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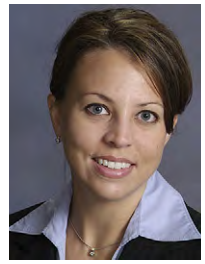
Atlas of the Oral and Maxillofacial Surgery Clinics

Preface

Joseph E. Van Sickels, DDS   Bethany L. Serafin, DMD
Guest Editors

Distraction osteogenesis is a relatively new tool that is useful to treat patients with bone and soft tissue deficiencies that may not be amenable to traditional operations. As with any technique, it is important to understand when it is indicated and the underlying biomechanical principles that allow it to be used. In this issue, we have asked a group of innovative practitioners to share their experiences with this modality of treatment for a variety of problems encountered in the maxillofacial skeleton. The problems addressed range from continuity defects of the mandible secondary to oncologic procedures to craniofacial birth defects to deficiencies of dento–alveolar ridges. The results that are achieved from these experts are impressive. In the articles on the use of distraction in patients with severe craniofacial defects, it is apparent that sleep apnea is frequently a co-morbidity. Several of the authors note that the facial skeleton is normalized and sleep apnea ameliorated with distraction.

As with any technique, complications may occur. In most of the articles, the authors address the management of complications and review contributing causes. Drs. Hanson and Melugin specifically address orthopedic and orthodontic techniques that can be used when the desired occlusal result is not achieved through distraction. A real treat is the article contributed by Drs. Saunders and Lee on the influence of mechanical environment on bone healing and distraction osteogenesis. They review basic tenants of bone healing and how it is modified by distraction osteogenesis. In a relatively short essay, the complex nature of this fascinating tool is explained. We hope the readers enjoy this issue of the *Atlas of the Oral and Maxillofacial Surgery Clinics* as much as we have enjoyed putting it together.

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The Influence of Mechanical Environment on Bone Healing and Distraction Osteogenesis

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Review of bone mechanics

To begin to understand the effects of mechanical forces on bone, such as those that occur during distraction osteogenesis (DO), it is necessary to consider the makeup of the bone and the features that enable it to respond to mechanical loading. Bone is a dynamic organ and, as such, it is in a constant state of change as affected by factors including nutrition, disease, and mechanical environment. Whether these changes alter the quantity or quality of the bone depends upon considerations such as their severity and duration. For practical purposes, bone can be considered a composite material. That is, in addition to water, bone is comprised of organic materials and inorganic matrix. While the organic material, such as collagen, gives bone its resilience and tensile strength, the mineralized matrix gives bone its compressive strength. The mineralized matrix also serves as the structural housing for the osteocytes. The osteocytes are the most abundant bone cells in the body and before becoming encased in their own matrix were bone-forming osteoblasts. These osteocytes reside in lenticular cavities called lacunae. In turn, the lacunae are connected to each other by way of a network of interconnecting channels called canaliculi. While the osteocyte bodies reside in the lacunae, their long, slender processes reside in the canaliculi. Interstitial fluid bathes the lacuno-canalicular network providing for nutrient exchange. This network may also play an important role in transducing mechanical signals. The osteocytes are able to physically link with each other through this porous environment and, many believe, amplify the mechanosensory response at the cellular level such that, among other functions, minimal loading can maintain bone integrity. These bone cells not only link and form networks with each other, but they also maintain contact with the surface-residing osteoblasts. It is hypothesized that the osteocytes act as strain gauges sensing mechanical deformation and communicate this signal to bone-forming osteoblasts that coordinate their activity with bone-resorbing osteoclasts, possibly by way of soluble signaling (Fig. 1). Two important bone types emerge, distinguishable largely by the level of porosity. Cortical (or compact) bone, comprising the hollow shafts of long bones and the thin cortices surrounding trabecular bone, typically has a porosity on the order of 5% to 10%; whereas cancellous (or spongy or trabecular) bone forming the bodies of flat and cuboidal bones typically has a porosity on the order of 75% to 95%. With the interstitial fluid running throughout these porous bone networks, bone is characterized not only by its porous mineral matrix, but also its fluid constituents, giving rise to the distinction that bone is also referred to as a poroelastic material.

When a bone is under mechanical load, its performance is governed by its size, shape, and the material that comprises it. Collectively, these features determine the mechanical properties

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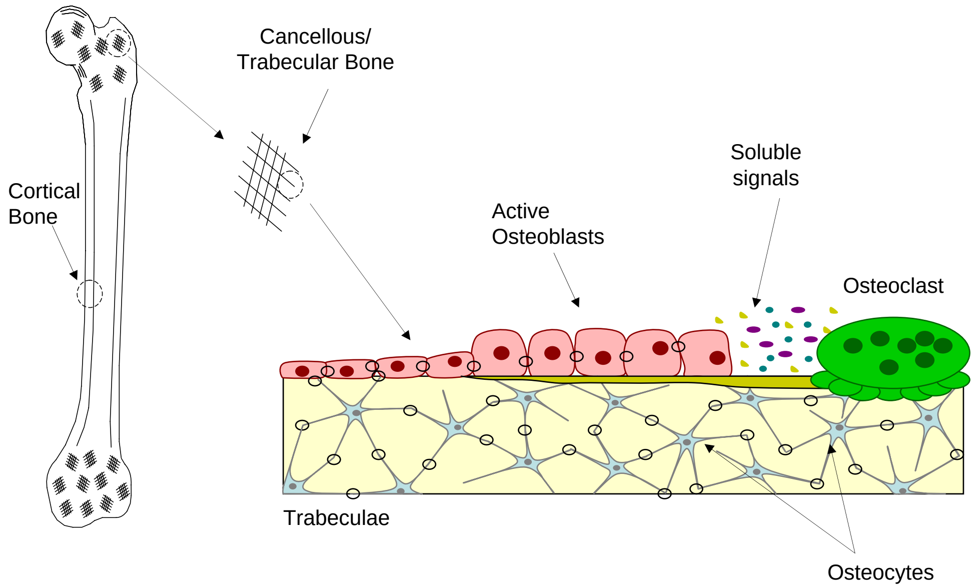

Fig. 1. Bones, such as the femur, are comprised of both cortical and cancellous bone. At the cellular level, bone is comprised of osteocytes, osteoblasts and osteoclasts. Osteocytes, embedded within the bone matrix, physically link (*black circles*) with each other and the bone-forming osteoblasts on the surface of the bone. Osteoclasts are the bone-resorbing cells that along with osteoblasts coordinate bone formation/resorption.

owing to the fact that they govern the mechanical performance of the bone. Mechanical properties are of two types. Material properties are independent of geometry and describe the substance which makes up the bone. Structural properties are dependent upon geometry and describe the behavior of the structure as a function of the size and shape, or form, it takes. The difference between these concepts can be easily understood if thought of in terms of extremes. For example, in Fig. 2 the steel I-beam (structural building support) and the steel bolt would have identical material properties because they are both made from steel. However because the I-beam is several times larger than the bolt, the structural properties would be quite different. Mechanical properties are determined by mechanical testing and are associated with a particular mode of loading, such as compression or tension.

Structural properties are experimentally measured quantities. In the laboratory, one needs only to test a specimen while recording load (load cell) and displacement (displacement sensor) to develop a load versus displacement curve plotting displacement on the horizontal axis and load on the vertical axis. As shown in Fig. 3, if a bone is tested to failure, the bone will undergo

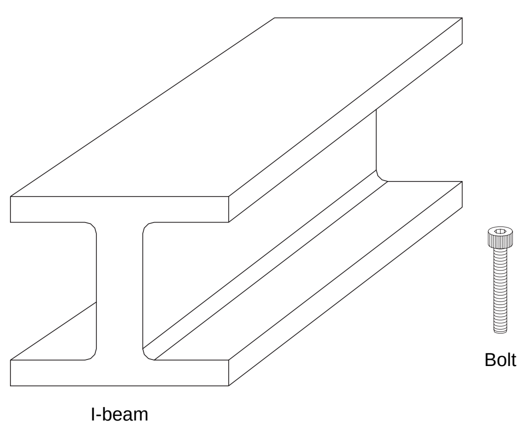

Fig. 2. The steel I-beam and bolt illustrate the concept of material and structural properties. If both objects are made from steel, they will have the same material properties. However, given the difference in size and geometry, they will not have the same structural properties.

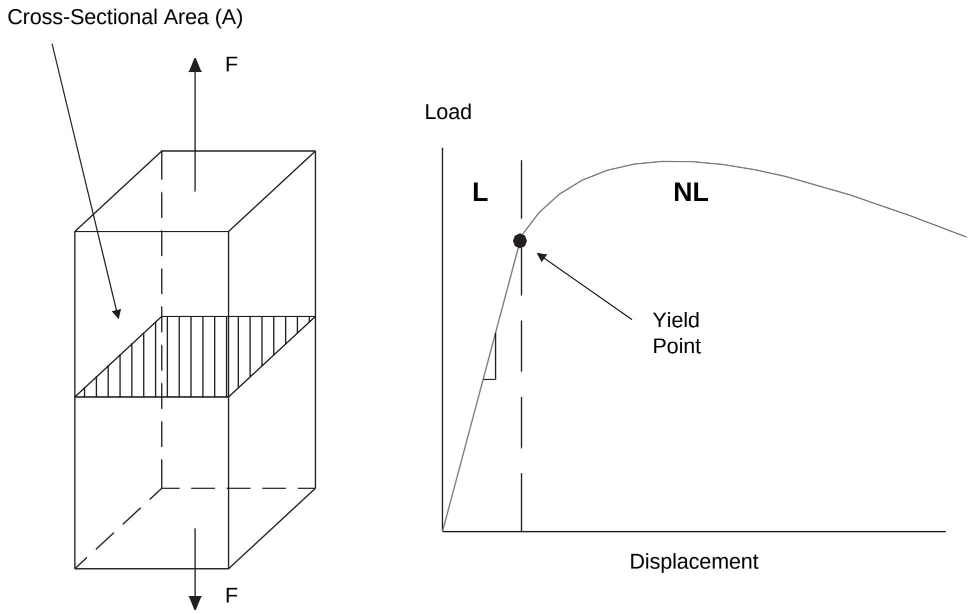

Fig. 3. Structural properties are determined from mechanical testing. If a tensile load is applied to the block, the block will undergo an elongation, or a change in length with the applied load. If the load and displacement are recorded, the load-displacement curve will represent the mechanical behavior of the object. If tested to failure, the specimen will experience both elastic and plastic deformation. The linear (L) portion of the curve represents the area in which loading and subsequent unloading will not cause permanent deformation (damage) to the object. The nonlinear (NL) portion of the curve represents the area in which loading and subsequent unloading will cause permanent deformation to the object.

elastic (linear) and plastic (nonlinear) behavior. If we concentrate on only the linear, elastic portion of the curve (to the left of the dashed line), it can be seen that the linear region of the load-displacement curve represents the region in which load is directly proportional to displacement. In this region repeated loading and unloading of the material will not result in permanent deformation and the rate of loading is theoretically not a factor. When the load-displacement curve reaches the point where it is no longer linear (the yield point) permanent deformation will result and the behavior of the material in this region is dependent upon the rate of loading. In the linear region, the slope of the load-displacement curve is called the "stiffness." Stiffness is an important structural property and is a measure of the compliance of the specimen. That is, the larger the stiffness of a bone, the less likely it is to deflect or deform under a given load.

Material properties are calculated from the data obtained in a load-displacement curve. Stress and strain are constitutive relations and neither can exist independent of the other. Recognizing that a "stress" is simply a measure for a force (load) over a given area and that "strain" is a measure of how much an object changes in length with respect to its initial length ($\Delta L/L_o$), the loads in the force-displacement data divided by the cross-sectional area of the object will generate the stresses. In addition, the incremental displacement data taken with respect to the initial length of the specimen will generate the strains (Fig. 4). A consequence of this simple conversion is that the load-displacement and stress-strain curves will have similar shapes, but different numerical scales.

Bone can be subjected to a variety of different loading modes, as demonstrated in Fig. 5. Here a coupon of bone is shown before and after loading in compression, tension, and shear, respectively. While tension and compression occur along the same axis perpendicular to the loading plane, they have opposite effects on the shape of the material. The shear occurs parallel to the plane and has the effect of moving part of the object relative to another part. Stresses can be more succinctly defined by the affect they have upon an object. Dilatational (hydrostatic) stresses (see Fig. 5) result in volume changes whereas deviatoric stresses result in volume distortion. The mechanical loading mode (eg, compression) is not uniform throughout an object. This implies that, if a coupon of bone is subjected to a compressive load, every point within that

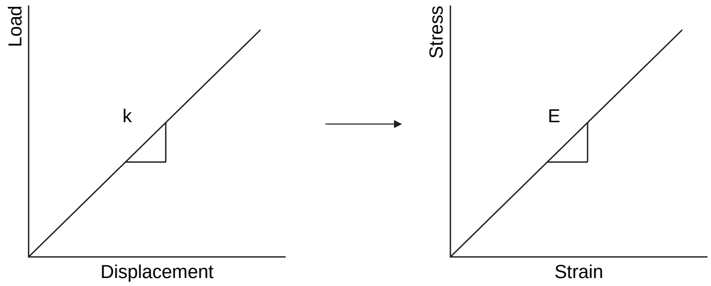

Fig. 4. Mechanically loading an object in the elastic region yields a linear load-displacement curve. The slope of this curve is the structural property known as stiffness (k). While the structural properties can be determined from this curve, material properties may be determined by converting the load-displacement curve into a stress-strain curve by taking into account the object dimensions. The slope of this curve is the material property known as Young's modulus (E).

coupon is not in compression. This may at first seem confusing, but it is an important concept to grasp when studying the mechanical effects of loading bone. Although the mechanics of this are beyond the scope of this writing, the reader needs to be aware that even the simplest loading modes result in complex stress and strain states throughout the bone. As such, compression on a bone coupon can result in regions of the bone experiencing shear. Given that bone, like many objects, is weaker in shear than in compression, a uniform compression load causes the bone to fail in its weakest loading mode, shear. This is illustrated in Fig. 6. The shear experienced is highest along a plane 45° to the normal and fracture occurs along this plane. This is also the reason that a long bone subjected to pure torsion will experience a spiral fracture along a 45° plane. This behavior is not limited to bone and the reader can easily demonstrate this effect by performing the classic demonstration of applying axial torsion to a piece of blackboard chalk. This demonstrates that by understanding how the various mechanical loading modes affect bone, one can look at a bone fracture to infer the type of loading that caused the failure.

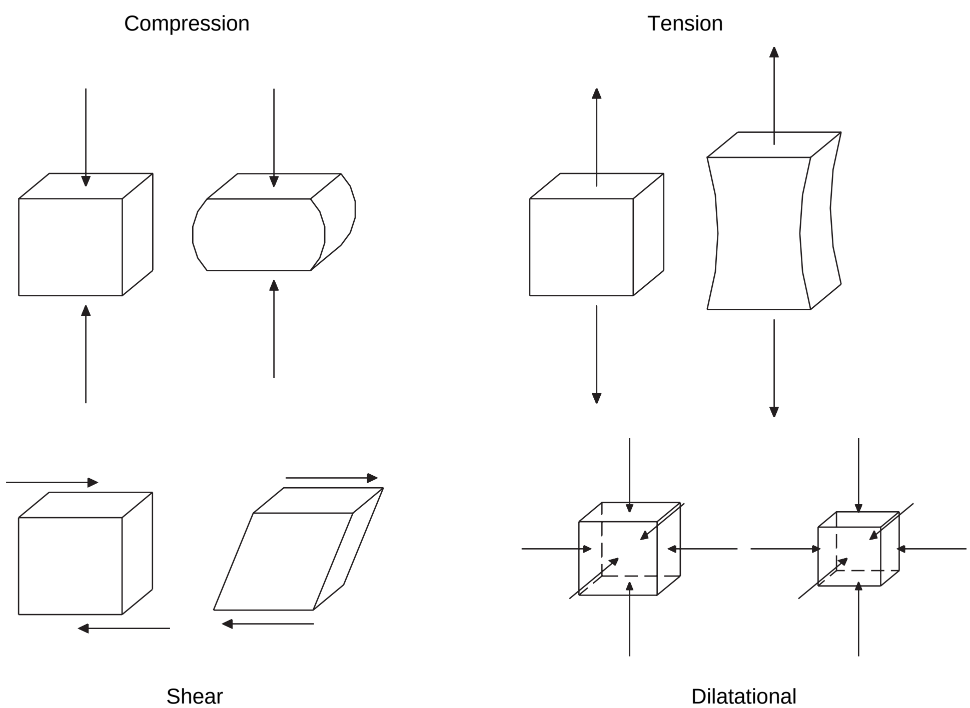

Fig. 5. Objects may be loaded in different loading modes including: compression, tension, and shear. Compression has the tendency to shorten and bulge an object; tension has the tendency to lengthen and thin an object; and shear has the tendency to distort an object. Stresses may further be classified by the effect they have on the object, particularly their ability to dilate or deviate the object. Dilatational (hydrostatic) stresses function to uniformly alter the size of the object without distorting its shape.

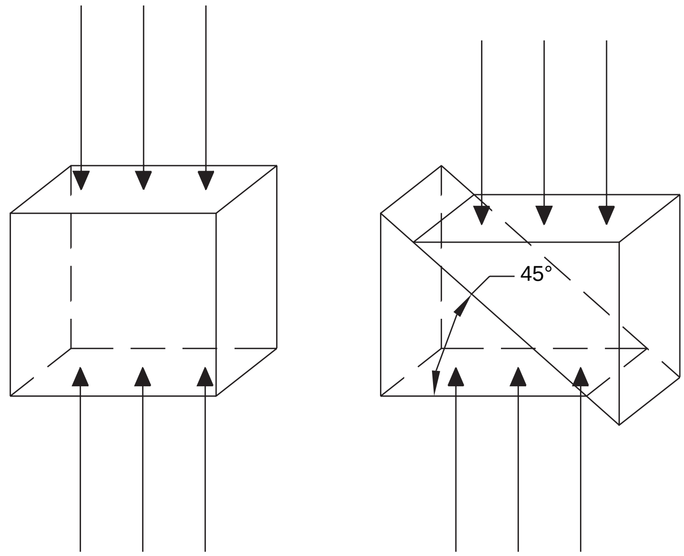

Fig. 6. Objects under simple loading can experience complex stress states. Even if this simple block is loaded in pure compression, shear stresses will be generated within the object. Because many objects, including bone, are weaker in shear than compression, objects loaded in this manner will fail by shear. Given that shear is maximal on a plane 45° to the axis, the shear will occur along this plane.

This is not limited to the loading mode, but is also reflected in the speed with which the fracture occurred. When bone is fractured slowly, such as occurs during low-energy trauma (falling), the bone has time to absorb energy and a simple fracture results. When bone is fractured quickly, such as occurs during high-energy trauma (a motor vehicle accident), the bone does not have time to absorb the energy and the fracture is comminuted. For obvious reasons, it is desirable that a fracture created by osteotomy/corticotomy in the initial stages of DO is noncomminuted, simple, and stable.

The slope of the stress-strain curve in the linear region is known as the modulus of elasticity or Young's modulus (E) and is one of three material properties that are needed to completely define a material. For bone, reported values for the Young's modulus for human cortical bone varies from 17.4 GPa in the longitudinal direction to 3.51 gigaPascal (GPa) in shear and the reported values for the Young's modulus for cancellous bone varies from 1 to 20 GPa, owing to testing dependence and the increased difficulty in testing trabeculae in comparison to cortical bone.

The second material property known as Poisson's ratio (ν) is a measure of how elongating or compressing an object will cause necking or bulging, respectively. The Poisson's ratio is a measure of how loading in the axial direction affects the structure transversely (laterally). With few exceptions, axial tension results in transverse necking while axial compression results in transverse bulging (see Fig. 5). For practical purposes the formulation for Poisson's ratio −[lateral strain/axial strain] is preceded by a negative to account for this inverse relationship and yield a positive numerical value. For bone, a reasonable value of Poisson's ratio is 0.3.

The third material property, the shear modulus (G) is the slope of the shear stress-shear strain curve in the linear region and is readily determined from a torsion test. Whereas the three material properties completely define a material, the three properties are not independent. That is, determination of any two can enable the calculation of the third, using the relation, $G = E/[2(1 + \nu)]$.

Many materials, such as bone, behave differently depending upon the direction in which they are loaded. When a material property is a function of the loading orientations, the material is termed "anisotropic." To determine the degree of anisotropy in the laboratory, samples of the material, such as bone, are cut from the block and tested with respect to each of the three orientations (Fig. 7). The load-displacement curve is converted to a stress-strain curve and the elastic modulus is determined. At the same time the loading is applied, the cross-sectional area changes perpendicular to the loading direction are measured to calculate Poisson's ratio. If the elastic

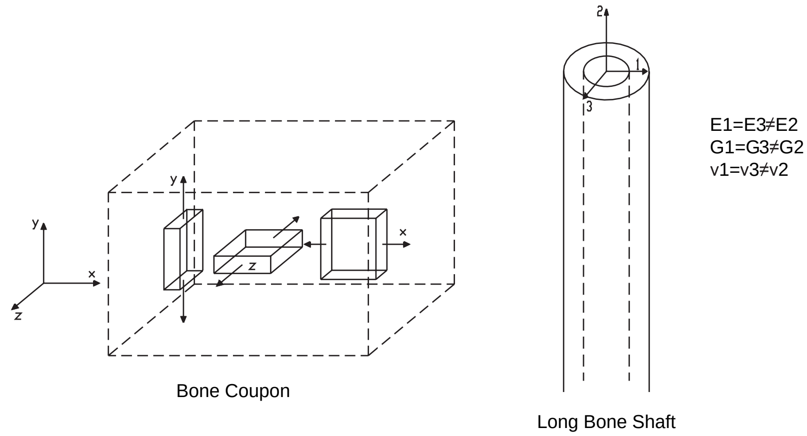

Fig. 7. Material properties often have directional dependence. When material properties are a function of the loading orientation, this degree of anisotropy can be determined by cutting samples from a section of the object and loading these identical samples in each of the three orientations (*x,y,z*). Bone is often classified as transversely isotropic implying that the bone behaves the same in the transverse plane, but not in the longitudinal plane, as shown for a cylindrically shaped bone shaft. (E) Young's modulus. (G) Shear modulus. (ν) Poisson's ratio.

moduli and Poisson's ratios for each of the three orientations are the same, the material is said to be ''isotropic'' and the material is completely defined by one E, one G and one ν (three terms). If the values for each of the three orientations are not the same, the material is said to be ''orthotropic'' and completely defined by three E's, three G's and three ν's (nine terms). Bone is generally considered transversely isotropic (six terms). It is approximated that bone behaves roughly the same in a plane transverse to the long axis of the bone but behaves differently along the axis.

