). The soft tissue profile was prosthetically guided for about 6 months using an implant-supported provisional. This was followed by the placement of a definitive, screw-retained implant restoration (see Figs 30a and 30b). Without the use of distraction osteogenesis for aiding in vertical bone regeneration, this reconstruction would have likely required the use of pink ceramic on the restoration.

Ridge management in children – tooth autotransplantation

Multiple techniques are available for the management of missing teeth in adults. However, we do not have the same permanent options for tooth replacement in patients who are still growing. It is widely accepted that implants should not be placed until skeletal growth is complete. It is also generally believed that there are significant differences between the genders regarding completion of growth. Historically, the method of choice to determine the cessation of growth was to superimpose tracings from two cephalometric head films taken 1 year apart when growth is thought to be complete. If, when comparing these two tracings, no skeletal changes were seen, growth was considered to be completed, and it was thought that implants could be predictably placed. However, as new research continues to evaluate latent growth, even into adulthood, the interdisciplinary team is faced with new challenges that ultimately affect both function and esthetics. Based on this research, it is now being recommended to wait far longer than was previously thought before placing implants.[86-89]

Dental trauma most often occurs between the ages of 7 and 11.[90] Therefore, when tooth avulsion occurs there is often a debate about whether tooth replantation is the correct treatment. Concerns usually arise regarding the risk of ankylosis, or endodontic complications. This is not the best time to make a long-term treatment decision due to emotions surrounding the traumatic event. Replanting the tooth has several advantages.[91] Firstly, the replanted tooth will immediately serve as an esthetic replacement. Secondly, it will provide time for interdisciplinary collaboration to determine the most favorable treatment plan. Thirdly, it will maintain the alveolar ridge form better than a socket graft at that time. If the tooth develops ankylosis, decoronation or tooth autotransplantation can be considered.

These treatment options are essentially a ridge-management strategy.

An ankylosed incisor can compromise the alveolar ridge in the growing patient. As the adjacent teeth erupt, the ankylosed tooth will pull them towards it, resulting in tipping. In addition, the ridge will not develop at the site of the ankylosed tooth. The interdisciplinary team will need to make a decision at the correct time about whether to extract the ankylosed tooth or to perform decoronation. Decoronation is a procedure that is not often considered. The process involves crown resection of an ankylosed tooth just below the level of the bone crest and the removal of the gutta percha or the contents of the pulp canal.[92] The intention is to allow bone to form over the crest and to remove the interference with adjacent tooth eruption. The continued replacement resorption of the root will form bone and act as a natural ridge-preservation procedure. The management of avulsed teeth requires a continuum of care.[93] With this approach, options include tooth autotransplantation or future tooth replacement with a dental implant.

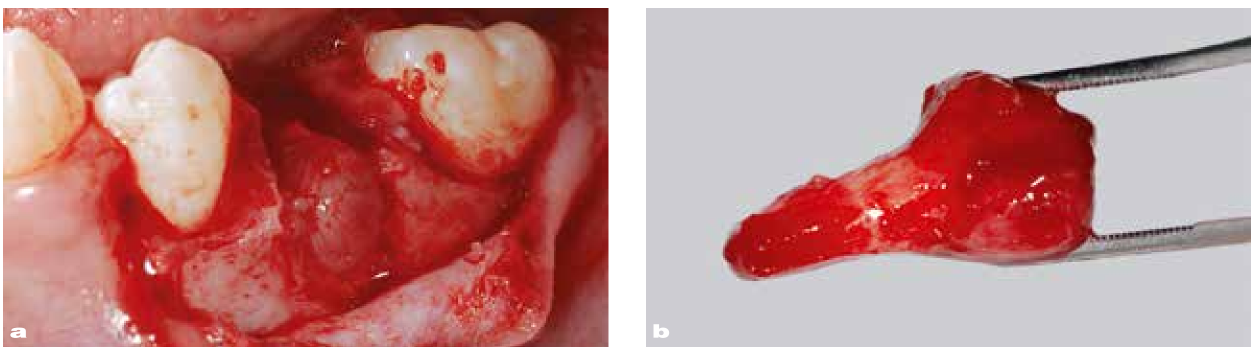
When considering tooth replacement in a child, tooth autotransplantation is a way of providing a natural, functional tooth. This is a surgical technique that can be used to replace traumatized maxillary incisors with premolars. In addition, other applications of this procedure are to treat teeth that are ectopically positioned or to manage patients with unilateral agenesis of premolars or geminated incisors.[94] A large variation in success rates has been published. When looking specifically at single-rooted tooth (premolar) transplantation, success rates are the highest, at 95%.[95-98] This is attributable to the reduced risk to the PDL when harvesting these teeth.