Biomechanics and molecular mechanisms of distraction

With a basic understanding of bone mechanics, a discussion of the role that mechanical loading plays in guiding DO can begin. The focus of this section will be on axial (linear) DO as the process of applying controlled elongation at an appropriate rate to induce de novo osteogenesis through intramembranous bone formation. DO requires a latent stage postfracture (osteotomy/corticotomy), an active distraction stage during loading application, and a consolidation stage ensuring sufficient mineralization and return of functional strength. Understanding the mechanics of fracture healing and distraction are critical to understanding the role mechanics plays in governing osteogenesis. Similarly, the molecular mechanisms of fracture healing and DO can be compared as both biological processes are regulated by three groups of signaling molecules: (1) proinflammatory cytokines (IL-1, IL-6, RANKL, OPG); (2) members of the transforming growth factor beta superfamily (TGF-β, BMP-2, BMP-4, BMP-6, bFGF, IGF); (3) angiogenic factors (VEGF A-D, Angiopoietin 1 and 2). However, there are distinct differences between fracture healing and DO, particularly the use of mechanical strain to stimulate bone formation during DO and the variation in expression of molecular regulators. Endochondral bone formation is the dominant form of ossification during fracture healing. Intramembranous ossification is the dominant form of ossification in DO, with only modest endochondral bone formation during early stages of DO and limited to the level of the periosteum and not throughout the distraction gap. The exact mechanisms by which strain influences the molecular regulators and, ultimately, the formation of bone remains unclear.

Initiating the latency stage is the surgical creation of an osteotomy in which a gap is created. Proinflammatory cytokines IL-1 and IL-6 are upregulated immediately, inducing osteoclastogenesis after the osteotomy, and then rapidly return to baseline. Additionally, the levels of RANKL and OPG appear to increase as the latency period ends and there is resorption of the early mineralized external callus adjacent to the distraction osteotomy. Expression of BMP-2, BMP-4, and BMP-6 during the latency phase appears to be related to differentiation of chondrogenic and osteoblastic cells and may reflect their roles during the short endochondral phase of DO.

While the latency period is important because it allows time for the biological process of osteotomy healing to occur, the mechanical environment that the osteotomy gap is exposed to during the distraction phase is of tremendous consequence. Likewise, it is during this dynamic period of mechanical strain that there is significant upregulation of the members of the TGF-β superfamily signaling osteoblast differentiation and uninterrupted bone formation. Their expression decreases gradually once the distraction has stopped. Coinciding with this active period of bone formation is the neoangiogenesis and the upregulation of the angiogenic factors. Unlike fracture healing where neoangiogenesis occurs in the external callus, the majority of new blood vessels occur in the medullary space and distraction gap. As bone formation is occurring, specific cytokines continue a role in this phase. The RANKL/OPG ratio increases at the beginning of distraction and promotes resorption of any remaining mineralized cartilage formed during the latency phase. IL-6 is expressed by cells within the fibrous interzone where the tensile strains are the highest and may contribute to the differentiation of osteoblasts and formation of intramembranous bone. Levels of all signaling molecule groups decrease during the consolidation phase as remodeling occurs. In an effort to develop a predictive model of the effects of the mechanical environment on bone formation, several researchers have proposed theories relating mechanical regulation to bone morphogenesis.

In 1979, Perren proposed the Interfragmentary Strain Theory. This theory predicts tissue type formed in fracture gaps as a function of the strain in the gap region, with the strain being defined as the ratio of the gap end displacement to the width of the initial gap. This theory provides for the case of a linear, one-dimensional system in which the strain is induced only along the long axis (longitudinal) of the bone. According to Perren's theory: primary, intramembranous bone formation occurs if the strains in the gap region are below 2%; secondary, endochondral bone formation occurs if the strains in the gap region are between 2 and 10%; granulation tissue formation occurs if the strains are between 10 and 100%; and a non-union occurs if strains are larger than 100%. This can be illustrated if a straight bone, or section of a bone, is assumed as shown in Fig. 8A. The strain in the gap site, because it is a measurement of changes or displacements between the gap ends, represents a measurement of the micromotion that occurs at the fracture site. The mechanical loading of the fracture induces the micromotion. If the micromotion is small (generating strain less than 2%), the fracture is relatively stable and at the tissue level, primary bone healing is observed. As the degree of micromotion increases (with increasing strain), the ability of bone to heal via intramembranous bone formation is affected and, if it heals at all, heals by way of endochondral bone formation and a cartilage matrix. Secondary bone healing with a temporary callus results from increased micromotion at the fracture site and serves two important mechanical functions. The callus serves to unite the fracture ends, stiffening the fracture gap. In addition, because the large deposit of callus tissue is significantly weaker than the native bone, the large deposit serves to distribute the load and reduce the overall gap strain.

At a cellular level the strain percentages are derived for each of the three cases: intramembranous ossification, endochondral ossification, and granulation tissue formation. If a fracture gap is to heal by way of primary intramembranous bone formation, the osteoblasts must be able to survive the strain, or micromotion, present in the bone gap. Osteoblasts are not able to tolerate strains exceeding the order of 2%. In the first case, if the fracture gap is bridged by a single row of osteoblasts (see Fig. 8A, 1) and the gap strain is less than 2%, the bone will heal via intramembranous ossification. In the second case (see Fig. 8A, 2), because chondrocytes are able to survive strains on the order of 10%, if strains of this magnitude are present, the gap will heal by way of endochondral ossification. In this case, as the chondrocytes begin to lay down cartilage bridging the gap ends, the stiffness of the fracture gap increases. As the stiffness increases, the interfragmentary strain (micromotion) decreases. Cartilage will continue to be formed until the gap stiffness has increased sufficiently to reduce the strains below 2%. At this point, the osteoblasts are able to infiltrate the gap and the cartilage scaffold is subsequently replaced by bone. In the third case (see Fig. 8A, 3), if the strains in the fracture gap are more than 10% but less than 100%, fibroblasts (as well as other cells stimulated by the injury) invade the fracture gap because these cells can survive these high strains. Whether or not the fracture heals depends upon the ability of the granulation tissue to stiffen the fracture gap so that it reduces the strain field to less than 10%. If the fibroblasts are successful, and the interfragmentary

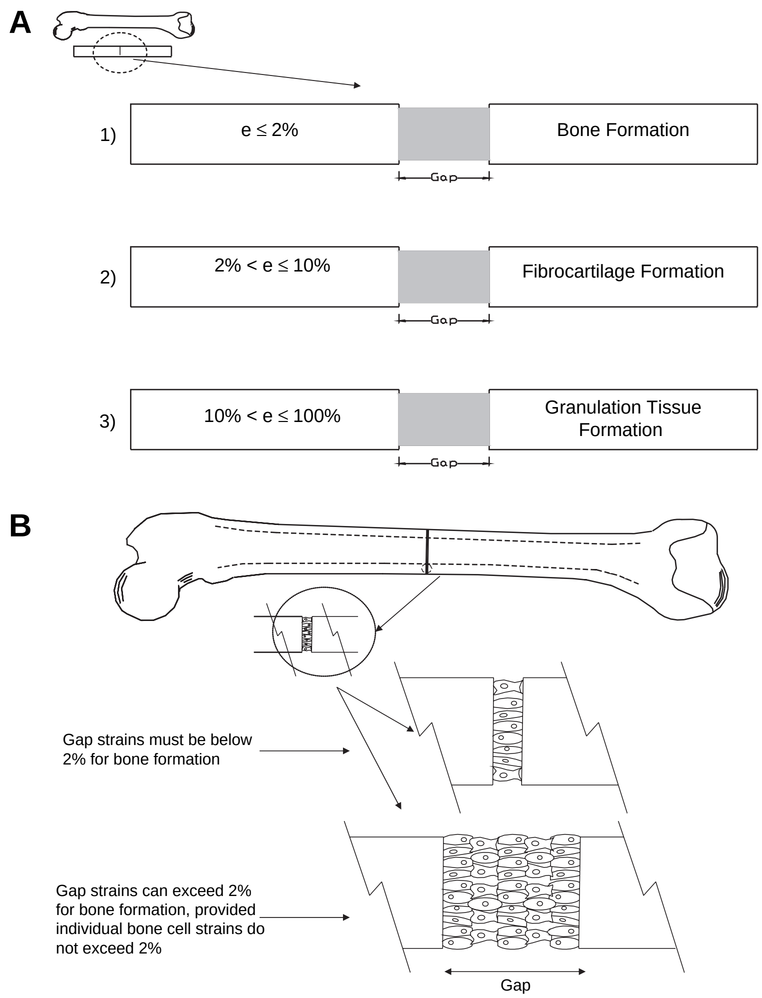

Fig. 8. (*A*) The Interfragmentary Strain Theory, proposed by Perren, suggests the type of tissue that occurs in a bone during fracture healing and the success of fracture healing are a function of the mechanical environment, specifically the strain (e) occurring in the fracture gap as a result of the displacement between the fractured bone ends. Furthermore, this theory recognizes that the effects of the mechanical environment on the cells, dictates the tissue and organ level responses. (*B*) The Interfragmentary Strain Theory proposes fracture gap strain levels on the order of 2% result in intramembranous or primary bone formation. This does not indicate that the total strain measured in the gap is less than 2%, only that the strains on the individual osteoblasts must be below this level in order for these cells to survive and form bone. Networks of osteoblasts can span a fracture gap and provided that their individual strains are below 2%, these osteoblasts can tolerate the mechanical environment and lay down bone.

strain is reduced to less than 10%, the environment will support the chondrocytes which will infiltrate and lay down cartilage. As before, if the cartilage stiffens the fracture site to a point where strains are less than 2%, osteoblast infiltration and bone formation will result. Thus, from a mechanical perspective, the mechanical environment dictates if a fracture will heal and the mechanism by which it heals.

Does this mean that anytime that bone is healing by way of intramembranous bone formation that the strain field is less than 2%? The answer is "no." As an example, if there is a rope with a series of knots evenly spaced throughout its length and force is applied to the rope, it will generate both stress and strain in the rope. The stress will be continuous throughout the rope and, if the load induces a stress of 10%, this is the stress that will be measured at each point along the rope. If the strain in the rope is 5%, this represents the strain over the entire length of the rope. As an example if there is a rope with a series of knots evenly spaced throughout its length and a force is applied to the rope, stress and strain will be generated in the rope. The stress will be continuous throughout the rope, and if the load induces a stress of 10 Pa, this is the stress that will be measured at each point along the rope. In a similar manner, if multiple osteoblasts are connected and spanning the fracture gap (see Fig. 8B), the total interfragmentary strain can exceed 2% and still result in intramembranous bone formation, provided the individual osteoblast strains are below 2%. Similar arguments can be made for fracture healing that is preceded by endochondral ossification and granulation tissue formation, and explain why the initial strain values proposed by Perren are rarely found in clinical application.

While relatively easy to understand, the Interfragmentary Strain Theory as explained here is overly simplified. As discussed, even the simplest loading modes induce complex stress and strain states in bone, and the theory does not sufficiently address this or the three-dimensionality of the stress/strain state in bone. Furthermore, the portion of Perren's theory that is presented here is valid only when the motion in the fracture gap does not exceed its size. Perren suggested that in these cases the bone ends would further resorb until the gap displacement no longer exceeded the gap width and healing could occur. Further concerns with this theory have been raised regarding discrepancies in temporal changes in the callus tissue and poor correlation with histologic observations.

There are other theories of the mechanics of bone morphogenesis which will be briefly discussed. The interested reader is encouraged to consult the references provided. Pauwels (1960) is credited with one of the earliest mechanical regulation of tissue morphogenesis theories. He proposed that tissue differentiation was dictated by local stress and strain fields; hydrostatic stresses result in the formation of cartilage whereas deviatoric stresses result in the formation of connective tissues, including bone. Carter (1988, 1998) proposed a theory of the mechanical regulation of tissue differentiation incorporating loading history. He suggested that high-hydrostatic stresses (compressive) support cartilaginous tissue formation while low-hydrostatic stresses (tensile) support bone tissue formation. Experimental models support this premise. Furthermore, high tensile strains support fibrous tissue formation that, in conjunction with hydrostatic compression, supports fibrocartilage formation. More recent theories using computer simulations have sought to incorporate the role of stem cells and fluid shear. Fluid

Fig. 9. Lateral view of the patient (*A*) before distraction and (*B*) after successful distraction. This is a 16-year-old male who sustained a gunshot wound to the right temporomandibular joint (TMJ) and underwent repair at age 10 years. He developed limitation in oral opening (25 mm) and slight deviation of the mandible to the right due to right TMJ bone overgrowth and fibrotic ankylosis. He also had significant mandibular retrognathia with an overjet of nearly 20 mm. At 16 years, he underwent a right condylectomy and myofascial flap rotation into the new joint space. His oral opening improved to 45 mm, however, his overjet was 15 mm. One and a half years later, he underwent bilateral mandibular osteotomies and distraction of the mandible. He was distracted for 16 days at 1.2 mm/day after a 3-day latency period. Though there was a period of noncompliance with the daily distraction, he was successful in correcting the severe retrognathia.

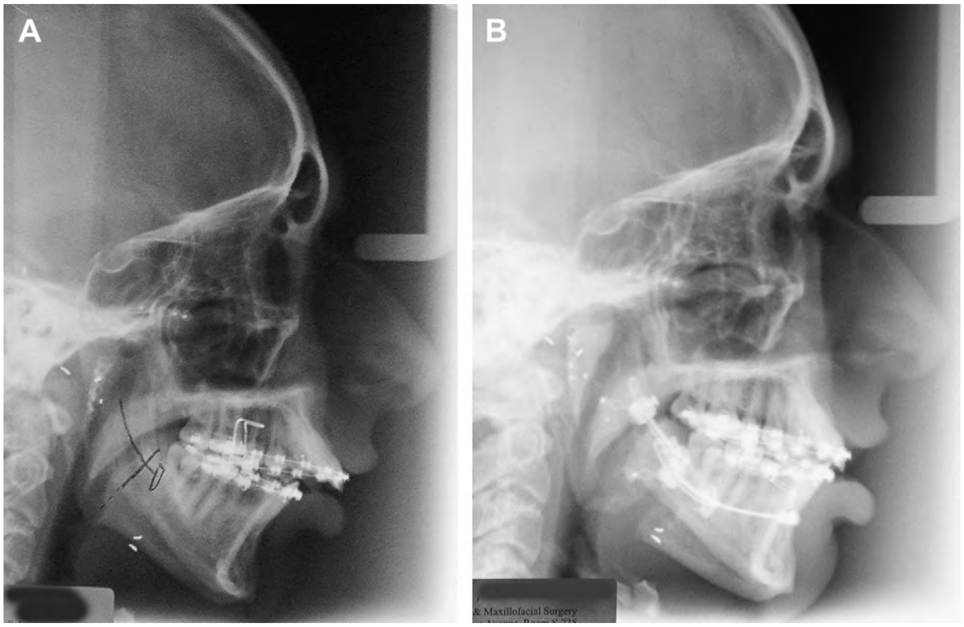

Fig. 10. Lateral cephalograms (*A*) immediately before the mandibular osteotomies and distractor placement and (*B*) 16 days after initiating the distraction phase. Note the significant preoperative overjet and improvement with distraction. The miniplates were from the original traumatic injury and repair.

shear is of particular interest as it is gaining acceptance as a mechanical regulator at the cellular level.

Summary

So why do we care about mechanics and mechanical theories of fracture healing and bone morphogenesis in DO? As noted at the beginning of this chapter, bone has the innate ability to heal itself and much of fracture fixation focuses on stabilizing the bone to allow the native healing process to occur. The goal of this stabilization is to maintain a mechanical environment that promotes ossification and fracture healing. In DO, understanding the basic mechanical properties of bone, as well as the response of bone to loading enables successful distraction. Critical to successful distraction is an appropriate latency period. If the latency period is not sufficient to begin the process of fracture healing and bone formation, premature loading will result in failure. Furthermore, the rate at which the bone is distracted is also important. If the bone is distracted too quickly, the strains at the fracture will be too high and nonunion will

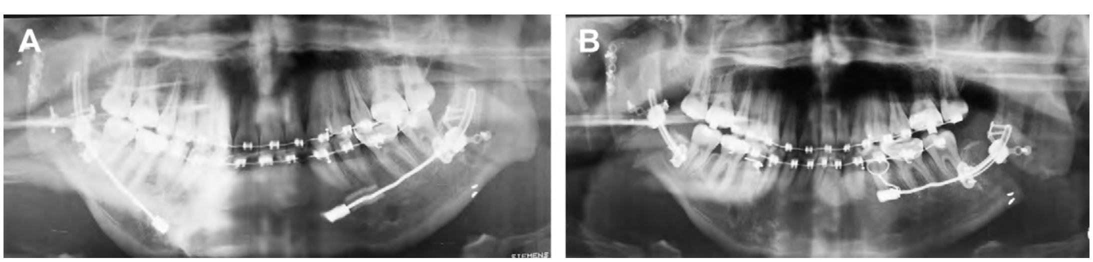

Fig. 11. Panorex (*A*) immediately after the mandibular osteotomies and placement of low-profile, curvilinear distractors and (*B*) after 16 days of distraction at 1.2 mm/day. There was a short period of noncompliance but the patient was able to continue with successful distraction. On the day 16, the right activating wire broke at the anterior footplate. Fortunately, he had achieved a normal class I dental relationship. The left activating wire was removed and the maintenance phase was initiated. By one year after distraction, the patient continued to have a stable skeletal result, normal class I dental relationship, normal oral opening and completed orthodontic therapy.

occur. On the other hand, if bone is distracted too slowly, it will undergo early consolidation (high regenerate stiffness). Distraction will be halted as the bone can no longer be manipulated by the distractor. In addition, understanding that bone behaves differently as a function of the orientation by which it is loaded, helps to determine the distraction rate. Additional factors also contribute to the success of osteogenesis and need to be considered when performing this procedure. Age has a tremendous affect on the osteogenic potential of bone. Given the high osteogenic potential in childhood, special cases of neonatal distraction do not require bone fracture and simply applying distraction to the bone elicits an adequate osteogenic response (J. Van Sickels, personal communication, 2007). In addition, alcoholism and smoking can decrease osteogenesis, and the metabolic bone disease, osteoporosis, is contraindicative to treatment by DO. A clinical case is provided that demonstrates the critical factors of mechanical strain theories, an appropriate distraction regimen, age, and patient compliance (Figs. 9–11).

DO, first described by Codivilla in 1905 and popularized by Gavril Ilizarov in 1951, was originally applied to long bones, and much of the characterization of the approach has been studied in this model system. Considerably less characterization has been conducted in craniofacial models. Mandibular and maxillary geometry are significantly more complicated than femur geometry. And while DO in the femur may be adequately addressed with a linear (one-dimensional) distraction, the nonlinear (three-dimensional) nature of many craniofacial deformities require planar distractors and a greater understanding of the influence of the mechanical environment. In addition, in orthopedic applications of limb lengthening, minimal length disparities between DO-treated and contralateral limbs are often inconsequential. In stark contrast, even slight disparities in craniofacial distraction can affect facial symmetry, which is further complicated by the fact that the cellular responses of the craniofacial complex to mechanical loading remain poorly understood. Therefore, it is critical for oral and maxillofacial surgeons performing these DO procedures to thoroughly understand how the mechanical environment contributes to the successful outcome of DO.

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Atlas of the Oral and Maxillofacial Surgery Clinics

Distractor Design and Options

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Unfortunately, few of these issues are or can be addressed by distractors that are commercially available today. Extraoral distractors, especially those applied to the mandible, are relatively easy to apply but have a variety of issues, including pin tracts and early mobility of pins (Fig. 1). Because of the distance from the bone and flexion of the pins, the amount of movement achieved with each turn of the distractor is not as exact as that seen with distraction devices applied intimately to the bone. Multivector extraoral distractors allow change in the primary vector of distraction as opposed to internal distractors where it is much more complicated to change the primary vector. Although continuously activated distractors have been developed for laboratory use, those available for clinical use require manual activation two or more times a day to achieve the desired rate and rhythm of distraction. This manual component to activation requires that patients be educated as to how and why the appliance the appliance is used. Follow-up visits often are required to assure that patients or their family members are using an appliance correctly.

The further away from the ideal center of distraction an appliance is placed, the more asymmetric the movement of the segments. The classic example of this is when a surgically assisted rapid palatal expansion is done (Fig. 2). The appliance is cemented to the teeth, yet the ideal point for attachment is to the middle of the palatal tissue. Because of the position of the distractor, when it is activated, there is more expansion at alveolar portion of the maxilla and less at the apex of the palate (Fig. 3). In addition, the rotation of the segments causes the palatal cusps of the upper molars to occlude with the lower molars with a resultant anterior open bite. Bone-born appliances currently used in Europe to expand the maxilla do not have this problem (Fig. 4).

Midface and maxilla

Submerged versus nonsubmerged

The basic distractor is a tram that allows expansion in one or more directions that has some sort of attachment to the bone, teeth, or both (Fig. 5). Submerged distractors have a port that emerges through the mouth or transcutaneously (Fig. 6). Nonsubmerged are extraoral and attached directly to the bone or teeth. Whether or not the mandible or the maxilla is addressed, the desired movement of segments is seldom in one direction. To change the primary extrinsic vector, the distractor needs multiple options or a second extrinsic vector, such as elastics, applied to appliances on the teeth. Midfacial advancement at the Le Fort III level and frontofacial advancements can be approached with internal or external devices depending on the

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Fig. 1. Pin tracts and scarring due to external pins.

Fig. 2. Tooth-borne device for surgically assisted palatal expansion.

circumstances. The internal devices usually are placed at the level of the body and arch of the zygoma in order to obtain true advancement of the midface rather than pivoting at the incisor region or the nasal root region (Fig. 7). Extraoral distractors used to move the maxilla or combinations of the maxilla and upper parts of the face allow the greatest opportunities to change the primary vector of distraction (Fig. 8). The wires used for the distraction can stretch the first few days and may not be a true indicator of advancement if the activation is based on turns of the distraction device alone. Extraoral distractors generate a moment arm caused by the point of

Fig. 3. Radiograph obtained at the end of 13 mm of expansion; note that expansion is greater at the dentoalveolar portion than at the apex of the palate.

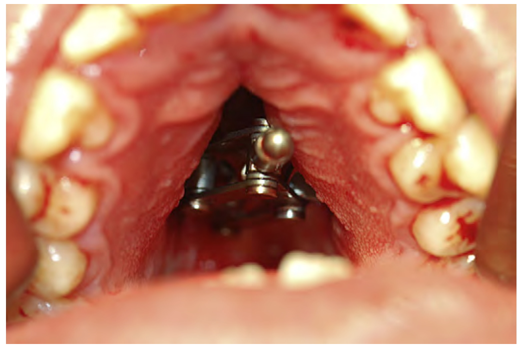

Fig. 4. Bone-borne device for surgically assisted palatal expansion.