The condition of the PDL is very important in the tooth transplantation process. Healthy PDL cells have an osteoinductive ability, helping to maintain the alveolar ridge.[99] Furthermore, it has been recognized that progenitor cells are present in the PDL.[100] The benefits of such vital cells can be appreciated in some of the more challenging treatments that involve alveolar ridge augmentation prior to tooth transplantation.[101,102] Although case reports of this sequenced treatment have reported performing the augmentations with autogenous bone, a recent report has demonstrated successful tooth autotransplantation into a ridge augmented with allograft bone.[103] For the patient with a compromised ridge form, the osteoinductive ability of the PDL can certainly benefit the reconstructive process.

Questions have been raised about the esthetic outcomes of autotransplanted premolars to incisor positions. Up to 25% of patients in one study reported dissatisfaction with the esthetics of their transplanted tooth.[104] This report noted 60% of the transplanted teeth varied in color and gingival width compared to the natural incisors. The authors stated that the compromised esthetic outcome was directly related to suboptimal tooth positioning and restorative techniques.[105]

Guidelines have been suggested to improve orthodontic tooth positioning to allow for optimal restoration.[93] This interdisciplinary approach requires continued communication throughout the process in order to appropriate the correct

Figs 31a and 31b



Figs 32a and 32b

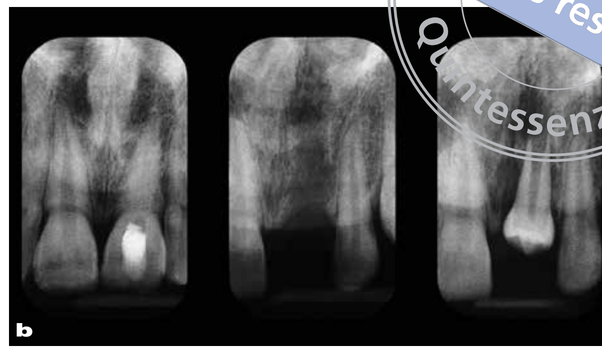
spacing for the transplanted tooth. Restoration can then follow, transforming the facial morphology of the premolar into that of an incisor and resulting in an optimal esthetic tooth replacement with a functional natural tooth.

The experience gained with tooth autotransplantation today is a precursor for future biological tooth replacements. Interdisciplinary teams from dentistry, engineering, and subspecialties in biology have been formed to lead the development of tooth regeneration.[106] Whether it will be tissue engineering using stem cell technology or biodegradable scaffolds, the outcomes of this collaborative effort will have influence in other areas of regenerative medicine.[107,108]

Case example

A 10-year old male patient presented with a history of traumatic avulsion of the maxillary left central incisor that had occurred approximately 6 months prior to presentation. The avulsed tooth was recovered at the time of the injury. However, it was not replanted until 2 h later. Therefore, the replanted tooth subsequently became ankylosed and began to experience infraocclusion (Figs 31a and 31b).

After considering all the potential treatment options, the treatment plan chosen was to extract the ankylosed central incisor and provide immediate replacement with the autotransplantation of the developing mandibular left second premolar. The benefit of this



Figs 33a and 33b

Fig 34

Fig 35

treatment option was twofold: to provide a natural, esthetic, and functional tooth, and to promote continued alveolar ridge development.

Surgical treatment and postoperative follow-up

The ankylosed central incisor was carefully extracted to preserve the surrounding socket wall and the resultant recipient site was prepared with burs similar to those used for implant placement. The size and shape of the recipient site was determined based on the root dimension of the premolar planned for transplantation. The primary mandibular molar was extracted and a mucoperiosteal flap was raised to gain access to the buccal bone (Figs 32a and 32b). Ostectomy of the alveolar bone was performed to expose the follicle surrounding the crown of the premolar. The transplant tooth was then carefully harvested taking care to avoid contact with the PDL. It was then transferred to the anterior maxilla (Fig 32b). The transplanted tooth was positioned passively within the recipient site and stabilized for several weeks with mattress sutures (Figs 33a and 33b). Monitoring the transplanted tooth both clinically and radiographically over 3 months showed eruption of the tooth and continued root formation.

Orthodontic treatment

Orthodontic tooth movement began 4 months after the transplantation procedure was completed. Prior to the

Figs 36a and 36b

Figs 37a and 37b

restoration of the transplanted premolar with composite, it is important for the orthodontist to position the tooth as ideally as possible in order to achieve the most natural and esthetic restorative result.[93] This is based on the following planes of space (Fig 34):

- Incisogingivally: The cementoenamel junction (CEJ) of the transplant tooth should be aligned with the CEJ of the adjacent central incisor.
- Mesiodistally: The transplant tooth should be positioned mesial of center, leaving 1/3 of the remaining space on the mesial of the transplant and 2/3 of the remaining space on the distal of the transplant.
- Buccopalatally: The transplant tooth should be positioned slightly palatal on the ridge in order to allow the restorative material to be mainly additive in nature, with minimal removal of tooth structure.

Restorative phase

The restorative phase can be initiated after the preferred tooth position is achieved. This restoration can be completed with composite resin using a direct or indirect technique. Given the differences in mesiodistal tooth dimensions when comparing the transplant to the natural central incisor, the composite restoration should start subgingivally in order to get a smooth emergence profile. The difficulty in the direct application of composite is applying and finishing the material subgingivally. Following a slight gingivectomy to improve the tissue symmetry, the transplant tooth was minimally prepared to decrease the thickness at the cervical height of contour and create a slight finish line (Fig 35). The composite veneer was then fabricated directly on the model, finished, and polished (Figs 36a and 36b). The restoration was adhesively bonded only after it was tried in to verify fit, occlusion, and esthetics (Figs 37a and 37b). Finally, the patient was referred back to the orthodontist for continuation and completion of orthodontic treatment.

Conclusions

Successful collaborative treatment requires shared knowledge and understanding among members of the dental team. This results in more effective communication and the clear assignment of responsibilities to each clinician in order to achieve the appropriate solution. This article has discussed an interdisciplinary approach for treating the esthetically compromised patient; specifically, patients who present with a deficiency in spacing for tooth restoration/replacement or a deficiency in alveolar ridge form.