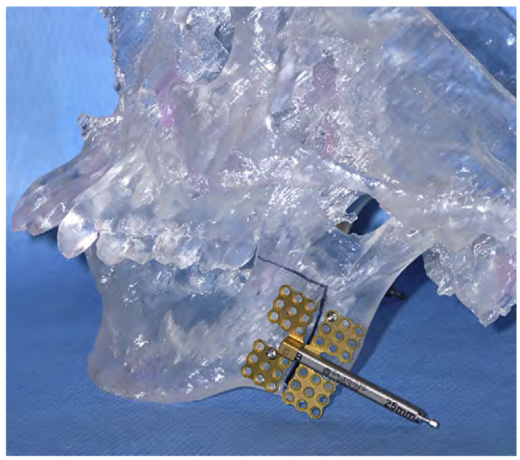

Fig. 5. Basic distractor with a tram that is attached to bone, which expands.

attachment to the segment and the design of the osteotomy. With an external distractor, the vector can be modified by changing the position of appliance of the rod. When this is done during distraction, however, increase or decrease in the tensional forces placed on the maxilla must be considered. For example, if the appliance is moved inferiorly, tensional forces increase, whereas the reverse is true when it is moved upward. Attachments for activating wires can be to the appliances fabricated to fit the teeth and directly to the bone (for more information see the article by Reddy and Elhadi elsewhere in this issue).

Fig. 6. Submerged distractor exiting through oral mucosa.

Fig. 7. Submerged distractor for midface advancement placed at the arch and body of zygoma with true midface advancement.

Intraoral appliances in the maxilla are appealing to patients but present challenges in their application and use (Fig. 9). With stainless steel and titanium distractors, a stereolithographic model of a patient facilitates bending of an appliance before reaching the operating room (Fig. 10). Once an appliance is placed, changing the primary vector during the course of therapy can be done only with secondary extrinsic vectors. Because most intraoral distractors are designed to have access through the mouth, several problems can occur. They may require contouring of the bone for better placement and control of vectors. This can cause difficulty with fixation of the device to the bone because of frequently encountered inadequate bone surface and quality. To have the distractor trams exit from the mouth, the trams sometimes need to converge (Fig. 11). In addition, the trams should be at the level of the occlusal plane to exit near the buccal orifice. To do this, some companies have modular sets, which allow the distractors to be customized to patients (Fig. 12).

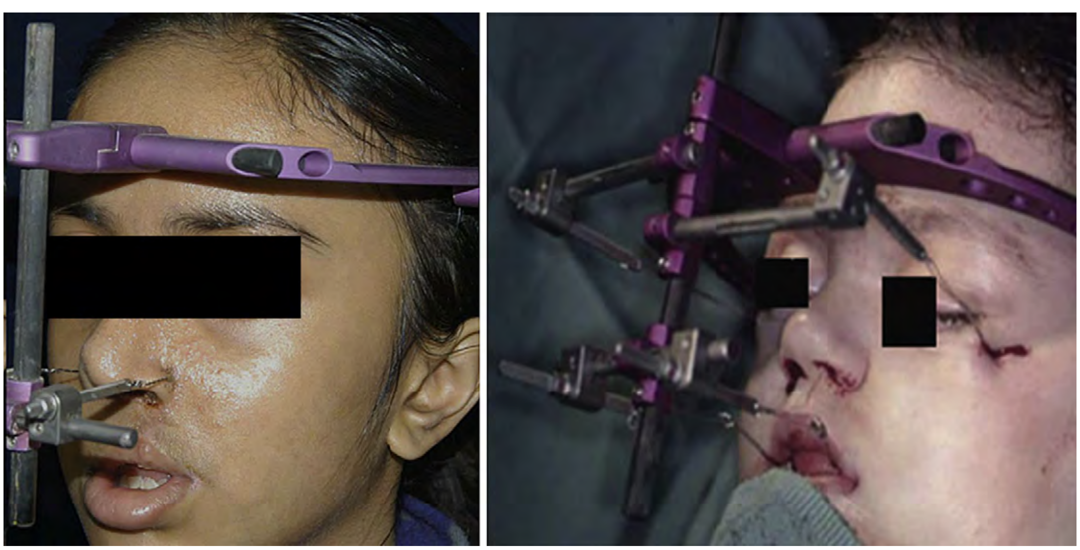

Fig. 8. Extraoral distractors for the movement of maxilla and upper part of face.

Fig. 9. Different type submerged appliances placed intraorally for maxillary advancement.

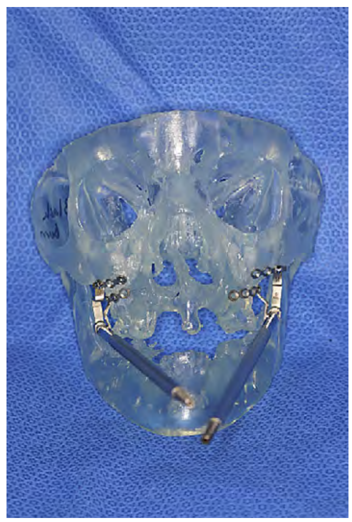

Fig. 10. Stereolithographic model with distractors applied.

Fig. 11. Convergence of trams for the intraoral submerged distractor.

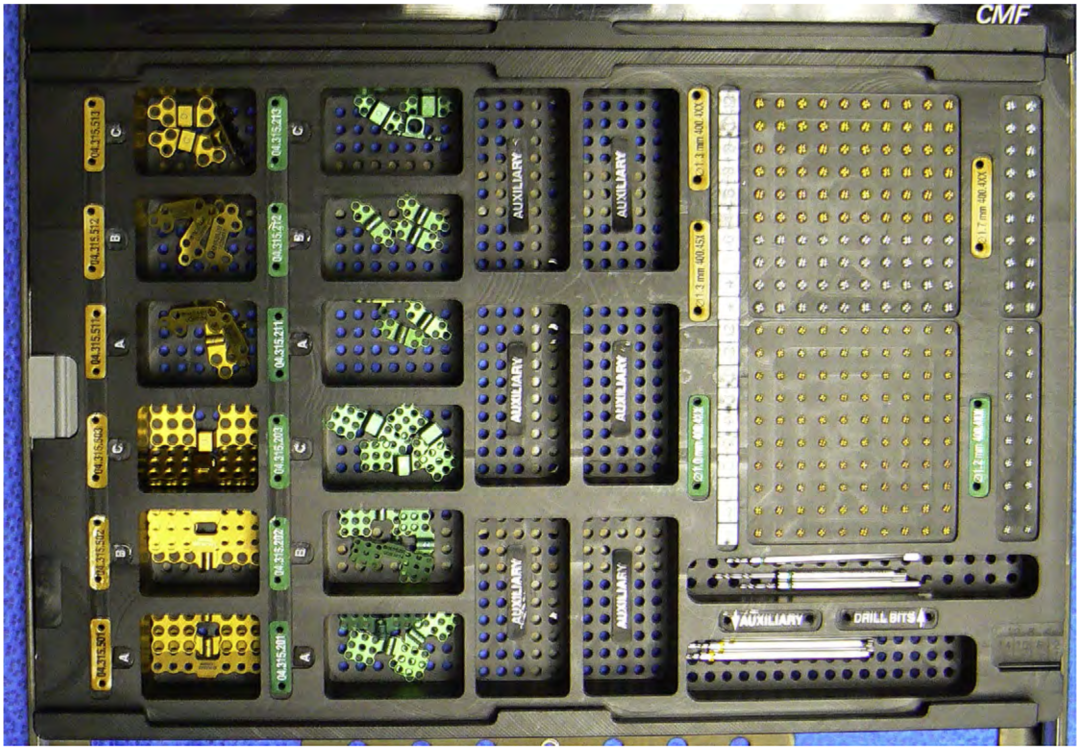

Fig. 12. Modular mandibular set; others are available for maxillary distraction.

Bone-borne versus tooth-borne

As discussed previously, appliances that are applied to the teeth usually create a moment arm resulting in uneven distraction because they are not at the center point of segment to be distracted. Tooth-borne appliances in the maxilla usually are custom made and cemented to teeth before surgery. The most common use is to widen the maxilla by surgically assisted rapid

Fig. 13. Nonsubmerged distractors with multiple vector control.

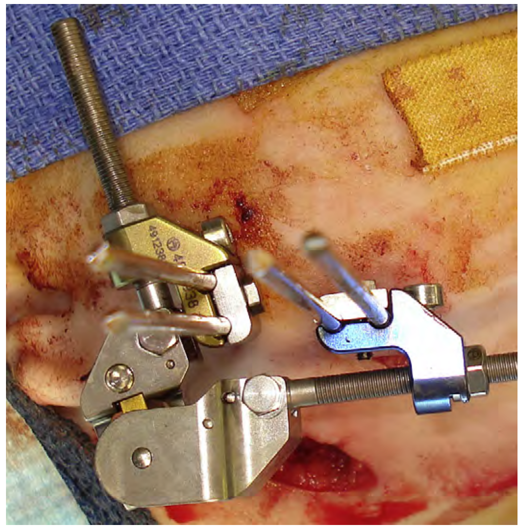

Fig. 14. Extraoral distractor with two trams and multivector control.

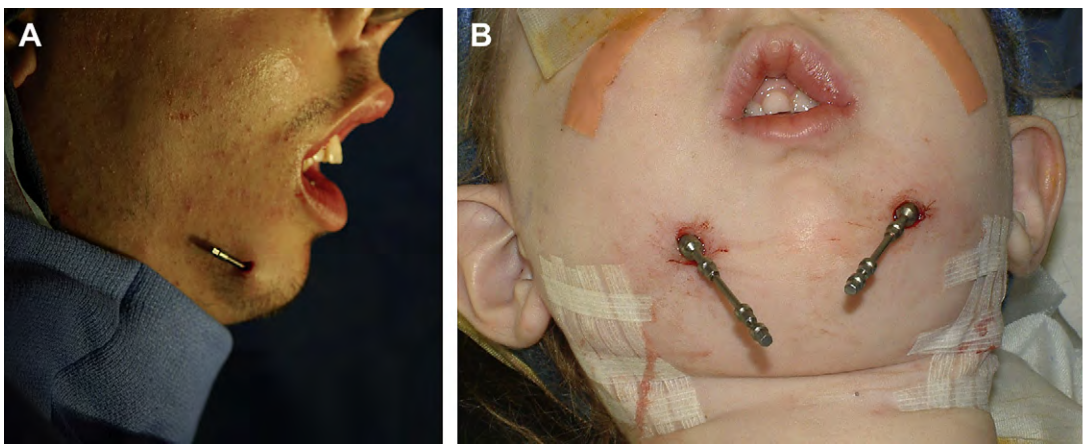

Fig. 15. Submerged distractor activating arm exiting transcutaneously in two different patients.

Fig. 16. Left-sided ramus distractor for vertical mandible height gain.

Fig. 17. Mandible angle distractor with 2 arms for gain in length of ramus and body.

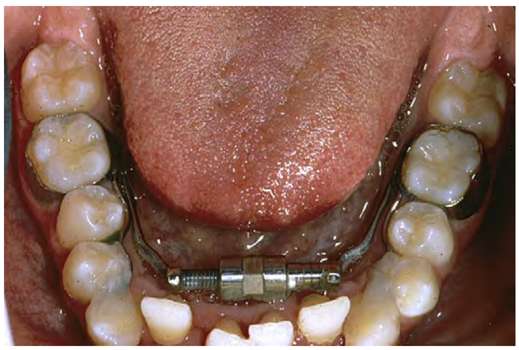

Fig. 18. Tooth-borne appliance behind the lower incisor for symphyseal distraction.

palatal expansion. Anterior-posterior intra-arch distraction, however, can be done for arch length discrepancies in the maxilla with and without crowding. (For more information, see the article by Reddy and Elhadi elsewhere in this issue.)

Mandible

Submerged versus nonsubmerged

Like the maxilla, the desired movement of the mandible seldom is in one direction. Deficiencies may be in vertical ramus length and sagittal anterior posterior deficiency with some patients presenting with a component of both deficiencies. Similar to the maxilla, nonsubmerged or extraoral distractors allow changes in the primary vector of distraction more easily than

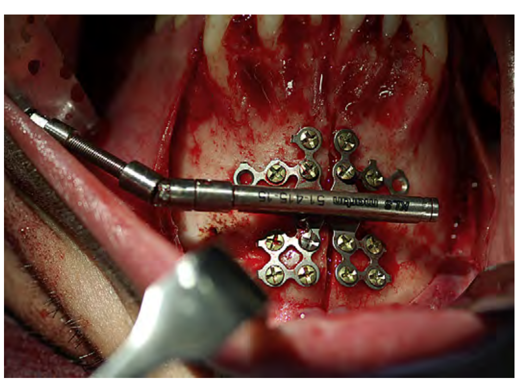

Fig. 19. Bone-supported submerged symphysis distractor with modular footplates.

buried distractors (Fig. 13). As discussed previously, there are many complications with the use of pins that include loosening of pins and pin tract infection. The components of the system include two trams connected to one another with the ability to change the primary vector direction in three planes in space (Fig. 14).

Submerged distractors can be accessed by a transcutaneous or intraoral approach (Fig. 15). The ramus may be vertically lengthened, the body can be horizontally lengthened, or both. A transcutaneous distractor for vertical lengthening of the ramus can be manipulated extraorally to achieve an ideal position. They usually come in a right and left side (Fig. 16). Distractors for the body come in different designs and can be adapted to the body or ramus depending on the desired access and surgeon preference (Fig. 17). Similar to distractors for the maxilla, some companies have modular components that allow a choice of footplates to attach to the bone.

Bone-borne versus tooth-borne

Several of the tooth-borne distractors are for intra-arch distraction of the mandible. The most popular type of intra-arch distraction is the symphysis to increase arch length while simultaneously resolving crowding (Fig. 18). Like surgically assisted rapid palatal expansion in the maxilla, these appliances allow more expansion near the teeth than the symphysis because the placement of the distractor is above the equator of the mandible. Some surgeons have addressed this issue with distractors that are totally bone borne or hybrids that are tooth and bone supported (Fig. 19).

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Intra-Arch Distraction

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Maxillary and mandibular widening

Mandibular-maxillary deficiency is one of the most common dentofacial deformities. This problem can present in the three dimensions of space: (1) anteroposterior, (2) vertical, and (3) transverse. It also may be combined with other maxillary alterations. In the past, the treatment of this dentofacial problem consisted of either integrated orthodontic-surgical treatment, or orthodontic dental compensations alone. The key to a correct diagnosis of the facial growth alteration is a comprehensive evaluation: the three-dimensional assessment of vertical, anteroposterior, and transverse skeletal and dental positions, and soft tissues. Cephalometric analysis should be performed for every patient to combine the surgical procedures needed to correct the deformities in one surgical intervention. The orthodontist should evaluate the patient for potential initial preoperative orthodontics, root divergence, and prediction for future orthodontic treatment. This new surgical philosophy treats the deformity through calibrated stimulation of the bone: the combination with orthodontics and surgery to correct certain deficiencies of the jaws.

Maxillary widening

When maxillary widening is needed, a tooth-borne appliance is placed 1 day presurgically, a Le Fort I osteotomy, with a complete downfracture going through the tuberosity instead of through the pterygomaxillary junction. A midline osteotomy is accomplished taking in consideration the nasal structures when the maxilla undergoes a three-dimensional movement, or an asymmetric distraction to correct an occlusal asymmetry (Figs. 1–10). The distraction protocol consists of a 7-day latency period, activation phase at a rate of 1 mm per day until desired movement is obtained, an immediate placement of an acrylic tooth added to the orthodontic arch at the distraction site, and switching the dental-borne appliance by a transpalatal bar for a 5- to 7-month consolidation period.

A three-dimensional treatment can be planned for the maxilla in one single stage. The age of treatment is based on three major considerations: (1) the canine eruption level, (2) the anatomic situation of the infraorbital nerve, and (3) the nasolachrymal duct. Patients with bidimensional or three-dimensional maxillary deficiencies can be treated by intraoral distraction osteogenesis to lengthen, widen, or augment vertically the maxillomalar complex at different osteotomy levels

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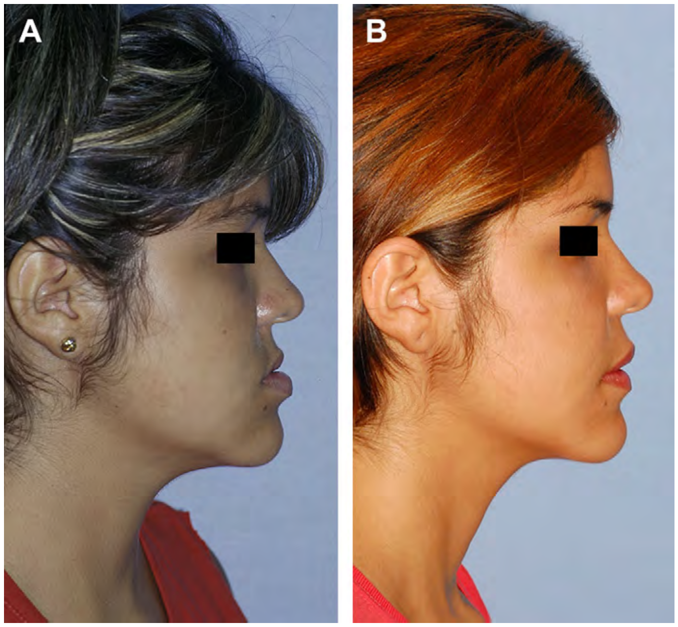


Fig. 1. A 21-year-old woman presenting with anteroposterior, vertical, and transverse deficiencies; severe maxillary crowding; and class III malocclusion and negative upper teeth exposure. The maxilla was advanced 6 mm, widened 8 mm, and inferiorly moved 3 mm in a single surgical stage. Facial features after the surgical movements. Follow-up photographs after combined three-dimensional maxillary repositioning before surgery (*A*) and 5 years later (*B*).

according to the individual clinical situation. Complete radiographs and photographs are obtained presurgery, immediately postsurgery, 3 months later, at the appliance removal stage, and 6 months after braces are removed. Dental models in an articulator should be taken before the surgery and after removal of braces.

These patients should undergo a combined surgical-orthodontics treatment ideally to correct the tridimensional problems. In those requiring a high Le Fort I, a conventional incision and osteotomy is accomplished, the maxilla is freely moved, and distractors are placed bilaterally anchored to the base of the zygoma and fixed to the maxilla with the adequate vector based on

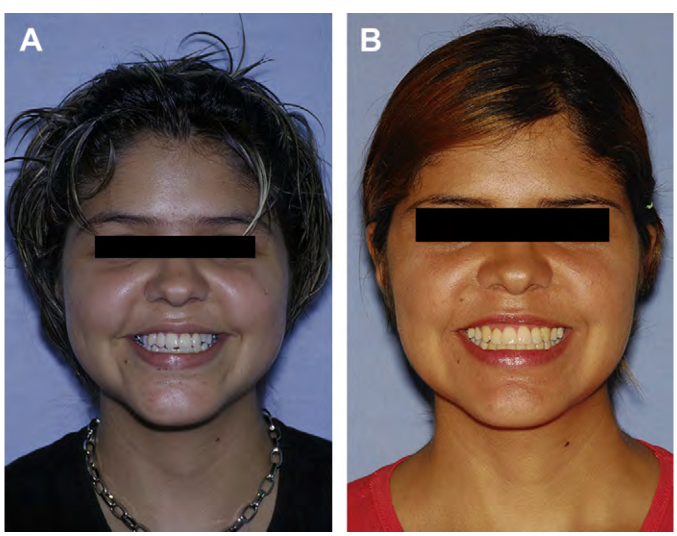


Fig. 2. Smiling photographs showing a wider postoperative smile and better teeth exposure. Nasal width was controlled by detailed cinch closure; the upper vermilion projection was maintained by muscles approximation and V-Y closure. Note the disappearance of tunnel smile and no need for premolar extractions.

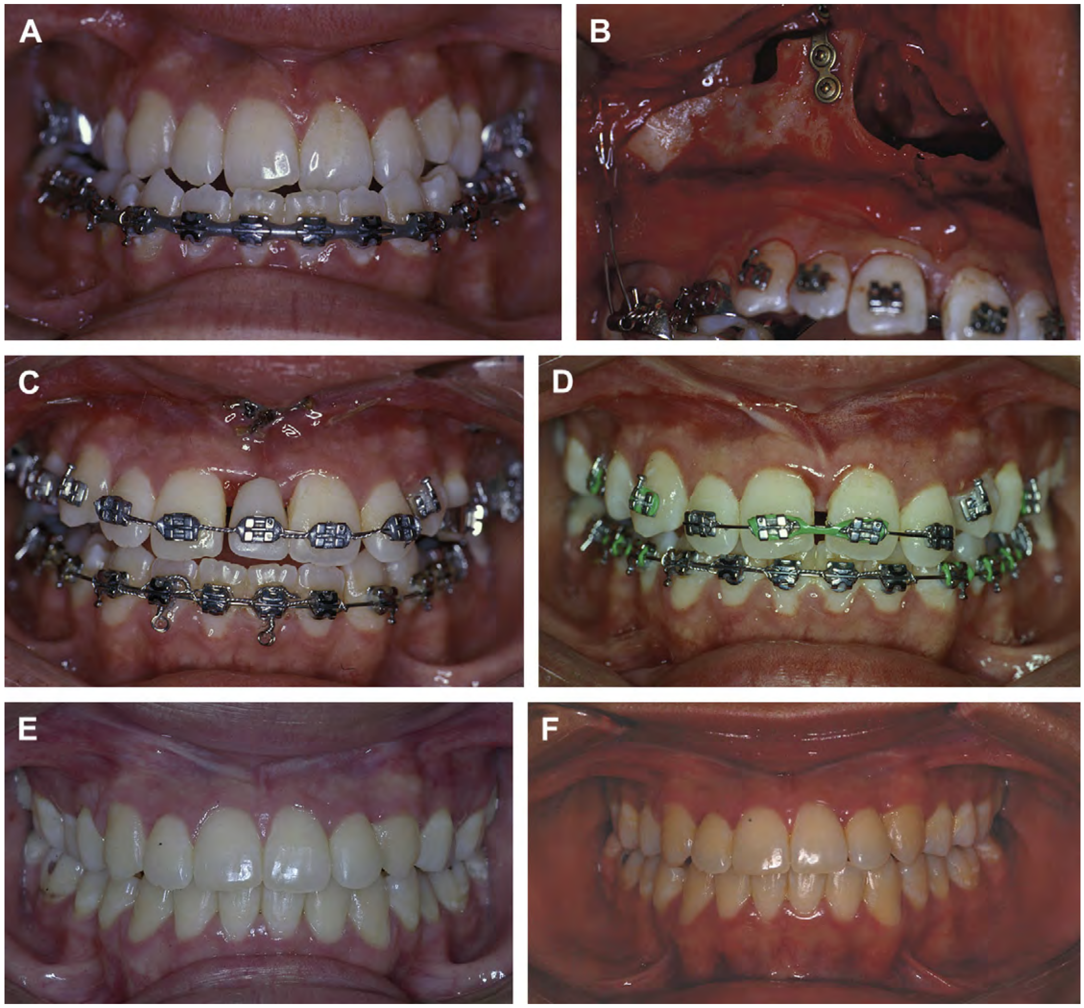
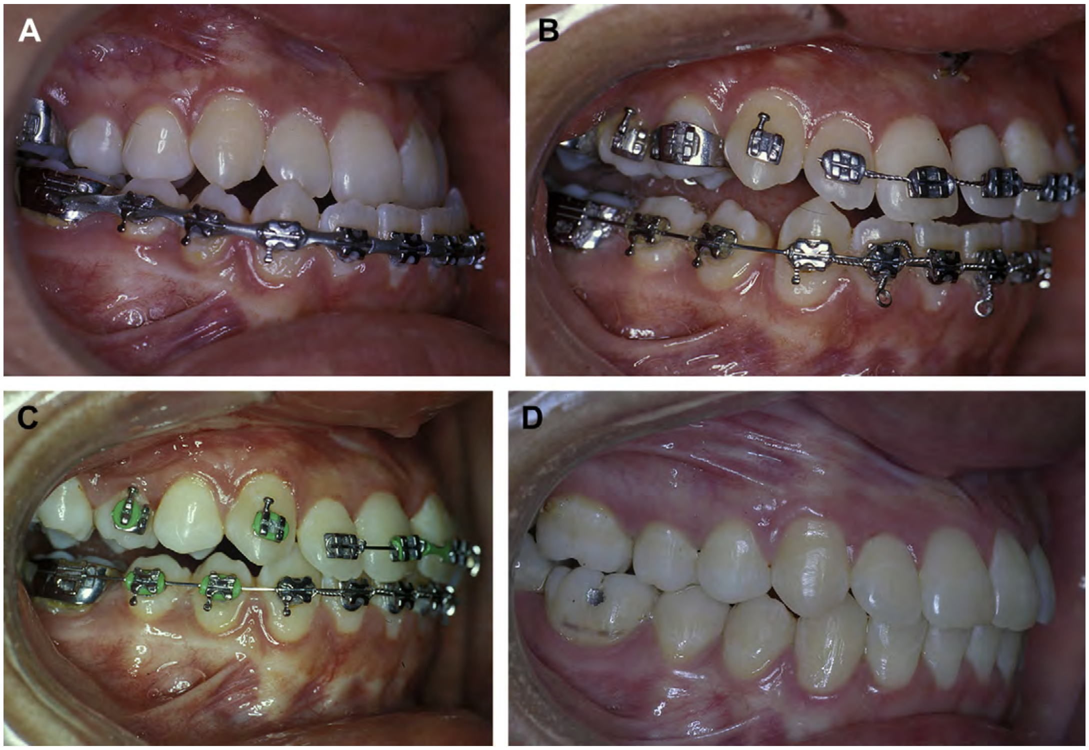


Fig. 3. Calculation of movements is based on radiographs, dental models mounted in an articulator, occlusograms, and cephalometrics. Note the surgical photograph. Flexible 1.5-mm width plates are used at the piriform rims and posterior skeletal suspension The 0.024-gauge wires permit slight changes postsurgically either by tightening or releasing the wires. A periosteal elevator is placed in the midline, between both fragments, and light pressure is exercised to widen the superior aspect of the osteotomy as the plates are fixated. The plates already have a step with the lateral and anteroposterior calculated repositioning.

the three-dimensional planning. A modified Le Fort III has an additional transconjunctival approach: the osteotomy divides the malar process, runs medially above the infraorbital nerve, the orbital floor is sectioned behind the infraorbital rim continuing underneath and obliquely anterior to avoid the nasolachrymal duct reaching the piriform rim, and posteriorly extended to the pterygo-maxillary suture. Finally, two wide-curved osteotomes are placed behind the maxillary tuberosities to displace the malar-maxillary complex. Once it is completely freed, the distractors are fixed, the posterior bar is screwed to the zygoma with 2.0 screws, and the anterior bar is fixed to the maxilla above the teeth.

Mandibular widening

The severe crowding in a patient is usually part of a micrognathia, which includes a deficiency in growth in all three planes with skeletal and dental problems. In the past, dental crowding was treated by compensatory orthodontics and dental extraction, obtaining unstable results or extremely narrow dental arches with tunnel smiles (Figs. 11–22). Because the functional matrix dictates the development of both maxilla and mandible, it is predictable that most of cases with



Figs. 4 and 5. The initial dental photograph with anterior and posterior crossbites, severe crowding, and semi-impacted upper canines. As the maxilla is advanced and widened, the posterior teeth positioning improves, and the space created in the midline by distraction osteogenesis is used to eliminate the crowding. An acrylic tooth is placed in the mid-line to avoid early dental movement into the distraction site and avoid periodontal and endodontic problems. The pontic is grinded 1 mm per month per side, starting 2 or 3 months after surgery, once the mineralization is adequate. At 7 months postsurgical the distraction space must be totally closed, achieved by controlled dental movements.

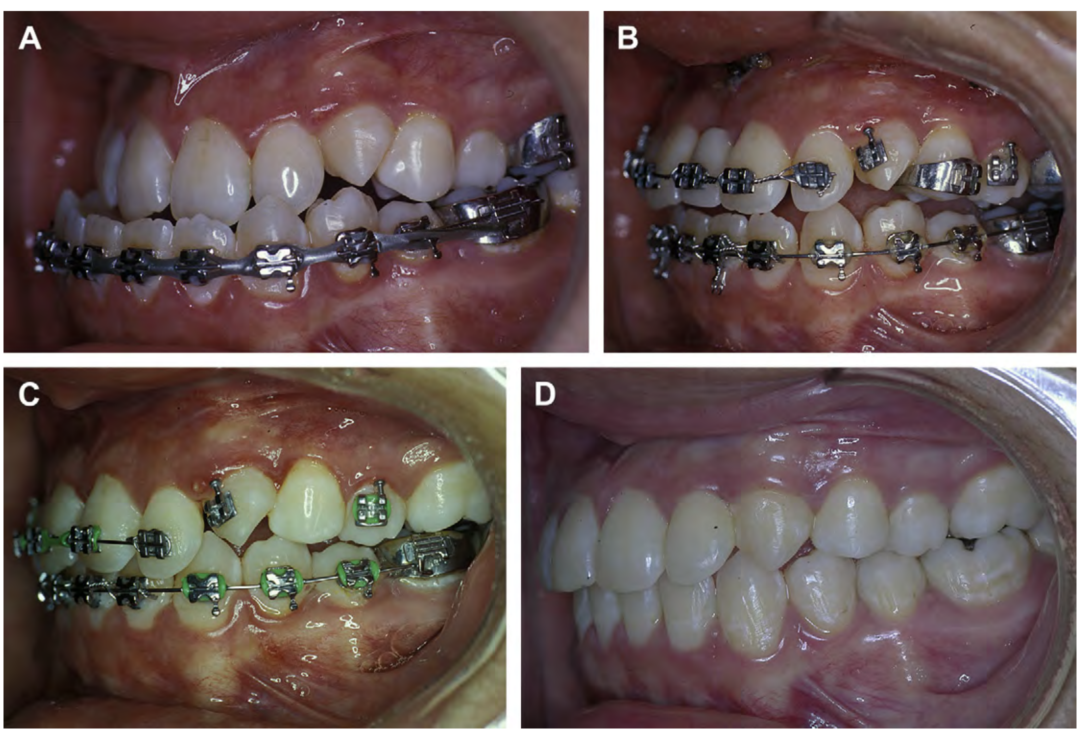
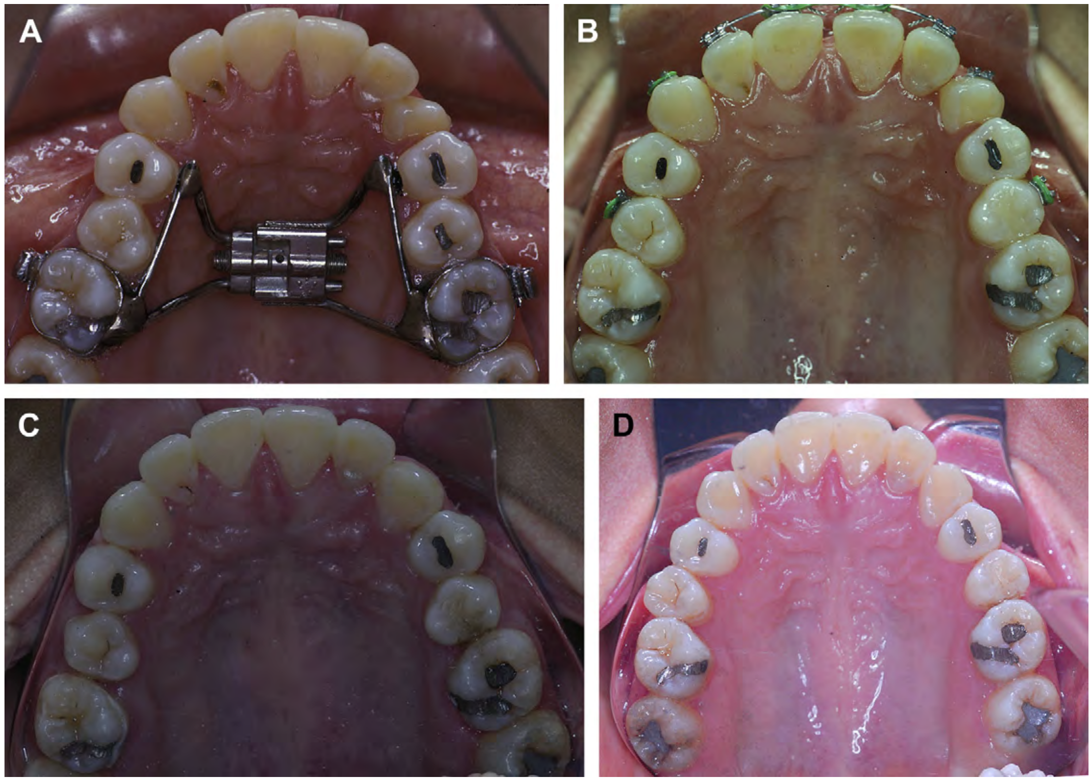


Fig. 5. (*continued*)



Figs. 6 and 7. Occlusal views showing dental movements. The distraction device should not be removed before 3 months; the bone healing process is faster than the soft tissues. Distraction appliance removal is followed by an immediate transpalatal bar between the first molars. This bar is maintained in place for the remaining of the orthodontic treatment. The palate mucosa is quite strong and tries to return to the original length and positioning. It takes 10 to 12 months for complete soft tissue healing.

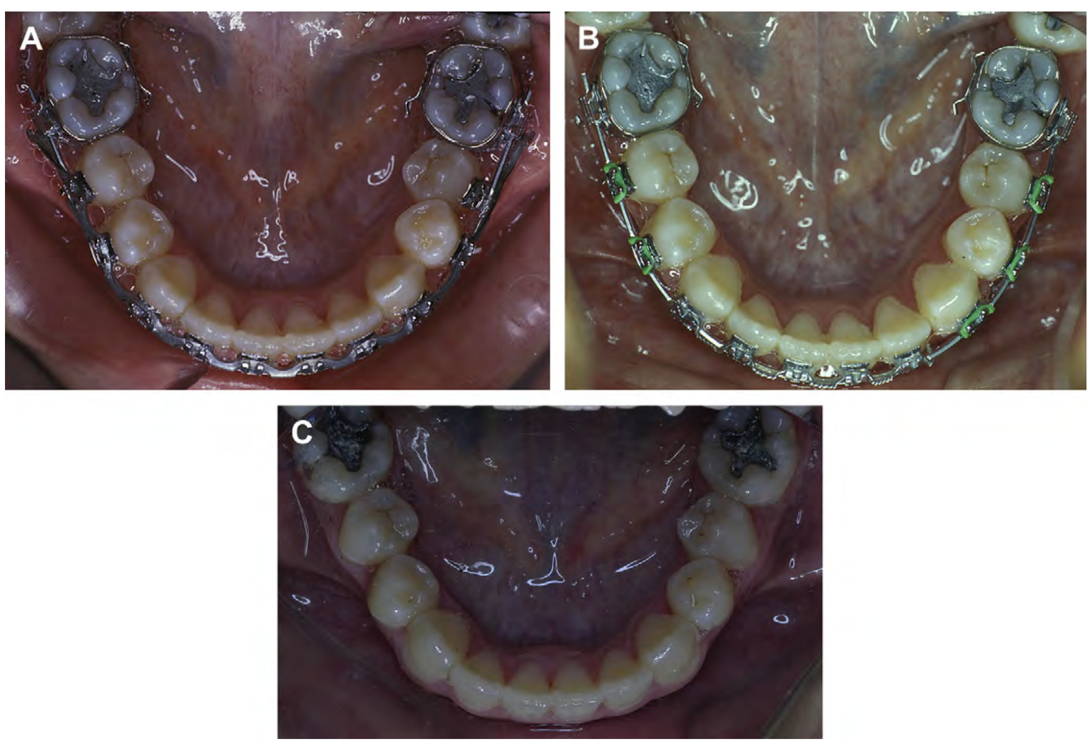
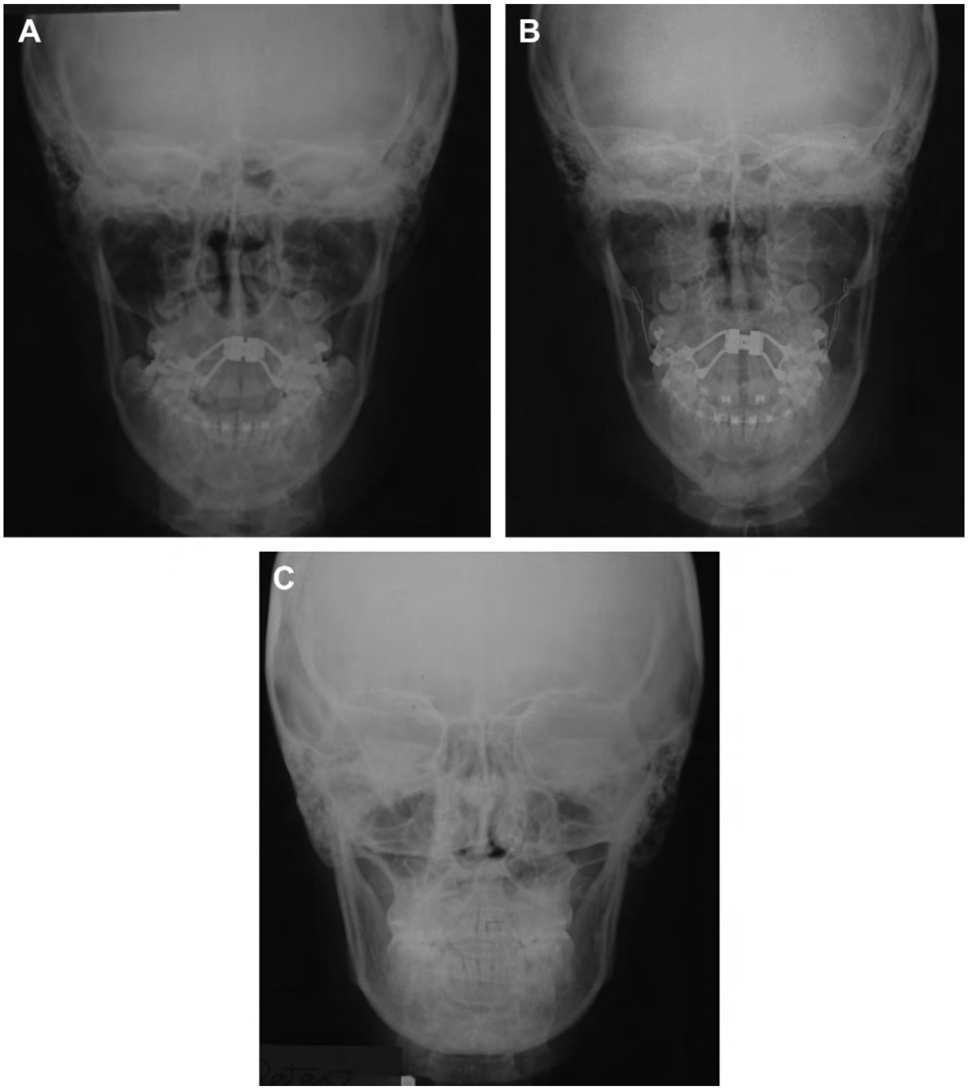


Fig. 7. (*continued*)



Figs. 8 and 9. The frontal radiographs are an important tool to diagnose and follow-up the transverse changes in distraction osteogenesis to widen the maxilla. The new maxillary positioning allows the orthodontist to locate the anterior teeth properly. Note that the mandibular presurgical orthodontics was completed before the distraction device was fixed to the maxillary molars. Once the surgery is scheduled, the orthodontist and surgeon agree on the amount of millimeter widening needed, and because no braces are used presurgically in the maxilla, there are no undesirable dental movements, especially moving the premolars out of the alveolar bone or lateral inclinations. At his moment the appliance is fixed to the molars and the remaining of the maxillary braces are fixed.

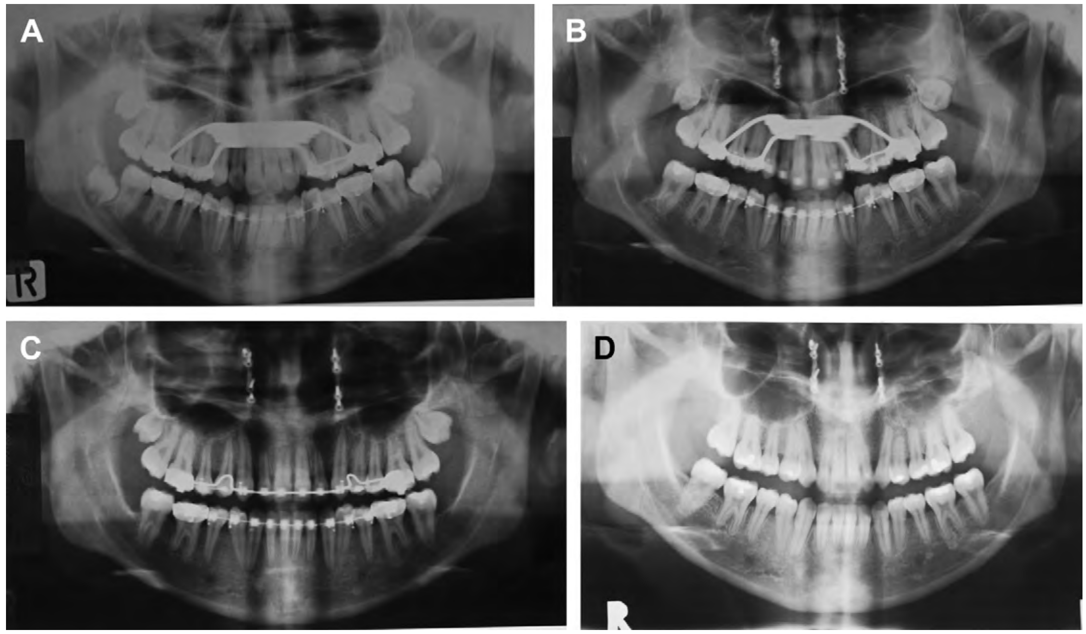


Fig. 9. (*continued*)

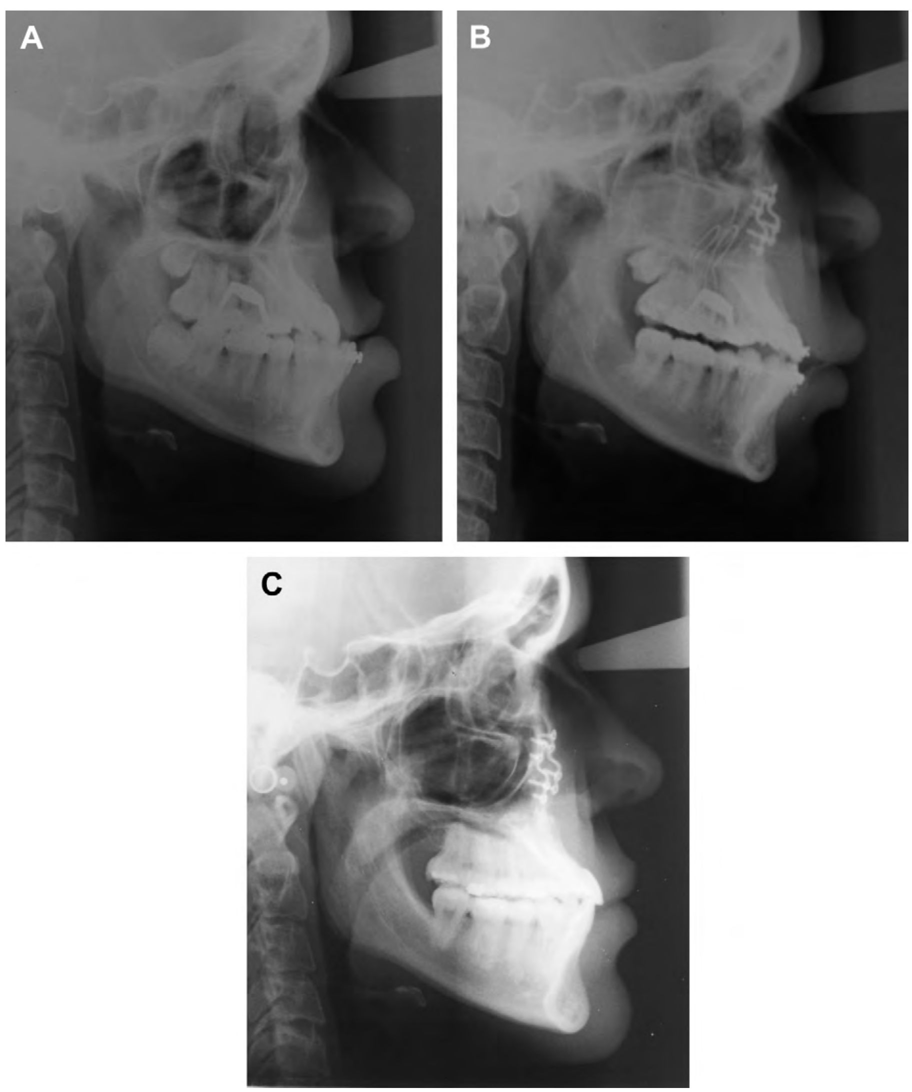


Fig. 10. Lateral radiographs show only maxillary anterior and inferior repositioning. Even though the SN-1 was augmented, the facial and smiling esthetics are adequate and no extractions were performed, other than the third molars.