References

1. O'Connor RV. The exciting world of interdisciplinary dentistry. Int J Periodontics Restorative Dent 2000;20:334–335.
2. Spear FM, Kokich VG. A multidisciplinary approach to esthetic dentistry. Dent Clin North Am 2007;51:487–505.
3. Kokich VG, Spear FM. Guidelines for managing the orthodontic-restorative patient. Semin Orthod 1997;3:3–20.
4. Keim RG. The art of interdisciplinary teamwork. J Clin Orthod 2013;47:513–514.
5. Salama H, Salama MA, Li TF, Garber DA, Adar P. Treatment planning 2000: an esthetically oriented revision of the original implant protocol. J Esthet Dent 1997;9:55–67.
6. Genco RJ, Genco FD. Common risk factors in the management of periodontal and associated systemic diseases: the dental setting and interprofessional collaboration. J Evid Based Dent Pract 2014;14(suppl):4–16.
7. Petri L. Concept analysis of interdisciplinary collaboration. Nurs Forum 2010;45:73–82.
8. Irwin RS, Flaherty HM, French CT, et al. Interdisciplinary collaboration: the slogan that must be achieved for models of delivering critical care to be successful. Chest 2012;142:1611–1619.
9. Spear FM. The importance of commitment and communication in the generalist/specialist relationship. Adv Esth Interdisc Dent 2007;3:1–2.
10. Klasser GD, Gremillion HA. Past, present, and future of predoctoral dental education in orofacial pain and TMDs: a call for interprofessional education. J Dent Educ 2013;77:395–400.
11. Wilder RS, O'Donnell JA, Barry JM, et al. Is dentistry at risk? A case for interprofessional education. J Dent Educ 2008;72:1231–1237.
12. Reeson MG, Walker-Gleaves C, Jepson N. Interactions in the dental team: understanding theoretical complexities and practical challenges. Br Dent J 2013;215:E16.
13. Abrams H, Kopczyk RA, Kaplan AL. Incidence of anterior ridge deformities in partially edentulous patients. J Prosthet Dent 1987;57:191–194.

14. Kokich VG. Maxillary lateral incisor implants: planning with the aid of orthodontics J Oral Maxillofac Surg 2004;62(9, suppl 2):48–56.
15. Ittipuriphat I, Leevailoj C. Anterior space management: interdisciplinary concepts. J Esthet Restor Dent 2013;25:16–30.
16. Feigenbaum NL. Aspects of aesthetic smile design. Pract Periodontics Aesthet Dent 1991;3:9–13.
17. Cosyn J, Raes M, Packet M, Cleymaet R, De Bruyn H. Disparity in embrasure fill and papilla height between tooth- and implant-borne fixed restorations in the anterior maxilla: a cross-sectional study. J Clin Periodontol 2013;40:728–733.
18. Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Angle Orthod 1958;28:113–130.
19. Kokich VG, Spear FM. Guidelines for managing the orthodontic-restorative patient. Semin Orthod 1997;3:3–20.
20. Bidra AS, Uribe F. Preprosthetic orthodontic intervention for management of a partially edentulous patient with generalized wear and malocclusion. J Esthet Restor Dent 2012;24:88–100.
21. Spear FM, Kokich VG, Mathews DP. Interdisciplinary management of anterior dental esthetics. J Am Dent Assoc 2006;137:160–169.
22. Vig RG, Brundo GC. The kinetics of anterior tooth display. J Prosthet Dent 1978;39:502–504.