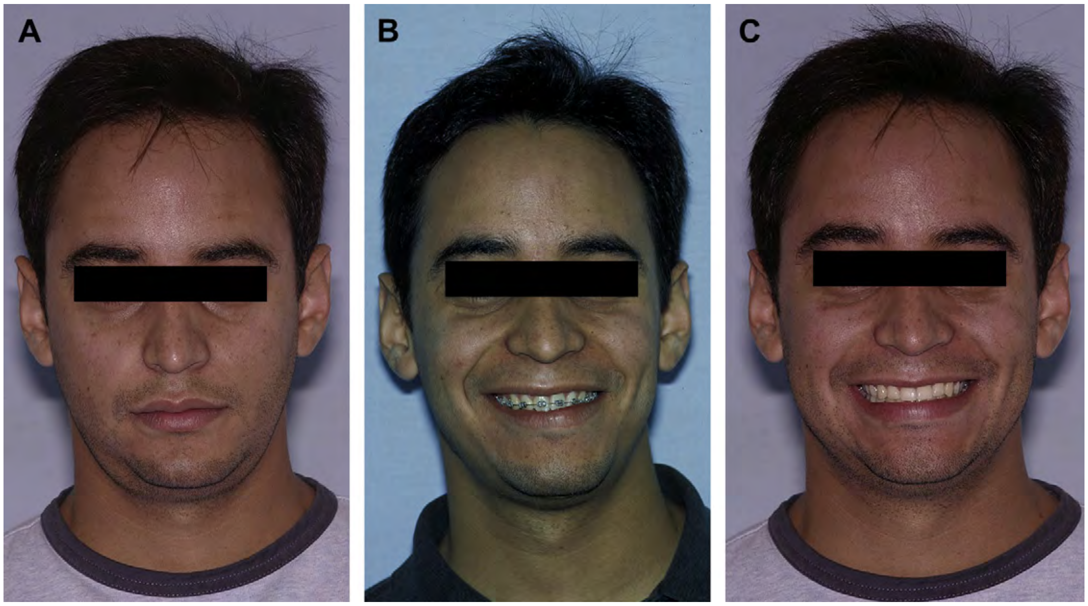


Fig. 11. A 29-year-old patient with a diagnosis of asymmetric mandibular anteroposterior, vertical, and transverse deficiency; asymmetric class II division 1, subdivision, with severe crowding and anterior unilateral crossbite. He was treated by unilateral mandibular posterior repositioning by sagittal split osteotomy, mandibular widening, and anterior and inferior repositioning genioplasty in a single surgical stage.

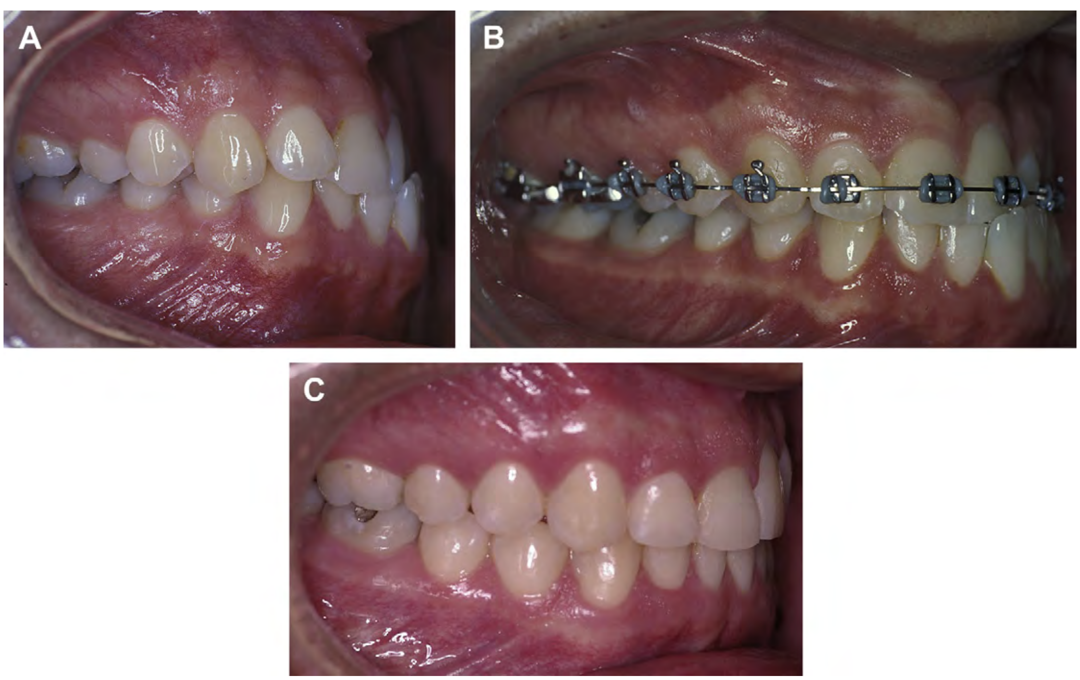


Fig. 12. Surgical-orthodontics treatment lasted 18 months. Presurgical orthodontics included maxillary braces placement, to align and level the arch, and temporary acrylic splint use to overcome the crossbite. Once the maxillary teeth were in the ideal position, the surgery was scheduled and distraction appliance was designed as a mono-arm welded to the first premolars and molars bands. The selection of the bands needs to be a size bigger than the ideal to ensure under the equator cemented device and that it will not be dislodged during surgery.

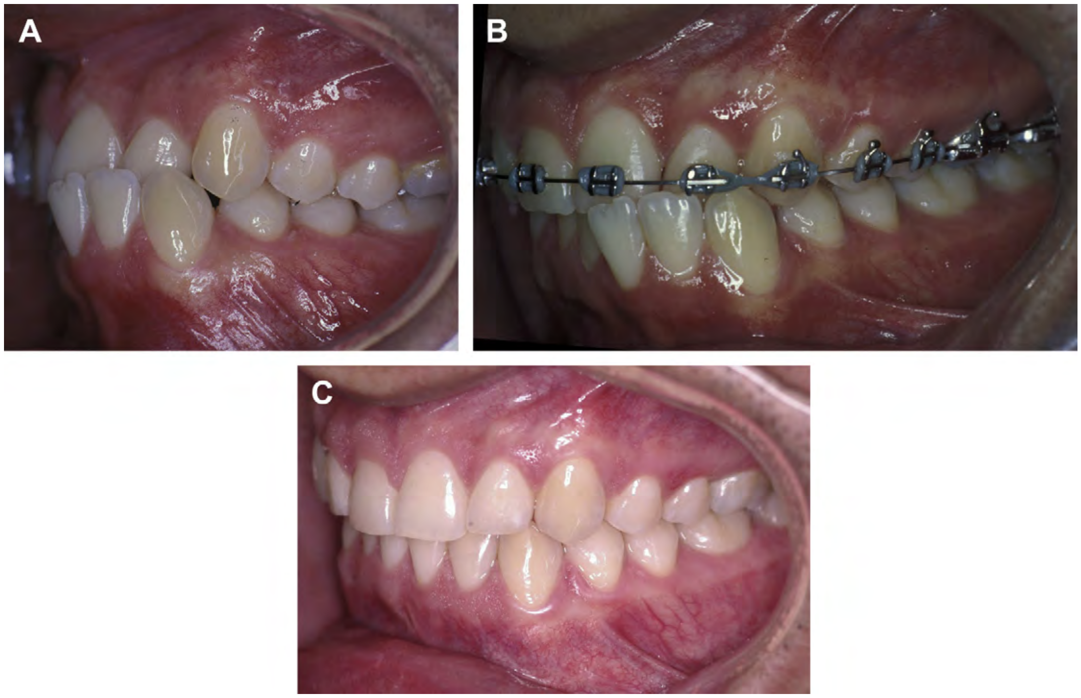


Fig. 13. The tooth-borne appliance reduces surgical time, avoids damage to the adjacent teeth roots, and is cost effective. The mandibular teeth movements are executed after the distraction consolidation period. The postsurgical orthodontics includes closure of the distraction gap, leveling, aligning, desrotating, and finishing. Presurgical mandibular orthodontics is to be avoided to maintain the teeth within the bone envelope.

skeletal class II and narrow arch present a problem with the maxilla. It is imperative to make a three-dimensional analysis to provide correct three-dimensional treatment.

All the variables involved in diagnosing these patients should be studied. In the authors' previous clinical study of mandibular widening they concluded that for an average of 7 mm of active distraction they obtained 7 mm of widening at the canine level, 5.22 mm at the first molar level, and 3 mm at the second molar level. This indicates that widening is achieved in full range in the midline, decreasing going back toward the molars, with an increase of the intercondylar distance of only 0.9 mm.

Some variables need to be considered in calculating the amount of widening required:

1. Available space versus required space
2. Inclination of the incisors (incisor-to-mandibular plane angle = 90 degrees)

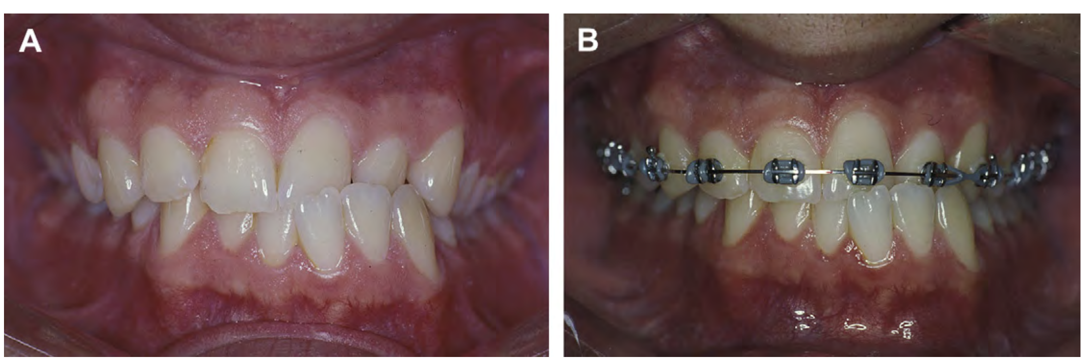


Fig. 14. The amount of mandibular widening is dictated by the amount of crowding, curve of Spee, Bolton discrepancy analysis, incisor-to-mandibular plane angle, the presence of an impacted anterior tooth, and over jet available. As the mandible widens 7 mm anteriorly, the second molar widens 3 mm, and the intercondylar distance increases 0.9 mm, the calculation is performed in the planning phase. If a crossbite develops in the model surgery, a maxillary widening procedure should be considered. The occlusogram is a very helpful tool for detailed evaluation and the communication between the team is fundamental.

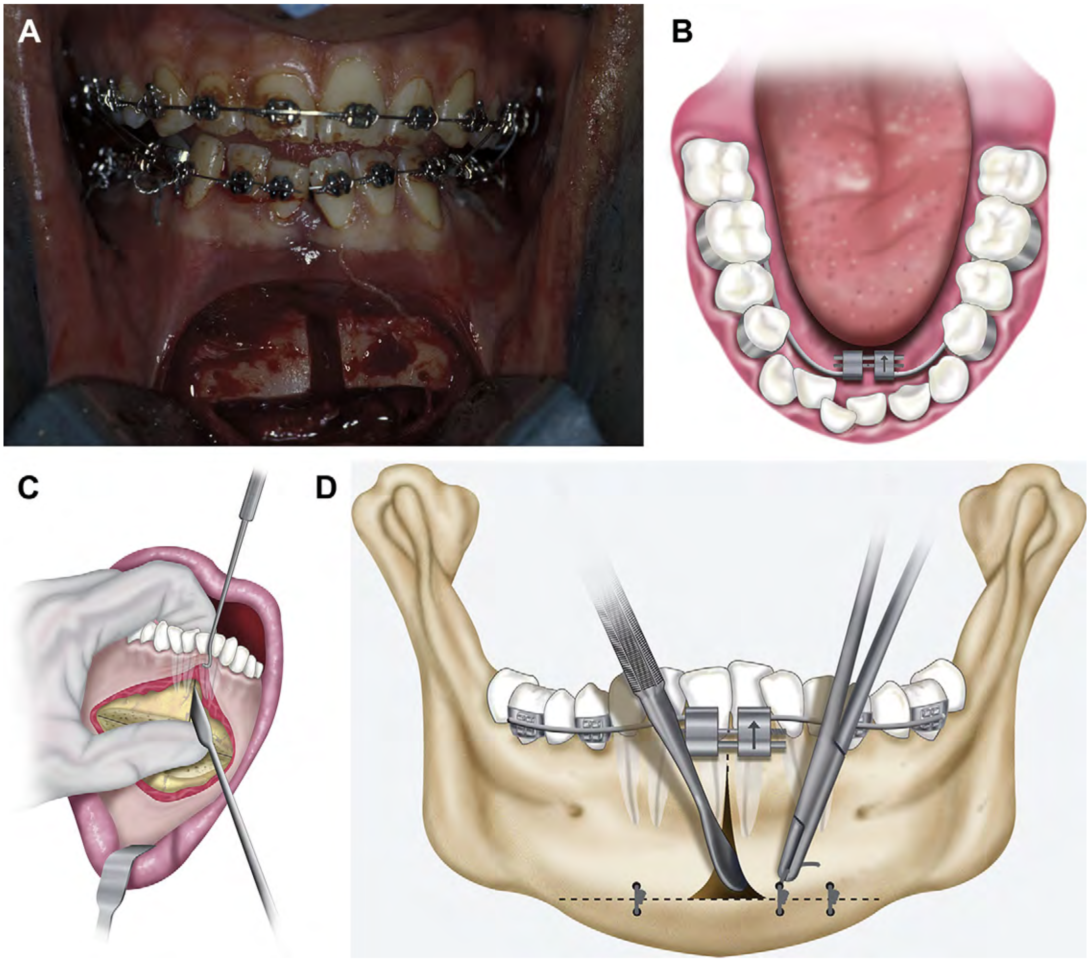


Fig. 15. Seventy-five percent of the patients requiring mandibular widening benefit from a simultaneous genioplasty. These are performed at the same time. First the chin osteotomy is completed, after references lines are drawn in the outer bone cortex, above and underneath the osteotomy site. These lines are carefully aligned during fixation measuring the genioplasty segment movement with calipers. At that moment a periosteal elevator is used to open the vertical osteotomy line at the bottom to create a triangle with the base inferiorly. This acute opening allows the chin segment to be fixated without disturbing the postsurgical distraction activation to open the gap between the incisors. The activation parallels the vertical osteotomy line, and the triangle becomes the rectangular distraction chamber.

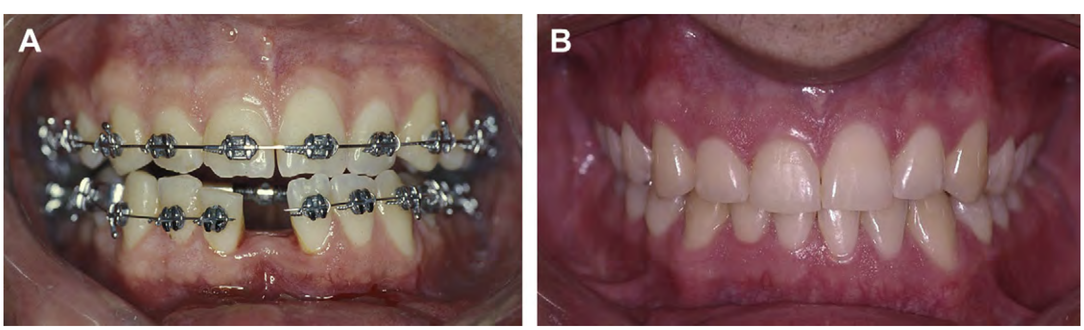


Fig. 16. Seven days later the appliance is activated. Collagen fibers bridging both segments are progressively stretched, creating the distraction chamber, and the transseptal fibers try to move the incisors within the space, long before adequate consolidation is obtained. A plastic tooth or metallic ligatures holding the incisors apart are necessary. Three months after surgery the teeth are brought back to the midline, progressively, 1 mm a month per side. If there is a midline deviation, this could be corrected allowing only one side to move over the other side maintaining the teeth anchorage with metallic ligatures.

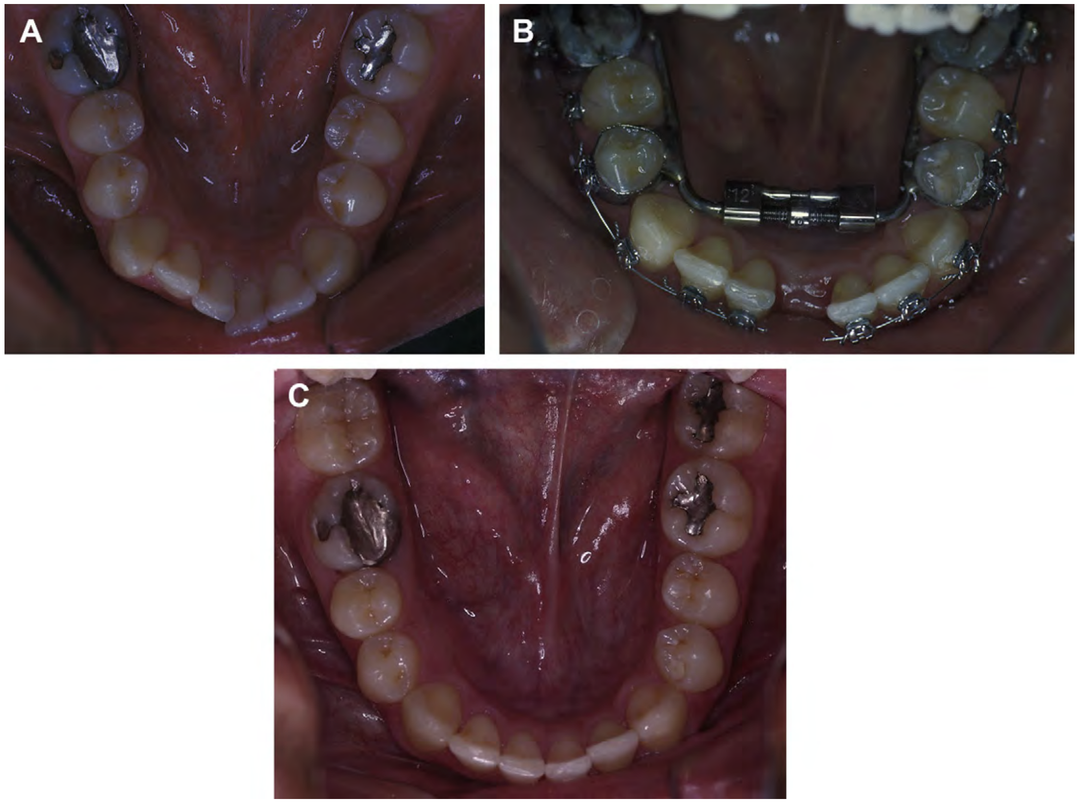


Fig. 17. Occlusal views showing the reshaping of the arch from V-shape to U-shape, eliminating the crowding and no premolar extractions. This miniaturized distraction device is ideal because it is easy to clean, does not impinge the tongue, the patient can activate it, and it can be worn a long time without limiting patient comfort. It could also be welded bucally, making activation even easier. Surgery was performed in 2003, with a 5-year follow-up.

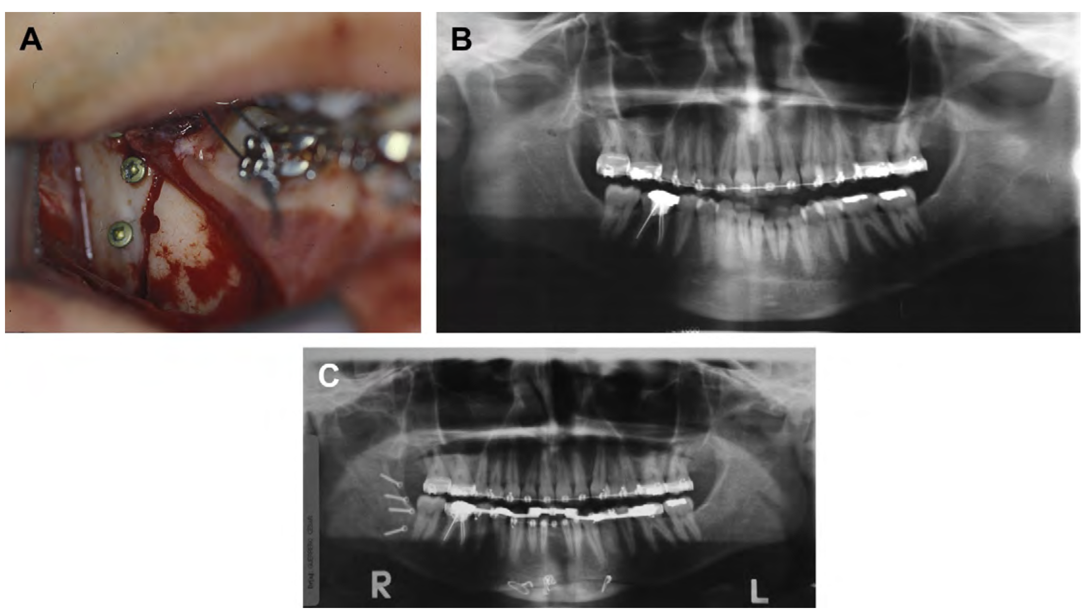


Fig. 18. The mandible is posteriorly repositioned in the right side using a sagittal split osteotomy. A reference line is drawn in the lateral cortex meticulously to fixate the proximal segment into the proper position (a 5-mm movement). Four bicortical screws are used, three above the nerve and one below. No intermaxillary fixation is needed. Once the distraction activation is completed, autocurable acrylic is placed over the body of the appliance. The diet progresses to a soft diet, 2 weeks in a liquid diet (blender diet) and 2 weeks in a soft diet, to continue to a regular diet 1 month after surgery.

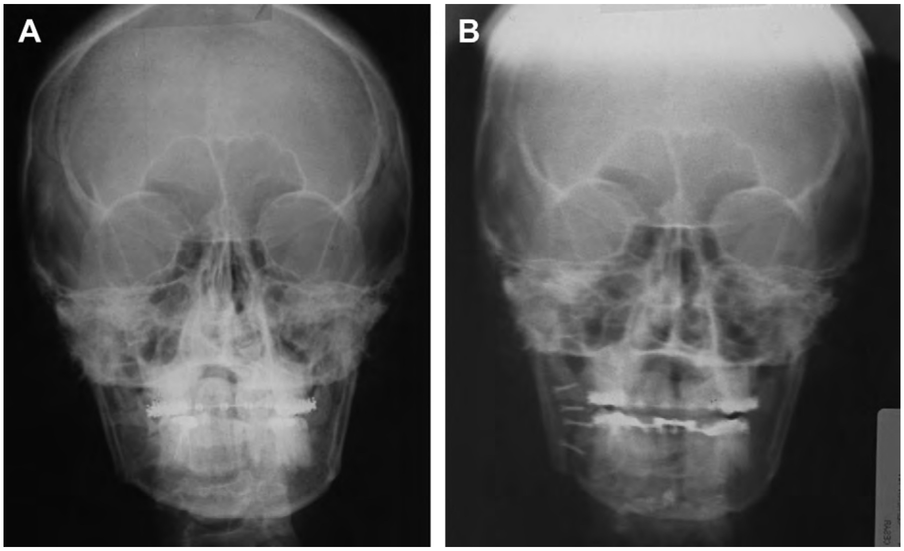


Fig. 19. Radiographs show mandibular repositioning, advancement genioplasty, and a good skeletal relationship. No premolar extraction and good incisors inclination.