23. Tjan AH, Miller GD, The JG. Some esthetic factors in a smile. J Prosthet Dent 1984;51:24–28.
24. Kokich VO Jr, Kinzer GA. Managing congenitally missing lateral incisors. Part I: Canine substitution. J Esthet Restor Dent 2005;17:5–10.
25. Kinzer GA, Kokich VO Jr. Managing congenitally missing lateral incisors. Part II: tooth-supported restorations. J Esthet Restor Dent 2005;17:76–84.
26. Kinzer GA, Kokich VO Jr. Managing congenitally missing lateral incisors. Part III: single-tooth implants. J Esthet Restor Dent 2005;17:202–210.
27. Weinberg LA, Kruger B. A comparison of implant/prosthesis loading with four clinical variables. Int J Prosthodont 1995;8:421–433.
28. Fugazzotto PA. Evidence-based decision making: replacement of the single missing tooth. Dent Clin North Am 2009;53:97–129.
29. Salama H, Salama M, Garber D, Adar P. The interproximal height of bone: a guidepost to predictable aesthetic strategies and soft tissue contours in anterior tooth replacement. Pract Periodontics Aesthet Dent 1998;10:1131–1141.
30. Abrams H, Kopczyk RA, Kaplan AL. Incidence of anterior ridge deformities in partially edentulous patients. J Prosthet Dent 1987;57:191–194.
31. Kois JC. Predictable single-tooth peri-implant esthetics: five diagnostic keys. Compend Contin Educ Dent 2004;25:895–896,898,900.
32. Spear FM, Mathews DM, Kokich VG. Interdisciplinary management of single-tooth implants. Semin Orthod 1997;3:45–72.
33. Thilander B, Odman J, Lekholm U. Orthodontic aspects of the use of oral implants in adolescents: a 10-year follow-up study. Eur J Orthod 2001;23:715–731.
34. Zachrisson BU. Single implant-supported crowns in the anterior maxilla: potential esthetic long-term (> 5 years) problems. World J Orthod 2006;7:306–312.
35. Cardaropoli G, Le[illegible] Wennström JL. Tissue [illegible] ations at implant-supported single-tooth replacements: a 1-year prospective clinical study. Clin Oral Implants Res 2006;17:165–171.
36. Grunder U, Gracis S, Capelli M. Influence of the 3-D bone-to-implant relationship on esthetics. Int J Periodontics Restorative Dent 2005;25:113–119.
37. Kokich VO Jr, Kinzer GA, Janakievski J. Congenitally missing maxillary lateral incisors: restorative replacement. Counterpoint. Am J Orthod Dentofacial Orthop 2011;139:435,437,439.
38. Esposito M, Ekestubbe A, Gröndahl K. Radiological evaluation of marginal bone loss at tooth surfaces facing single Brånemark implants. Clin Oral Implants Res 1993;4:151–157.
39. Chen ST, Darby IB, Reynolds EC. A prospective clinical study of non-submerged immediate implants: clinical outcomes and esthetic results. Clin Oral Implants Res 2007;18:552–562.
40. Fürhauser R, Florescu D, Benesch T, Haas R, Mailath G, Watzek G. Evaluation of soft tissue around single-tooth implant crowns: the pink esthetic score. Clin Oral Implants Res 2005;16:639–644.
41. Belser UC, Grutter L, Vailati F, Bornstein MM, Weber HP, Buser D. Outcome evaluation of early placed maxillary anterior single tooth implants using objective esthetic criteria: a crosssectional, retrospective study in 45 patients with a 2- to 4-year follow-up using pink and white esthetic scores. J Periodontol 2009;80:140–151.