3. Deep bite or a marked curve of Spee
4. Intermolar width
5. Size and shape of the incisors

The occlusogram is an important tool to be used in every individual where a transverse problem is suspected. Clinical indications and selection of patients include the following:

- Narrow V-shaped mandibles
- Severe mandibular crowding to avoid dental extractions
- Scissor's bite (Brodie's syndrome)
- Maxillomandibular transverse deficiency (tunnel smile, crocodile bite)
- Impacted anterior teeth to allow natural or forced eruption
- Retreatment after bicuspid extractions
- Congenital missing teeth

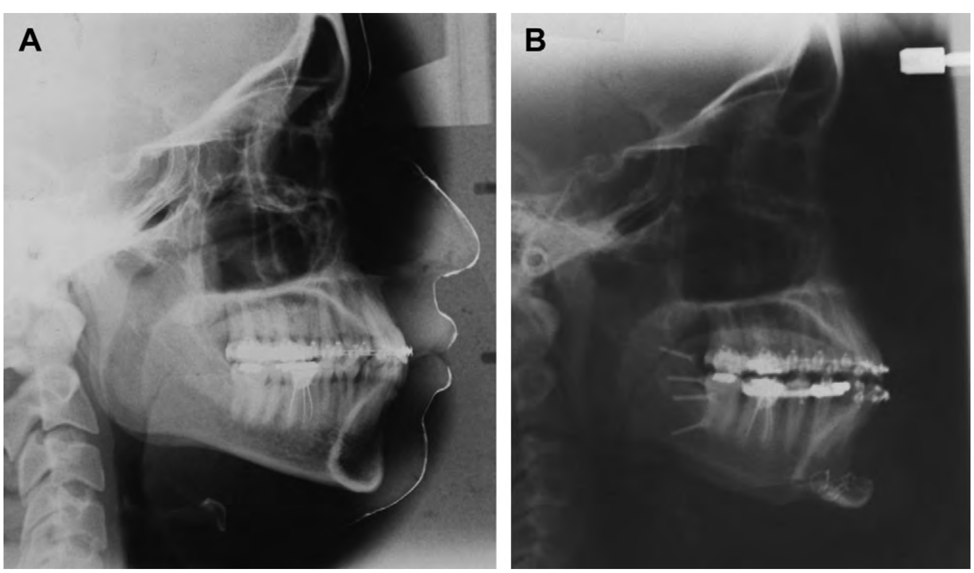


Fig. 20. Skeletal symmetry after unilateral sagittal split osteotomy and asymmetric genoplasty. The mandibular widening procedure is very stable, providing stable occlusion and adequate retainer wear.

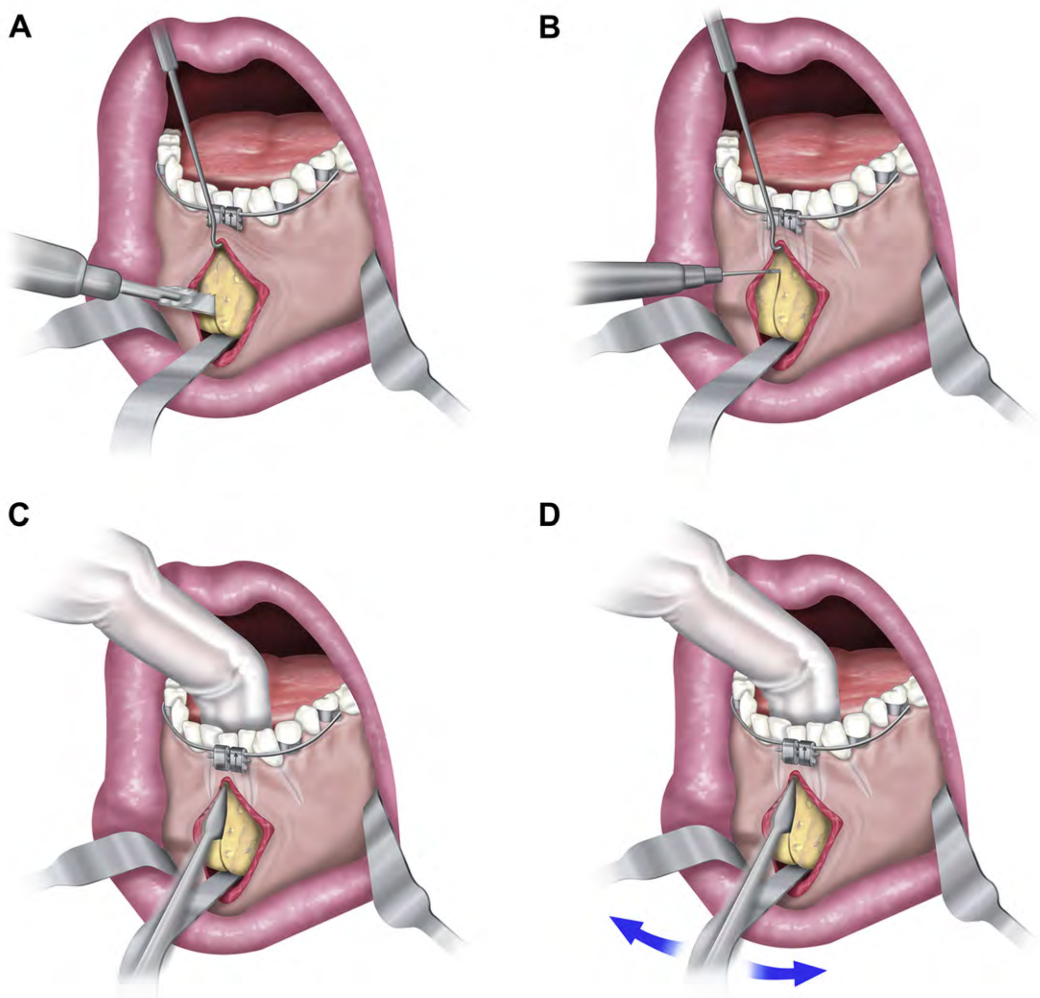


Fig. 21. A 15- to 18-mm long incision is made in the vestibule, down to the bone, to continue with a periosteal elevator to separate the periosteal layer from the inferior border of the mandible, all the way up to the interdental bone. A reciprocating saw is used to cut from the inferior border of the mandible to about the level of the dental roots. Then, a 701 bur is used to make holes in the outer cortex between the selected teeth. The procedure continues with a spatula osteotome, protecting the lingual mucosa with a finger. Once the midline is sectioned, and a complete fracture is warranty, the distraction appliance is activated 1.5 to 2 mm. The wound is then closed in layers. This ambulatory surgery can be performed under intravenous sedation.

Widening in the middle and genioplasty

The classical osteotomy is designed as a vertical cut in the middle of the symphyseal area, from the basal bone to the bone between the two central incisors. Conventional osteotomy for the genioplasty is performed 5 mm below the canine's apices; then, a vertical osteotomy in the midline is performed. The genioplasty is fixed with wires or rigid fixation; the vertical osteotomy is immediately widened at the bottom, using a periosteal elevator maintaining the gap open, while the wires are tightened or rigid fixation is applied. As the distractor is activated postsurgically the upper part of the vertical osteotomy widens. The clinician then observes a vertical parallel distraction site.

Widening outside the mid-line

When there is not enough space to perform the osteotomy, or severe crowding between the incisors, the bone space between the canine and the lateral is usually a good site, with enough

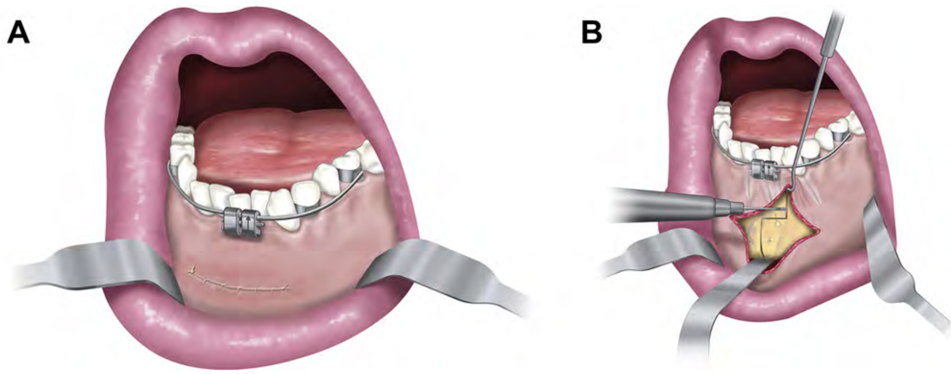


Fig. 22. Many patients present with no adequate space between the central incisors, more frequently than in the maxilla. Either presurgical orthodontics with very few brackets are used to open a gap between the dental roots, or another interdental space is used. Generally, there is a good space between the canine and lateral incisor. The osteotomy starts in the inferior border of the mandible and then a step is formed with the bur, to end the cut interdentally off-line. If the osteotomy is completed out of the midline chin asymmetry develops. If a genioplasty is indicated no step is necessary. Major mandibular widening (above 9 mm) needs to be performed combined with a genioplasty to avoid excessive chin width.

bone. The cut should end in the mid-line, even though an off midline site has been selected in the teeth region; a step osteotomy is necessary to avoid a chin asymmetry at the end of treatment.

Considerations

The interdental osteotomy must be planned using periapical radiographs, choosing the osteotomy site where enough bone is present at both sides of the cut. If there is not an ideal site, presurgical orthodontics must be performed to create enough interradicular space.

In some clinical situations, the genioplasty is indicated just to prevent widening of the chin, which may lead to an excessively wide chin with nonaesthetic results, despite a dental narrow arch, especially in the female patient, or when major mandibular widening is required (>8 mm). When a genioplasty is also intended, the gap left at the inferior border of the vertical cut is greater than at the crestal level to ensure bony separation in the activation period. Again, this maneuver is accomplished using an instrument within the vertical cut at the inferior level to separate the bony segments 5 to 6 mm while the fixation wires for the chin are tightened up or rigid fixation applied.

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Atlas of the Oral and Maxillofacial Surgery Clinics

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Alveolar Modification by Distraction Osteogenesis

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After approximately 10 years of clinical practice, alveolar distraction osteogenesis has evolved in reconstruction of the jaw and alveolus into three options: (1) definitive alveolar distraction osteogenesis—used to finalize reconstruction and establish an ideal alveolar ridge (orthoalveolar form), (2) adjunctive alveolar distraction osteogenesis—used as part of a bone grafting scheme for gaining increased bone mass, and (3) orthognathic alveolar distraction—used to obtain alveolar alignment and obtain a class I arch relation (orthoalveolar relation).

Each case is evaluated considering the defect that is present and the overall osteogenic potential of the remaining bone segments. With small defects, when there is plentiful bone stock available, definitive alveolar distraction is ideal. When the bone is atrophic or there is low volume bone stock in a scarred or ablated soft tissue bed, distraction is not as successful. The same factors that make bone grafting difficult make alveolar distraction difficult. Understanding the biomechanical factors present in each case allows the correct protocol to reconstruct the jaws based on what is biologically feasible. Because few clinicians do alveolar distraction, they must rely on the experiences of others as found in the literature. There are few published prospective studies, however, on alveolar distraction. Most of the protocols that are available were done when technology was in the developmental phase. The purpose of this article is to establish diagnostic and treatment planning criteria including presentation of a site classification to help establish treatment. When and how to use various distraction devices are only one part of the equation. It is perhaps more important that clinicians conceptualize what is achievable, by distraction or bone grafting, in the effort to recover orthoalveolar form.

Invenio quod defectio (discover what is missing) has become the dictum of restorative oral and maxillofacial surgeons. Previous efforts to place dental implants for support of prostheses, without regard to alveolar shape and projection, no longer are acceptable treatment in the vast majority of partially edentulous patients. Even in fully edentulous cases, efforts are made to regain a natural prosthetic restoration.

Diagnostic treatment planning

A cone beam CT scan or standard tomographic image helps establish the extent of alveolar deficiency in terms of quantity and quality of remaining bone (Fig. 1). Clinically, restorative dentists determine the restorative scheme estimating the need for alveolar augmentation. In some cases, the alveolar bone may even need to be reduced. Study casts are placed on an articulator and a diagnostic wax-up is done (Figs. 2 and 3). From the wax-up, a surgical template is made to help a surgeon reconstruct the alveolus. The clinical (benchtop) diagnostic work-up, therefore, is more important than a radiographic evaluation.

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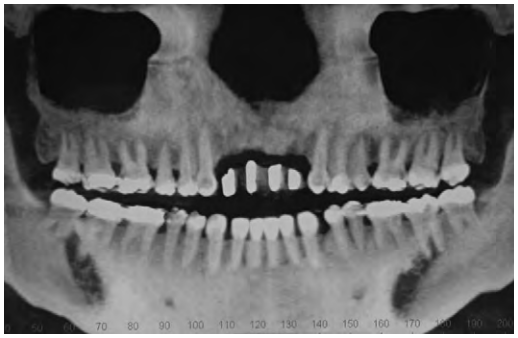

Fig. 1. A CT scan image can help establish the 3-D bone augmentation requirement needed to establish orthoalveolar form.

After clinical and radiographic evaluation, a decision is made regarding the augmentation requirement, implant placement locations, and the need for distraction osteogenesis. Depending on the size of the defect, reconstruction may require grafting, distraction, or a combination of the two. After reconstruction of the ridge and after the augmented (restored area) has healed, a conservative number of implants should be placed. Too many implants, placed too close together, can disrupt a viable augmentation and lead to late-term resorption and remodeling. Hence, the final prosthetic treatment plan must have surgical and restorative input with regard to the extent of augmentation and the number and width of implants to be placed in the augmented area.

When distracting segments, restorative needs should decide the endpoint of the active distraction. Modifications of a temporary appliance to accommodate the volume of bone and soft tissue are done as needed. The decision of when to stop active distraction is part of the planning process done in conjunction with model planning. In general, an overdistracted position of approximately 2 or 3 millimeters is recommended to allow for remodeling and future surgical-prosthetic modification at the time of implant placement (Figs. 4–8).

Defect assessment

Conceptually, an ideal edentulous alveolar osseous morphology (orthoalveolar form) should be recreated in 3-D. This means that the facial and palatal marginal bone height and adjacent supporting bone are present. After a dental extraction, these dimensions can be lost unless socket preservation grafting is done. The pattern of loss is highly variable and somewhat dependent on the trauma of extraction and concurrent infection. Postextraction studies have demonstrated significant facial plate resorption within 6 weeks of dental extraction, especially evident in the postorthodontic anterior maxillary dentition. Postextraction findings can range from mild

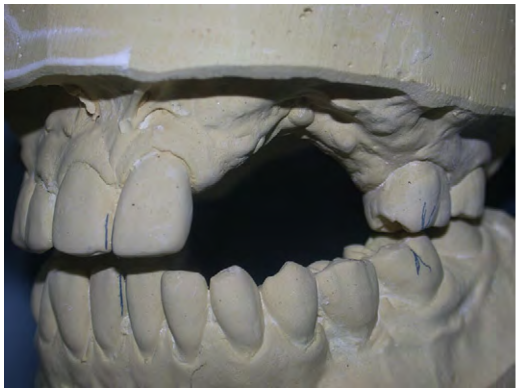

Fig. 2. A restorative dentist uses articulated study casts and a diagnostic wax-up to establish tooth position and the exact defect addition morphology.

Fig. 3. A restorative dentist uses articulated study casts and a diagnostic wax-up to establish tooth position and the exact defect addition morphology.

to severe facial plate loss (Figs. 9–11). When the lingual plate of bone is lost, the site becomes a vertical alveolar defect, which is much more difficult to treat without distraction osteogenesis. Finally, if bone is lost next to an adjacent tooth leaving an exposed root surface, the defect is a difficult lesion to treat. This is true especially if the involved teeth are retained (Figs. 12–14).

Considering all of these variables, coming up with a meaningful defect and site classification is challenging. For a classification to be of value, it should be descriptive and help decide treatment. The following is a site classification based on mild, moderate, and severe vertical bone loss (classes I–III) with a fourth class (class IV) designating significant loss of bone on adjacent teeth (Figs. 15–18).

Class I is a mild, alveolar deficiency with up to 5 millimeters of vertical loss; class II is a moderate deficiency site with 6 to 10 millimeters of vertical bone loss; and class III is severe with greater than 10 millimeters of bone loss. Of these, most mild and some moderate cases could be treated with the sandwich osteotomy, but this is not possible in the severe category. The more complex class IV lesion must address the value of keeping compromised adjacent teeth that have significant bone loss. A good rule of thumb is to remove any tooth with 50% bone loss or more unless orthodontic forced eruption is prescribed. This may require root canal therapy and placement of crowns, something that should be weighed against tooth removal and implant placement after postdistraction bone level is deemed satisfactory. The added complexity of bone loss on teeth next to the osseous defect is what defines a class IV lesion as it relates to distraction osteogenesis. As complexity or severity of bone defects increases, there is an increased need for bone grafting before or after distraction is done.

Some clinicians use alveolar distraction as an adjunct to preparing a site for definitive bone graft reconstruction. Distraction is used to enhance the soft tissue envelope via distraction histiogenesis prior to increasing the bone mass definitively through bone grafting. With this approach, a difficult situation with a relatively poor prognosis can be transformed into a more ideal condition. The defect is treated by transport distraction and later augmented via open flap

Fig. 4. Overdistraction involves trimming the underside of the prosthesis to allow room for advancement of the alveolus during distraction.

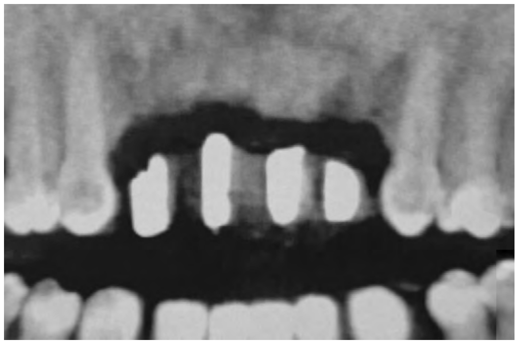

Fig. 5. An x-ray guide helps inform surgeons of how far to move pre-existing bone in relation to the desired future tooth position.

grafting, obtaining better alveolar crestal morphology. The increased bone mass thus follows creation of a definitive architectural framework.

Class I lesions (site defects) usually are distracted as opposed to having a sandwich bone graft when there are prosthetic concerns in the esthetic zone (anterior maxillary region). In the maxillary anterior region, the esthetics of the alveolar ridge is critical to restoring a natural smile. Because distraction is a fluid process, it can be managed by a surgeon and prosthodontist to obtain a better alveolar-gingival form by molding the regenerate zone during consolidation. It is not a one-shot process, such as an augmentation or a sandwich bone graft, where ''you get what you get.'' Instead, segment position can be modified during or after distraction by use of the target stent or provisional appliance. Even a mild case of 3- to 5-mm vertical deficiency sometimes is distracted to gain a more ideal alveolar position (Figs. 19–21). When the ridge form and position are not a problem, a sandwich bone graft frequently can eliminate the need to distract a class I lesion.

In class II lesions with a defect of up to 10 millimeters, distraction is done more frequently to obtain ideal ridge form. If the residual alveolus is squared off and not too thin at the crest, the distraction can finalize the augmentation required. If not, a follow-up particulate bone graft may be required (Figs. 22–24).

Class III lesions need augmentation with a bone graft to increase the bone stock in order to do a distraction. Occasionally, when there some bone present, the site is distracted first with follow-up grafting done to obtain an ideal ridge form. In more severe cases, implants usually are not placed at the time of secondary bone grafting as the grafting still may be extensive with insufficient bone stock for implant primary fixation (Figs. 25–27).

Class IV site defects are best converted to class II or III sites by removal of the adjacent compromised teeth or by including the teeth in the distraction segment in order to move the entire bone level crestally in line with the alveolar plane (Figs. 28–32). By making a complex defect less complicated by extracting adjacent teeth, the final alveolar result is more predictable. Osseointegration of dental implants and esthetics for patients are improved. Patients must be

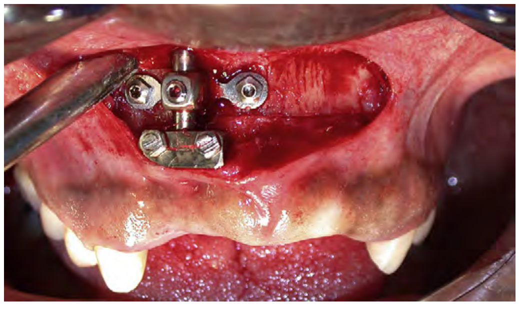

Fig. 6. The distraction site is approached with a vestibular incision. Intraoperative judgment is made of bone quality and a desirable vector for an overdistracted alveolar position.

Fig. 7. After distraction, a "short tooth" provisional is used to gauge if there has been enough vertical movement to allow for "cutback" to be done during implant placement.

Fig. 8. Implants are placed well apically and relatively deep to allow for marginal and papillary gingival development.

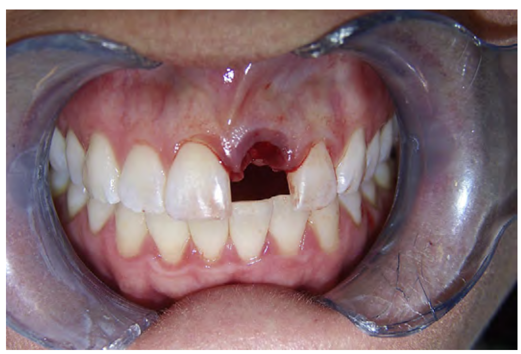

Fig. 9. Mild postextraction finding in which little marginal bone is disturbed at the time of dental extraction.

Fig. 10. Moderate postextraction bone loss with significant loss of buccal plate.

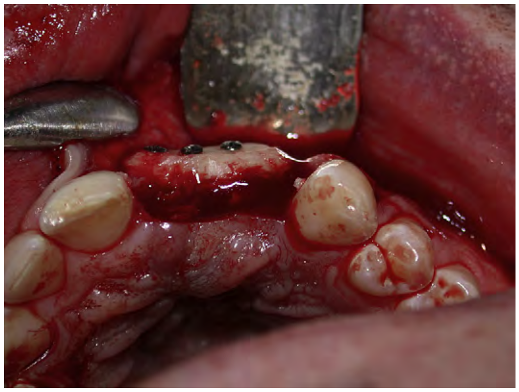

Fig. 11. A severe category of bone loss indicates buccal and palatal plates have significant bone loss requiring bone grafting prior to distraction.

Fig. 12. A preoperative distraction site in which a single-tooth implant was lost and subsequent bone loss involved adjacent teeth.

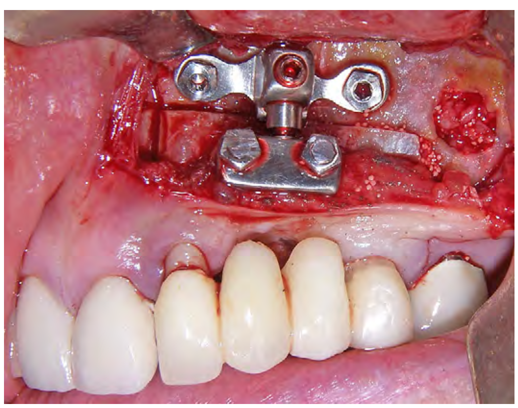

Fig. 13. Adjacent teeth are included in the distraction procedure in order to adequately advance the defect to the alveolar plane.