42. Buser D, Halbritter S, Hart C, et al. Early implant placement with simultaneous guided bone regeneration following single-tooth extraction in the esthetic zone: 12-month results of a prospective study with 20 consecutive patients. J Periodontol 2009;80:152–162.
43. Donos N, Mardas N, Chadha V. Clinical outcomes of implants following lateral bone augmentation: systematic assessment of available options (barrier membranes, bone grafts, split osteotomy). J Clin Periodontol 2008;35(8, suppl):173–202.
44. Aghaloo TL, Moy PK. Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? Int J Oral Maxillofac Implants 2007;22(suppl):49–70.
45. Jensen SS, Bosshardt DD, Gruber R, Buser D. Long-term stability of contour augmentation in the esthetic zone: histologic and histomorphometric evaluation of 12 human biopsies 14 to 80 months after augmentation. J Periodontol 2014;85:1549–1556.
46. Chen ST, Buser D. Esthetic outcomes following immediate and early implant placement in the anterior maxilla – a systematic review. Int J Oral Maxillofac Implants 2014;29(suppl):186–215.
47. Grunder U. Crestal ridge width changes when placing implants at the time of tooth extraction with and without soft tissue augmentation after a healing period of 6 months: report of 24 consecutive cases. Int J Periodontics Restorative Dent 2011;31:9–17.
48. Rungcharassaeng K, Kan JY, Yoshino S, Morimoto T, Zimmerman G. Immediate implant placement and provisionalization with and without a connective tissue graft: an analysis of facial gingival tissue thickness. Int J Periodontics Restorative Dent 2012;32:657–663.
49. Donnelly MW, Swoope CC. Periosteal tension in the stimulation of bone growth in the mandible [Masters thesis]. Seattle: University of Washington, 1973.
50. Ostler MS, Kokich VG. Alveolar ridge changes in patients congenitally missing mandibular second premolars. J Prosthet Dent 1994;71:144–149.
51. Stepovich ML. A clinical study on closing edentulous spaces in the mandible. Angle Orthod 1979;49:227–233.
52. Hom BM, Turley PK. The effects of space closure of the mandibular first molar area in adults. Am J Orthod 1984;85:457–469.
53. Lindskog-Stokland B, Hansen K, Ekestubbe A, Wennström J. Orthodontic tooth movement into edentulous ridge areas – a case series. Eur J Orthod 2013;35:277–285.
54. Eliášová P, Marek I, Kamínek M. Implant site development in the distal region of the mandible: bone formation and its stability over time. Am J Orthod Dentofacial Orthop 2014;145:333–340.
55. Nováčková S, Marek I, Kamínek M. Orthodontic tooth movement: bone formation and its stability over time. Am J Orthod Dentofacial Orthop 2011;139:37–43.
56. De Backer H, Van Maele G, De Moor N, Van den Berghe L. An up to 20-year retrospective study of 4-unit fixed dental prostheses for the replacement of 2 missing adjacent teeth. Int J Prosthodont 2008;21:259–266.
57. Salama M, Coachman C, Garber D, Calamita M, Salama H, Cabral G. Prosthetic gingival reconstruction in the fixed partial restoration. Part 2: diagnosis and treatment planning. Int J Periodontics Restorative Dent 2009;29:573–581.
58. Hannon SM, Colvin CJ, Zurek DJ. Selective use of gingival-toned ceramics: case reports. Quintessence Int 1994;25:233–238.
59. Krennmair G, Seemann R, Weinländer M, Wegscheider W, Piehslinger E. Implant-prosthodontic rehabilitation of anterior partial edentulism: a clinical review. Int J Oral Maxillofac Implants 2011;26:1043–1050.
60. Ishikawa T, Salama M, Funato A, et al. Three-dimensional bone and soft tissue requirements for optimizing esthetic results in compromised cases with multiple implants. Int J Periodontics Restorative Dent 2010;30:503–511.
61. Rocchietta I, Fontana F, Simion M. Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review. J Clin Periodontol 2008;35(8, suppl):203–215.
62. Fiorellini JP, Nevins ML. Localized ridge augmentation/preservation. A systematic review. Ann Periodontol 2003;8:321–327.
63. Tinti C, Parma-Benfenati S. Vertical ridge augmentation: surgical protocol and retrospective evaluation of 48 consecutively inserted implants. Int J Periodontics Restorative Dent 1998;18:434–443.
64. Parma-Benfenati S, Tinti C, Albrektsson T, Johansson C. Histologic evaluation of guided vertical ridge augmentation around implants in humans. Int J Periodontics Restorative Dent 1999;19:424–437.