Fig. 14. Final alveolar form is created after implants have replaced the involved teeth, thereby achieving a more esthetic result.

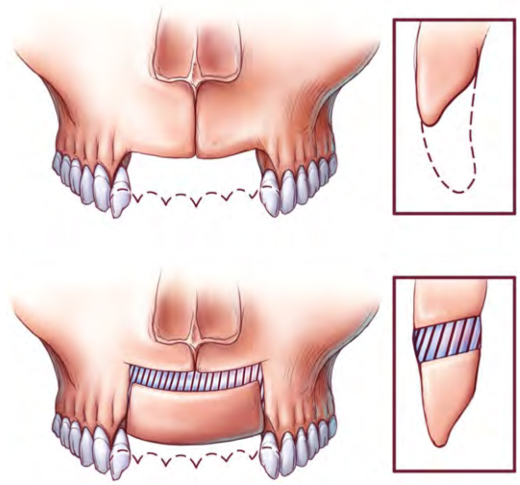

Fig. 15. Class I distraction defect of 5 mm of vertical loss ideally is treated by sandwich osteotomy but occasionally treated by distraction in order to meet certain esthetic criteria.

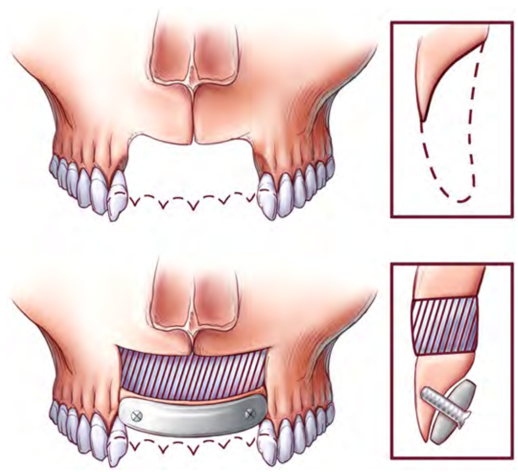

Fig. 16. Class II vertical defects are 6 to 10 mm and amenable to a distraction protocol.

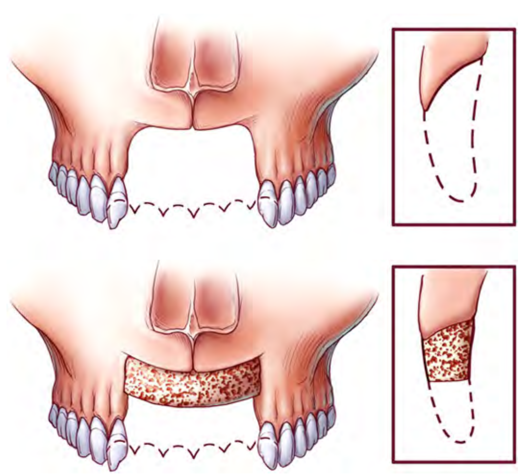

Fig. 17. Class III defects are greater than 10 mm of vertical loss and usually have inadequate bone mass to distract to a definitive position so bone graft augmentation is done first.

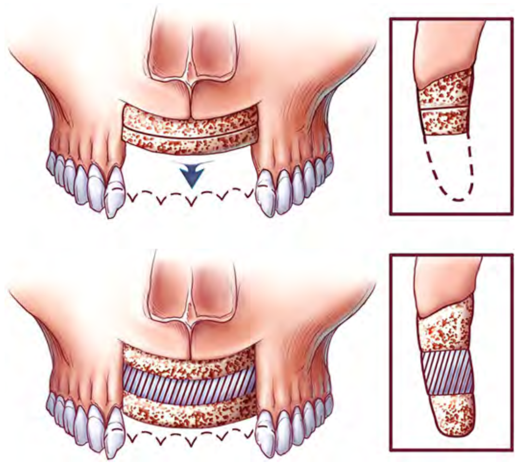

Fig. 18. A class III defect post grafting then can be distracted into a more ideal position.

informed of the difficulty of treating a defect with exposed root surface in an esthetic manner without dental extraction or orthodontic forced eruption. A class IV site defect can occur when a single implant has failed resulting in loss of the supporting bone of adjacent teeth. A single-tooth implant site suddenly becomes a three-tooth site—difficult explain except by biologic principles.

Definitive versus adjunctive distraction osteogenesis

When distraction is used as an adjunct, the goal is different from if it is used as definitive treatment; these two concepts must not be confused. When using distraction prior to definitive bone grafting, the bone graft may not give the desired results. Even regrafting the site may lead to a compromised result. If distraction already has been done, this becomes a third attempt at reconstruction, which could have been avoided. It is better, at times, to establish a definitive basal bone through bone grafting and distract this augmented area into an ideal position. Distraction of an unstable fragment of bone in advance of a major augmentation graft that fails can result in a worse defect than was present to begin with. So, when to do a definitive distraction or adjunctive distraction with bone grafting afterward is perhaps the most important question when establishing a treatment plan. Site classification helps determine the appropriate protocol.

One way to decide if a case is definitive or adjunctive distraction case is to establish the esthetic demand. In cases where esthetic demand is not as important, such as the lower arch or bicuspid or molar zone, the distraction can be done first and bone grafting later. When

Fig. 19. A mild class I case in the esthetic zone done by distraction rather than sandwich osteotomy to better establish final alveolar gingival position.

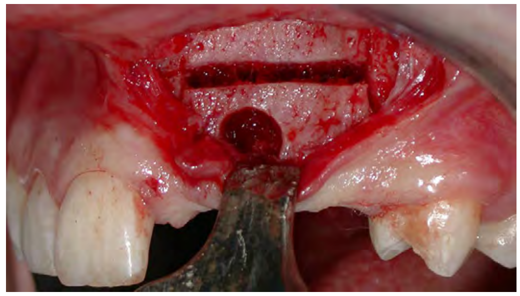

Fig. 20. A mild vertical defect distraction osteotomy done through a vestibular incision.

cosmetics is of primary importance, the use of distraction to gain final orthoalveolar form is optimal, which means establishing a stable basal bone mass that, when distracted, creates orthoalveolar form. When uncertain as to which to do first, ''overdistraction'' of a segment may be the best option. An example of this option is when the alveolar crest is very thin but a few millimeters apical from the alveolar crest is adequate. In this case, the segment is overdistracted and the thin ridge is reduced at the time of implant placement leading to a more ideal ridge form. This approach is particularly useful in full arch distraction cases (Figs. 33–36). The final decision on whether or not to use distraction as a definitive or adjunct treatment often comes down to one of surgical judgment; what is the simplest approach to manage a patient with the least surgical intervention?

Adjunctive distraction osteogenesis

When bone mass is minimal, an adjunctive approach is needed. In order to reconstruct severe anterior maxillary defects, the treatment must include distraction histiogenesis, which creates new soft tissue. Adequate quality and quantity of hard and soft tissue must be present or the final restoration will be compromised but neither bone distraction nor onlay bone grafting alone can satisfy this requirement. After severe avulsive trauma, healed soft tissue often is deficient and scarred to the underlying bone. For adequate, tension-free soft tissue closure to be performed in order to prevent wound breakdown over a large onlay bone graft, adequate soft tissue must be present. Thus, if bone graft augmentation is required, reconstruct the soft tissue first prior to grafting.

In severe defects, lack of soft tissue becomes the driving force that leads to distraction osteogenesis. After trauma, scar formation on the ridge and loss of soft tissue from avulsion injury absolutely limits the effectiveness to elevate tissue and achieve a tension-free closure over a bone graft. With the slow movement of distraction with translation of bone and soft tissue, however, significant histiogenesis creates soft tissue for secondarily coverage of a bone graft. Distraction osteogenesis is an excellent way to eventually regain bone and soft tissue. Therefore,

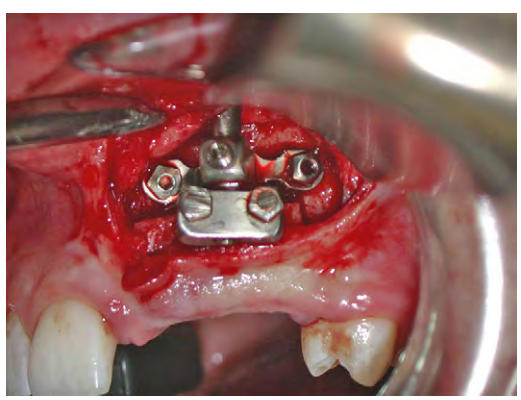

Fig. 21. A class I site treated with a biphase distraction device.

Fig. 22. A class II case with a vertical defect of up to 10 mm requires a large prosthesis to cover the defect.

Fig. 23. A class II case must have adequate alveolar width as was present here.

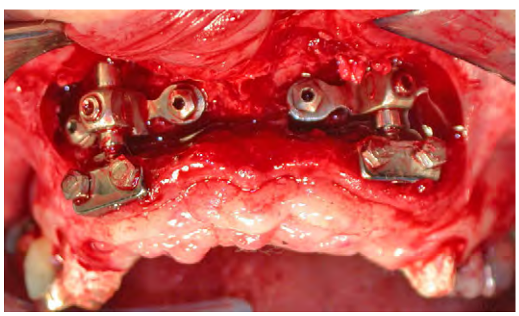

Fig. 24. A distraction approach is used in order to move each side of the arch differentially to the target position—a good approach to managing a complex class II defect.

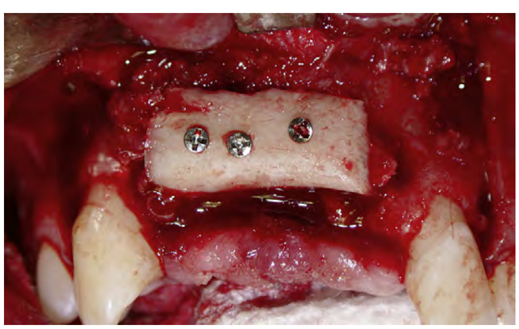

Fig. 25. A class III site may have minimal or poor quality bone but can be augmented with a bone graft to gain enough bone mass for definitive distraction osteogenesis.

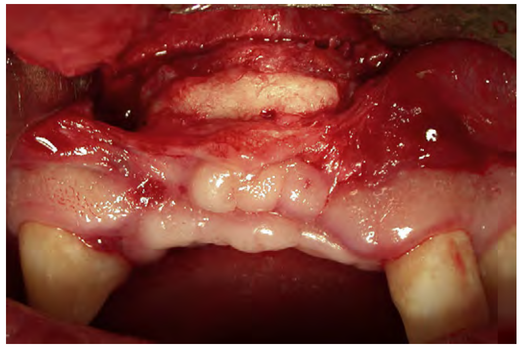

Fig. 26. Wound closure of a class III site is one of the many variables surgeons must attend to in order to ensure consolidation of the graft. Here, the vestibular wound is made 4 months later demonstrating adequate bone graft incorporation.

the treatment plan for reconstructing severe maxillary defects first must address the issue of soft tissue expansion, followed by timely bone grafting. After adequate healing, implants are placed and prosthetic reconstruction done.

In a severely compromised anterior maxillary case, the following protocol is followed.

1. Diagnostic setup and imaging to diagnose the extent of bone loss.
2. Placement of a distraction device that increases the vertical dimension of bone and soft tissue.
3. Wait 7 days after device placement, then distract the alveolus 2 mm twice a day for 1 mm total daily until the alveolar crest is at or exceeds the alveolar plane (during distraction, a removable prosthesis needs adjustment of the flanges and teeth to create space for the alveolus).
4. After 6 to 8 weeks, the distraction device is removed and a bone graft is placed to achieve appropriate ridge form (consolidation of the distraction zone is incomplete at this stage). A template is used to guide the placement of the bone graft.
5. After 4 months, implants are placed using a surgical guide stent (at this time the distracted and augmented bone consolidation should be complete).
6. After the implants are integrated, they are exposed and a temporary fixed prosthesis is placed. When satisfactory, a final prosthesis is designed and placed.

Class III defect treatment

The following case report illustrates this protocol.

A 22-year-old man sustained a major avulsive injury of the hard and soft tissue of the anterior maxilla (Fig. 37). A diagnostic setup of the planned restoration determined that at least 12 mm of bone and soft tissue would be needed for proper esthetics (class III site defect).

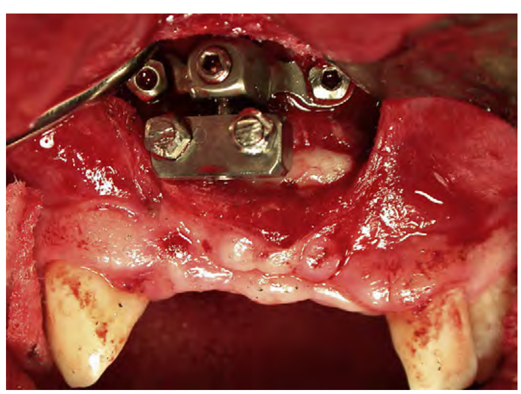

Fig. 27. Once consolidation is certain, a class III case can be distracted to a more definitive position.

Fig. 28. Class IV sites involve significant vertical bone loss around teeth associated with the vertical defect.

Placement of the distraction device

A sulcular incision was made two teeth distal to the defect bilaterally. Broad-based releasing incisions were made vertically. A crestal incision was made across the defect. A full-thickness mucoperiosteal flap was raised to expose the anterior maxilla. A palatal flap was minimally reflected. A 12-mm alveolar distractor (KLS Martin, Jacksonville, Florida) was adapted to the defect. The osteotomies were performed with the distractor in place. The distractor then was removed and the osteotomies completed. The vertical osteotomies were slightly tapered and made 2 mm mesial to the tooth roots bordering the defect. The distractor was replaced in its original position and secured with screws (Fig. 38). A test distraction of 4 mm was performed to insure passive movement of the distracted segment. The segment then was returned to its original position. The periosteal side of the flap then was scored with a 15 blade to ensure passive closure over the distractor. The flap then was closed with 4-0 chromic suture in an interrupted fashion. The patient's removable partial denture had a hole made in it to allow for emergence of the distractor tram. This transitional device also maintained the vector of the distractor and prevented it from moving palatally (Fig. 39). After a latent period (time of initial healing) of 7 days, the distractor was activated at a rate of 1 mm per day (0.5 mm 2 times a day) for 12 consecutive days. As the alveolus moved inferiorly, the labial flange of the transitional denture had to be removed to make room for the transported segment. After 12 days, the distraction was stopped and the bone allowed to consolidate (Fig. 40).

Removal of the distractor and bone graft

After 8 weeks, the alveolar form appeared well healed and the next stage of the treatment was initiated. A vacuum form of the planned restoration was made to serve as a template for the position of the onlay bone graft. A crestal incision was made and the soft tissue elevated from

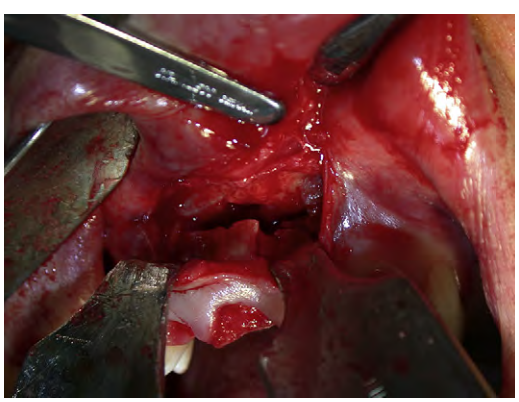

Fig. 29. A class IV site can be distracted from a vestibular approach despite the presence of compromising teeth or concomitant to grafting of dental extraction sites.

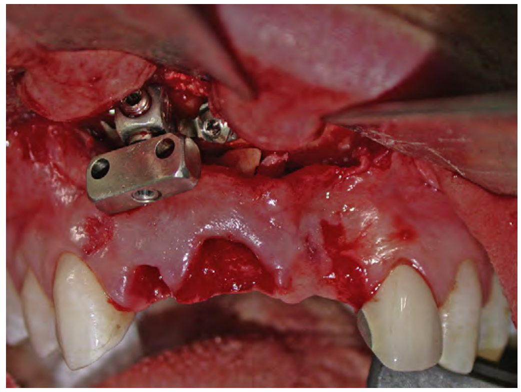

Fig. 30. A distraction device is applied to a class IV site in which two grafted extraction sockets simultaneously are distracted in conjunction with the edentulous space.

the distractor, exposing its distracted position (Fig. 41). The distraction device was removed and the bone evaluated. Bone had formed across the distraction gap but was deficient horizontally as expected. The template was placed and wax was used to form a template for the bone grafts. Corticocancellous blocks were harvested from the iliac crest and secured over the alveolus as guided by the template (Fig. 42). The periosteum was relieved to allow for a tension free closure.

Implant placement

After 4 months of bone graft consolidation, a new surgical template was made to guide the placement of the implants. A crestal incision was combined with vertical release incisions and the bone graft was exposed. Fixation screws were removed and implants placed in each tooth position (Fig. 43). After 4 months for osseointegration, the implants were exposed and a fixed prosthesis fabricated (Fig. 44). At placement, the patient was satisfied with the appearance of the restoration. His smile line covered small gingival discrepancies that commonly occur with the restoration of severe soft and hard tissue defects (Fig. 45).

Alveolar alignment by distraction osteogenesis

The third role of distraction is alveolar alignment, which is not uncommon finding in edentulous patients seeking ideal implant treatment. Orthognathic surgery has been used for almost 50 years to align jaws and associate teeth into an Angle's class I dental arch relation. As known for years, when atrophy of the jaws occurs through overclosure or alveolar atrophy, totally edentulous patients tend to present as an Angle's class III skeletal malocclusion. Bone

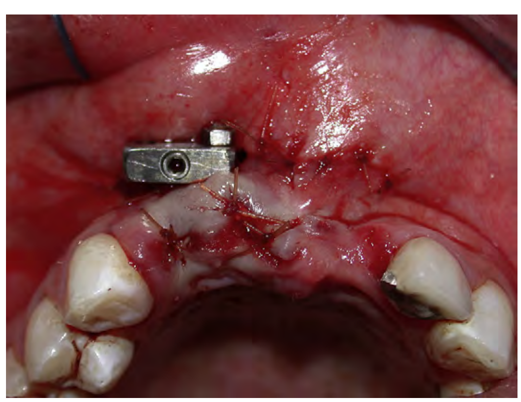

Fig. 31. A low-profile distraction device is preferred in the esthetic zone.

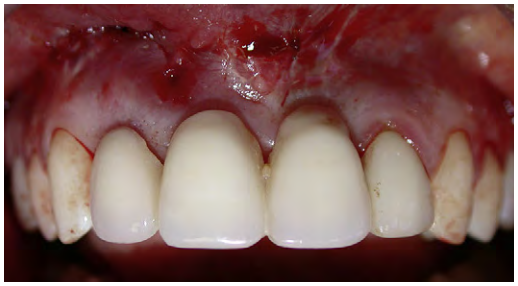

Fig. 32. The elongated teeth observed on the temporary placed at the time of surgery will be cut back as the alveolar process is distracted into the target position.

Fig. 33. Alveolar distraction can proceed until there is blanching of the mucosa against the temporary prosthesis as observed in this Le Fort I edentulous maxilla distraction.

Fig. 34. Radiographic findings of a full arch Le Fort I distraction when the maxilla was brought down and forward more than 10 mm.

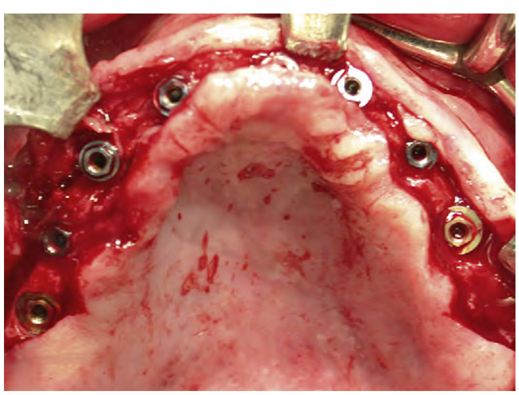

Fig. 35. After 4 months of healing, the distraction devices are removed and implants are placed.

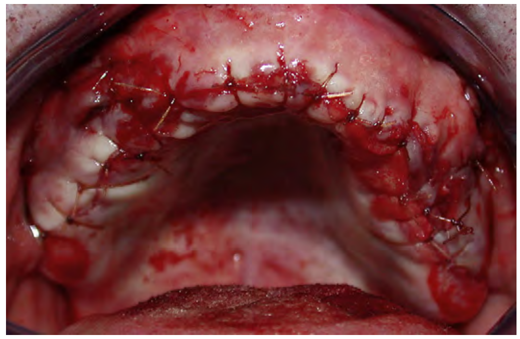

Fig. 36. Wound closure with implants buried.

Fig. 37. A planned setup demonstrates a 12-mm vertical bone deficiency.

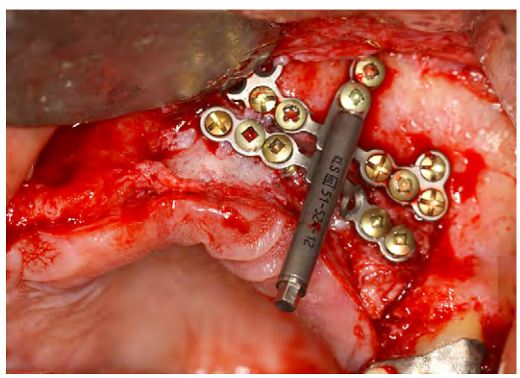

Fig. 38. Through a vestibular incision, a distraction device was adapted before and after Le Fort I osteotomy.

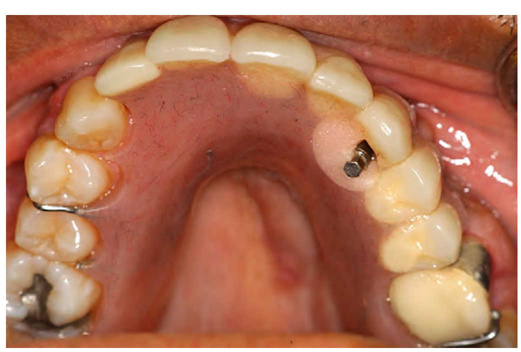

Fig. 39. The transitional removable partial denture allows for the activating arm of the distractor.

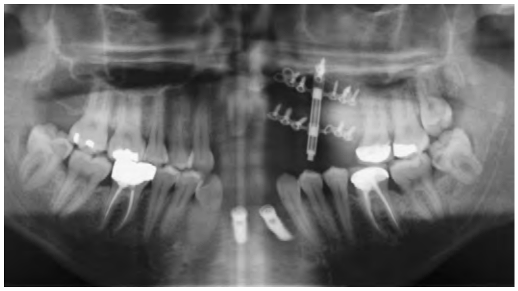

Fig. 40. As the distraction was accomplished 1 mm per day in 0.5-mm increments 2 times per day, the alveolus moved inferiorly necessitating removal of the denture flange every 2 to 3 days. A panoramic radiograph shows the extent of the distraction.

resorbs in three planes in space but often at a higher rate for the alveolar facial plate, with a greater effect in the maxilla than the mandible so that the net effect is a class III jaw relation and a crossbite alveolar relation in the transverse posterior dimension. Orthognathic surgery procedures can align edentulous arches, but without teeth, placement of the segments in space is less precise. In contrast distraction, segmental or full arch with bone-borne appliances has some advantages over traditional orthognathic procedures. Three procedures that should be considered for alveolar re-alignment are rapid palatal expansion, rapid alveolar expansion, and edentulous Le Fort I distraction.