65. Simion M, Fontana F, Rasperini G, Maiorana C. Vertical ridge augmentation by expanded-polytetrafluoroethylene membrane and a combination of intraoral autogenous bone graft and deproteinized anorganic bovine bone (Bio Oss). Clin Oral Implants Res 2007;18:620–629.
66. Urban IA, Lozada JL, Jovanovic SA, Nagursky H, Nagy K. Vertical ridge augmentation with titanium-reinforced, dense-PTFE membranes and a combination of particulated autogenous bone and anorganic bovine bone-derived mineral: a prospective case series in 19 patients. Int J Oral Maxillofac Implants 2014;29:185–193.
67. Kaigler D, Avila G, Wisner-Lynch L, et al. Platelet-derived growth factor applications in periodontal and peri-implant bone regeneration. Expert Opin Biol Ther 2011;11:375–385.
68. Geurs N, Ntounis A, Vassilopoulos P, Van der Velden U, Loos BG, Reddy M. Using growth factors in human extraction sockets: a histologic and histomorphometric evaluation of short-term healing. Int J Oral Maxillofac Implants 2014;29:485–496.
69. McKay WF, Peckham SM, Badura JM. A comprehensive clinical review of recombinant human bone morphogenetic protein-2 (INFUSE Bone Graft). Int Orthop 2007;31:729–734.
70. Boyne PJ, Lilly LC, Marx RE, et al. De novo bone induction by recombinant human bone morphogenetic protein-2 (rhBMP-2) in maxillary sinus floor augmentation. J Oral Maxillofac Surg 2005;63:1693–1707.
71. Fiorellini JP, Howell TH, Cochran D, et al. Randomized study evaluating recombinant human bone morphogenetic protein-2 for extraction socket augmentation. J Periodontol 2005;76:605–613.
72. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. Plast Reconstr Surg 1992;89:1–8.
73. Esposito M, Grusovin MG, Felice P, Karatzopoulos G, Worthington HV, Coulthard P. Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment. Cochrane Database Syst Rev 2009;7:CD003607. doi:10.1002/14651858.
74. Chiapasco M, Romeo E, Casentini P, Rimondini L. Alveolar distraction osteogenesis vs. vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans. Clin Oral Implants Res 2004;15:82–95.
75. Chiapasco M, Consolo U, Bianchi A, Ronchi P. Alveolar distraction osteogenesis for the correction of vertically deficient edentulous ridges: a multicenter prospective study on humans. Int J Oral Maxillofac Implants 2004;19:399–407.
76. Enislidis G, Fock N, Millesi-Schobel G, et al. Analysis of complications following alveolar distraction osteogenesis and implant placement in the partially edentulous mandible. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;100:25–30.
77. Jensen OT, Cockr Kuhike L, Reed C. Ant maxillary alveolar distractio osteogenesis: a prospective 5-year clinical study. Int J Oral Maxillofac Implants 2002;17:52–68.
78. Froum SJ, Rosenberg ES, Elian N, Tarnow D, Cho SC. Distraction osteogenesis for ridge augmentation: prevention and treatment of complications. thirty case reports. Int J Periodontics Restorative Dent 2008;28:337–345.
79. Salama H, Salama M. The role of orthodontic extrusive remodeling in the enhancement of soft and hard tissue profiles prior to implant placement: a systematic approach to the management of extraction site defects. Int J Periodontics Restorative Dent 1993;13:312–333.
80. Mantzikos T, Shamus I. Forced eruption and implant site development: soft tissue response. Am J Orthod Dentofacial Orthop 1997;112:596–606.
81. Mantzikos T, Shamus I. Forced eruption and implant site development: an osteophysiologic response. Am J Orthod Dentofacial Orthop 1999;115:583–591.
82. Korayem M, Flores-Mir C, Nassar U, Olfert K. Implant site development by orthodontic extrusion. A systematic review. Angle Orthod 2008;78:752–760.
83. Reitan K. Clinical and histologic observations on tooth movement during and after orthodontic treatment. Am J Orthod 1967;53:721–745.
84. Mirmarashi B, Torbati A, Aalam A, Chee W. Orthodontically assisted vertical augmentation in the esthetic zone. J Prosthodont 2010;19:235–239.

85. Nozawa T, Sugiyama T, Yamaguchi S, et al. Buccal and coronal bone augmentation using forced eruption and buccal root torque: a case report. Int J Periodontics Restorative Dent 2003;23:585–591.
86. Bernard JP, Schatz JP, Christou P, Belser U, Kiliaridis S. Long-term vertical changes of the anterior maxillary teeth adjacent to single implants in young and mature adults. A retrospective study. J Clin Periodontol 2004;31:1024–1028.
87. Heij DG, Opdebeeck H, van Steenberghe D, Kokich VG, Belser U, Quirynen M. Facial development, continuous tooth eruption, and mesial drift as compromising factors for implant placement. Int J Oral Maxillofac Implants 2006;21:867–878.
88. Andersson B, Bergenblock S, Fürst B, Jemt T. Long-term function of single-implant restorations: A 17- to 19-year follow-up study on implant infraposition related to the shape of the face and patients' satisfaction. Clin Implant Dent Relat Res 2013;15:471–480.
89. Jemt T, Ahlberg G, Henriksson K, Bondevik O. Tooth movements adjacent to single-implant restorations after more than 15 years of follow-up. Int J Prosthodont 2007;20:626–632.
90. Andreasen JO, Ravn JJ. Epidemiology of traumatic dental injuries to primary and permanent teeth in a Danish population sample. Int J Oral Surg 1972;1:235–239.
91. Steiner DR. Avulsed maxillary central incisors: the case for replantation. Am J Orthod Dentofacial Orthop 2012;142:8,10,12,14,16.
92. Malmgren B, Cvek M, Lundberg M, Frykholm A. Surgical treatment of ankylosed and infrapositioned reimplanted incisors in adolescents. Scand J Dent Res 1984;92:391–399.
93. Janakievski J. Avulsed maxillary central incisors: the case for autotransplantation. Counterpoint. Am J Orthod Dentofacial Orthop 2012;142:9,11,13,15,17.
94. Tsukiboshi M. Autotransplantation of teeth. Chicago: Quintessence, 2001.
95. Schwartz O, Bergmann P, Klausen B. Autotransplantation of human teeth. A life-table analysis of prognostic factors. Int J Oral Surg 1985;14:245–258.
96. Kallu R, Vinckier F, Politis C, Mwalili S, Willems G. Tooth transplantations: a descriptive retrospective study. Int J Oral Maxillofac Surg 2005;34:745–755.
97. Andreasen JO, Paulsen HU, Yu Z, Bayer T, Schwartz O. A long-term study of 370 autotransplanted premolars. Part II. Tooth survival and pulp healing subsequent to transplantation. Eur J Orthod 1990;12:14–24.
98. Andreasen JO, Paulsen HU, Yu Z, Schwartz O. A long-term study of 370 autotransplanted premolars. Part III. Periodontal healing subsequent to transplantation. Eur J Orthod 1990;12:25–37.
99. Hjortdal O, Bragelien J. Induction of jaw bone formation by tooth autotransplantation. Nor Tannlaegeforen Tid 1978; 88:319–322.
100. McCulloch CA. Progenitor cell populations in the periodontal ligament of mice. Anat Rec 1985;211:258–262.
101. Mensink G, Karagoz[illegible] KH, Strackee SD, van Tee[illegible]seling RA, Smeele LE, Becking AG. Autotransplantation of two maxillary premolars in a free vascularized fibula reconstructed mandible. Int J Oral Maxillofac Surg 2011;40:219–221.
102. Hillerup S, Dahl E, Schwartz O, Hjørting-Hansen E. Tooth transplantation to bone graft in cleft alveolus. Cleft Palate J 1987;24:137–141.
103. Janakievski J. Tooth autotransplantation to an alveolar ridge augmented with allograft bone. (manuscript in press).
104. Czochrowska EM, Stenvik A, Zachrisson BU. The esthetic outcome of autotransplanted premolars replacing maxillary incisors. Dent Traumatol 2002;18:237–245.
105. Zachrisson BU, Stenvik A, Haanaes HR. Management of missing maxillary anterior teeth with emphasis on autotransplantation. Am J Orthod Dentofacial Orthop 2004;126:284–288.
106. Snead M. Whole-tooth regeneration: it takes a village of scientists, clinicians, and patients. J Dent Educ 2008;72:903–911.
107. Modino SA, Sharpe PT. Tissue engineering of teeth using adult stem cells. Arch Oral Biol 2005;50:255–258.
108. Kim K, Lee CH, Kim BK, Mao JJ. Anatomically shaped tooth and periodontal regeneration by cell homing. J Dent Res 2010;89:842–847.