Rapid palatal expansion

The Mommaerts palatal expander, used as a distraction device, is non–tooth borne and can expand the maxilla up to 15 mm. When the alveolus itself is of sufficient width (5 mm), but in a 5-mm or greater crossbite, rapid palatal expansion is justified. If an arch is in a gross crossbite, 10 mm or more, the expansion procedure, done bilaterally or unilaterally, is an excellent modality to improve alveolar position prior to implant placement (Figs. 46–50).

Rapid alveolar expansion

Another way to transpose an alveolus that is in crossbite is to split the alveolus crestally using an intra-alveolar device (Laster Crest Expander). This device expands the facial plate and translates the ridge into axial alignment. This usually is done in a slow distraction protocol, but a rapid expansion of 3 to 4 millimeters, done over only 2 days, heals like an extraction socket and, therefore, often can be used. In compromised settings, a slow distraction protocol of 1 mm per day for 10 days is recommended (Figs. 51–56). The split bone segment must be maintained as osteoperiosteal flaps or bone resorption will occur.

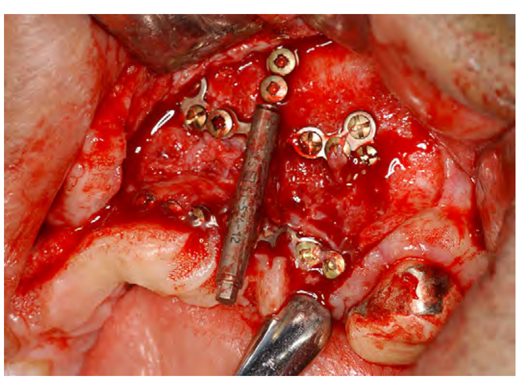

Fig. 41. After 8 weeks, the distraction device was removed.

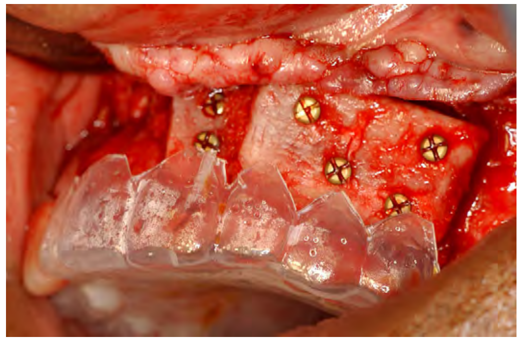

Fig. 42. The device was removed. Bone formed palatally but a horizontal deficiency was present, as expected. Bone wax was adapted to the ridge to form a template for carving the bone grafts. The bone grafts were harvested from the iliac crest and secured in position with titanium bone screws. The bone grafts were placed in appropriate position for the implants with enough bone available to support interdental papilla.

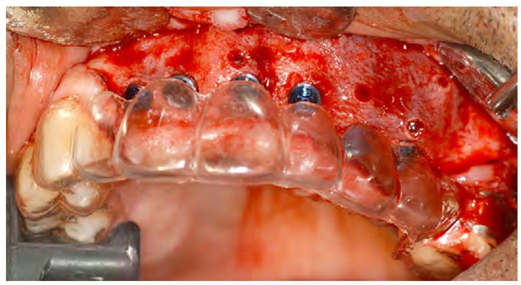

Fig. 43. After 4 months, a template was made to guide implant placement. The alveolus now had improved bone dimension in the vertical and horizontal aspects. Implants were placed using the template, approximately 3 mm apical to the planned gingival margin.

Fig. 44. Four months later, the ridge was ready for implant exposure. Transfer impressions were made and custom abutments made.

Fig. 45. Each crown was designed as a single replacement tooth, without splinting. The final restoration in place. Small gingival defects are hidden by the patient's low smile line.

Fig. 46. A palatal expander is placed in an orthodontic case prior to surgery.

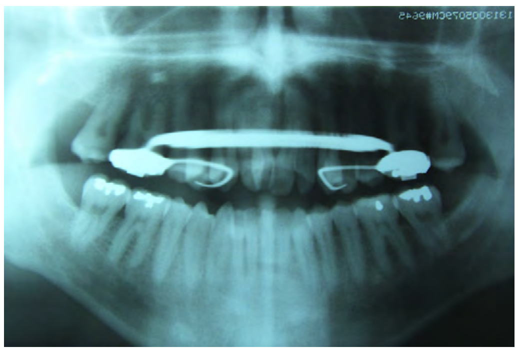

Fig. 47. Radiograph showing placement of a palatal expander prior to surgery.

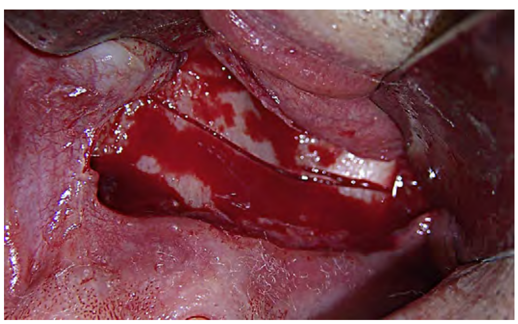

Fig. 48. A maxillary bone cut is made in preparation for alveolar arch expansion.

Fig. 49. Using a key to turn the device, the palate can be expanded 10 mm or more.

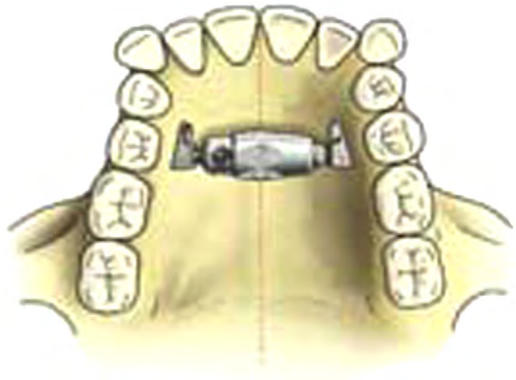

Fig. 50. An all-in-one transpalatal device is fixated to the palatal shelves and spreads the palate apart aligning relative crossbite edentulous ridges.

Fig. 51. A narrow alveolar ridge can be distracted to gain alveolar width using a Laster Crest Expander.

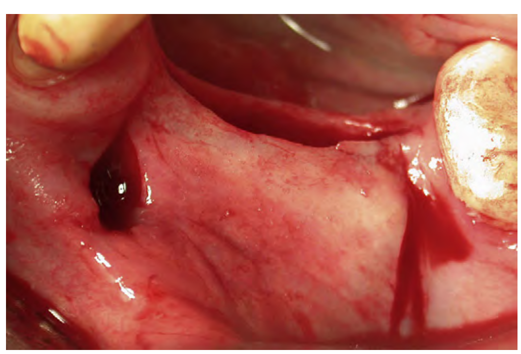

Fig. 52. The alveolus is split crestally by piezo-surgery or a sagittal saw.

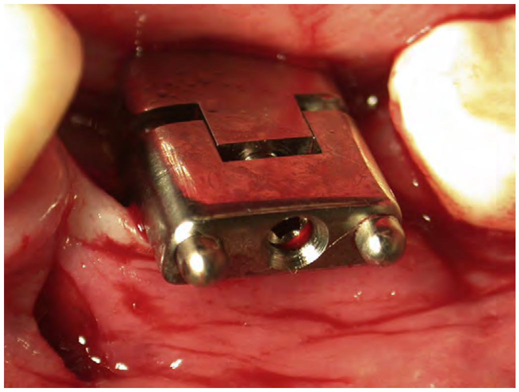

Fig. 53. The ridge expander is gently tapped into place in the posterior mandible.

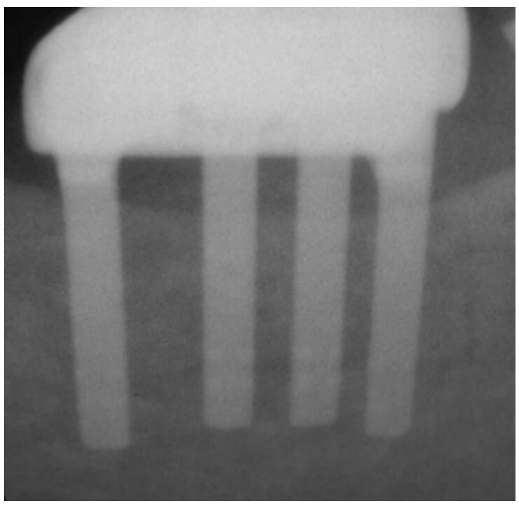

Fig. 54. A radiograph taken 4 weeks after the expander was placed. A slow distraction protocol of 1 mm per day was used for 10 days and left to heal for 3 weeks, widening the alveolus 4 mm.

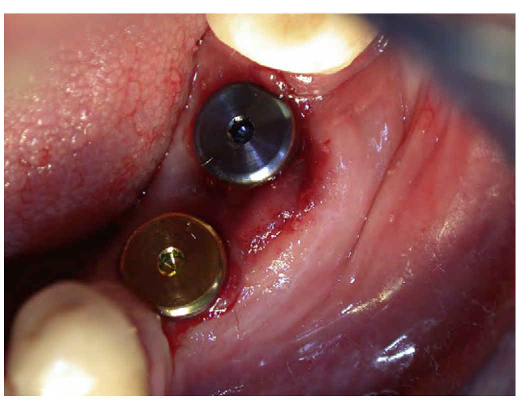

Fig. 55. After 5 weeks, the expander was removed and implants were placed.

Fig. 56. The final restoration was inserted 3 months later.

Fig. 57. A patient who had oligodontia may present with significantly decreased arch circumference resulting from multiple missing permanent teeth leading to poor arch development.

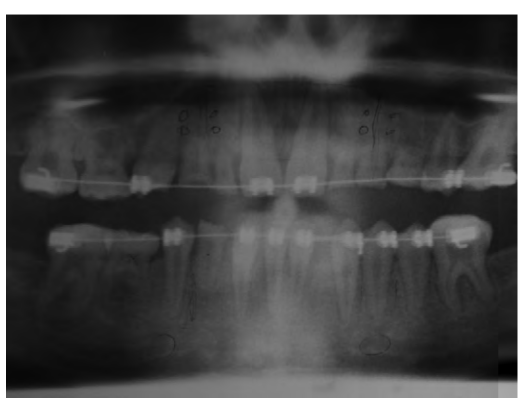

Fig. 58. Preoperative panorex showing inadequate space for permanent size teeth.

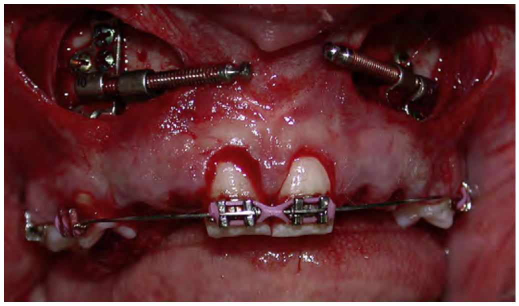

Fig. 59. Bilateral distraction devices for arch expansion movement of segmental osteotomies are placed in the maxilla after several primary teeth are extracted.

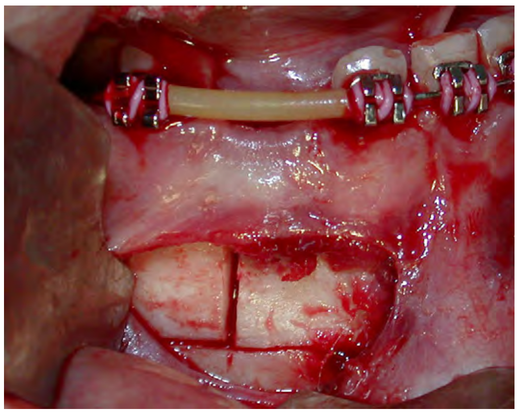

Fig. 60. A subapical bone cut is made to prepare for the distraction device for mandibular hoop expansion.

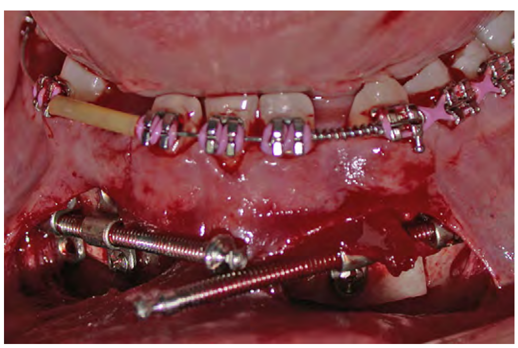

Fig. 61. Bilateral distraction devices are placed in the mandible after extractions of primary teeth.

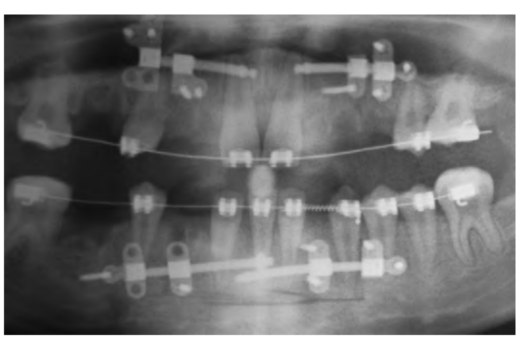

Fig. 62. Postoperative panorex showing distraction devices before activation in the maxilla and mandible.

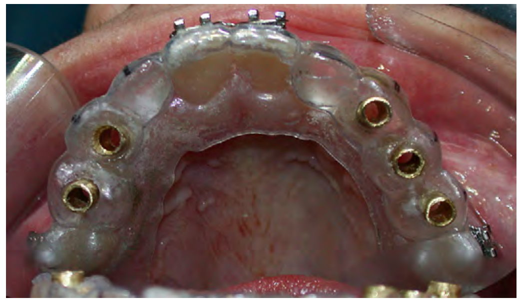

Fig. 63. Five months post operative, the alveolar arches are lengthened in both jaws, the distraction devices are removed, and implants are placed using a guide stent.

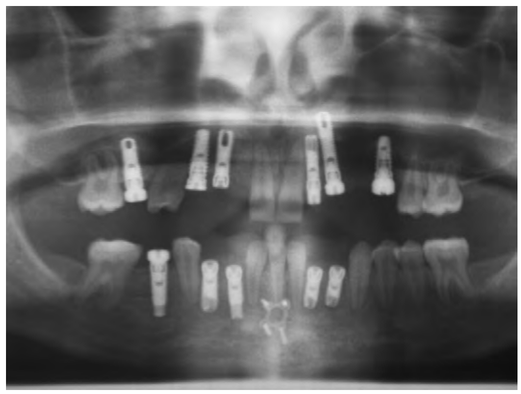

Fig. 64. Postoperative panorex showing implant placement on the maxilla and mandible.

Fig. 65. Temporary prosthesis after implant placement.

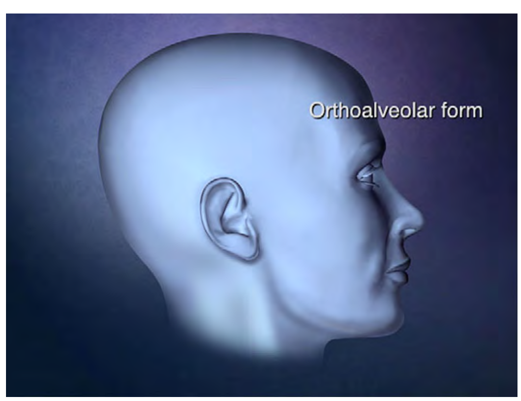

Fig. 66. The concept of orthoalveolar form suggests facial harmony with jaw bone relation in proper vertical dimension aligned class I arch relation.

Fig. 67. A face in harmony suggests a dentition in class I relation.

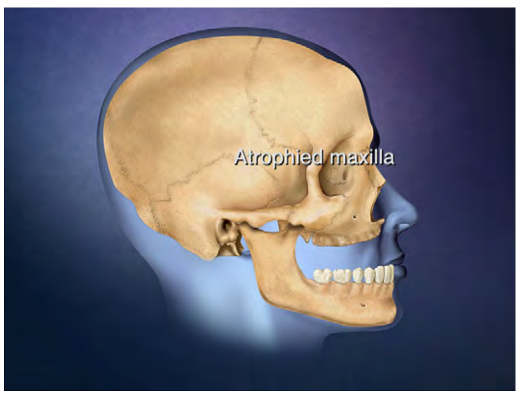

Fig. 68. Severe maxillary atrophy leads to a pseudo–class III arch relation and a markedly decreased vertical dimension.

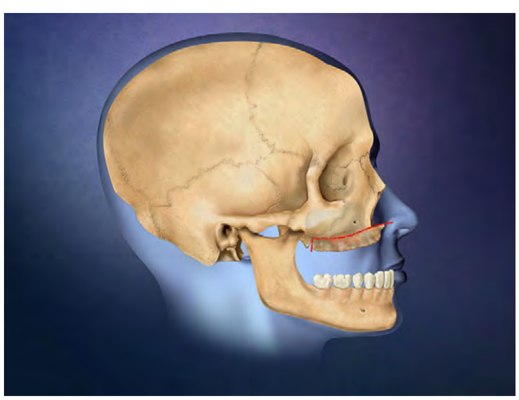

Fig. 69. If alveolar height is acceptable, a Le Fort I osteotomy cut is done to begin distraction of the maxilla down and forward.

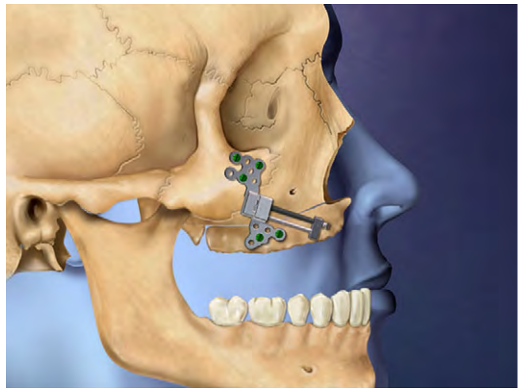

Fig. 70. Application of distracters bilaterally is done taking care to have equal vectors, which are directed down and forward.

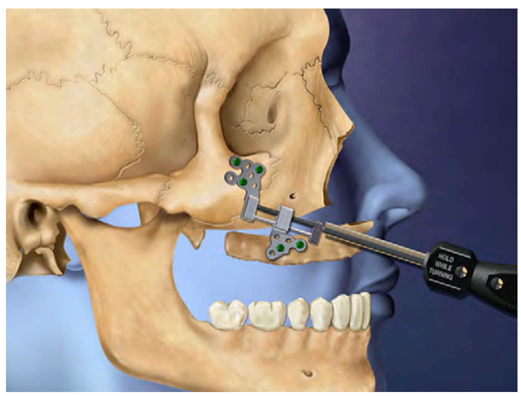

Fig. 71. Distraction begins 1 week after surgery and extends for 2 to 3 weeks as needed at a rate of l mm per day.

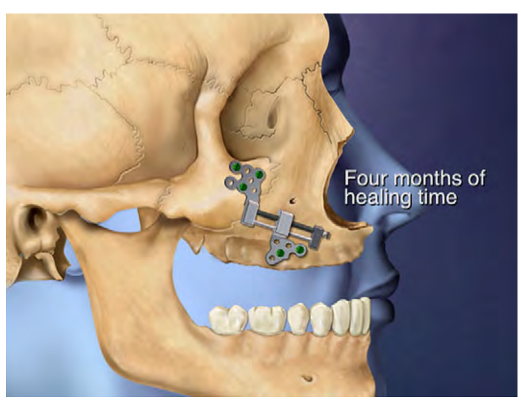

Fig. 72. After cessation of distraction, the jaw is left to heal for 4 months.

Fig. 73. Despite reduced alveolar height, a Le Fort I approach recovers alveolar form indirectly by changing the entire jaw complex into a class I arch relation.

Fig. 74. Implants are placed via a guide stent.

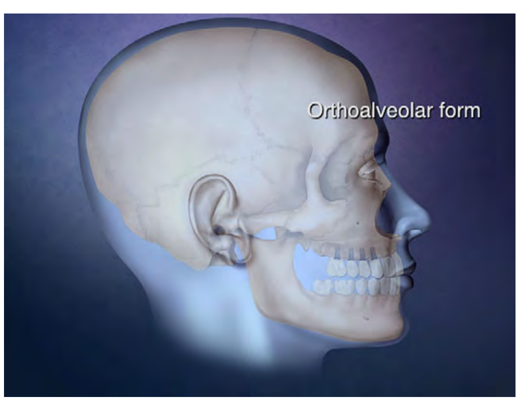

Fig. 75. The final dental restoration mimics the missing orthoalveolar form.

Fig. 76. A preoperative cephalometric radiograph on a Le Fort I distraction patient.

Fig. 77. A preoperative side view showing class III deficiency.

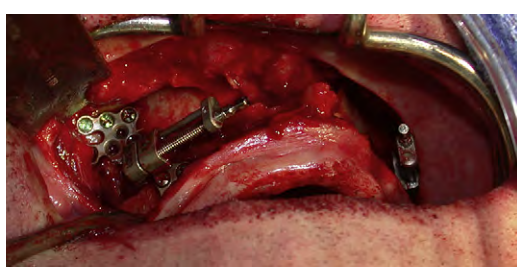

Fig. 78. A Le Fort I osteotomy is performed and bilateral distraction devices are placed to bring the maxilla down and forward.

Fig. 79. After the distraction is complete and left for 4 months to heal, the maxilla is found to be in class I alignment.

Fig. 80. A panorex showing 10 to 12 mm of distraction in the maxilla.

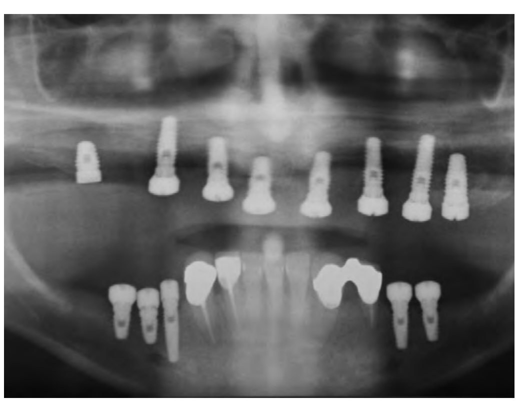

Fig. 81. The distraction devices are removed and implants are placed.

Fig. 82. Final restoration.

Alveolar segmental distraction osteogenesis

Alveolar segments can be moved to lengthen arch form, such as mandibular body osteotomies or maxillary subapical osteotomies. A case of oligodontia is illustrated that was treated with distraction procedures using intraoral devices (Figs. 57–65).

Le Fort I distraction

Many patients have pre-existing skeletal malocclusions prior to the loss of their teeth or present as an edentulous Angle's class III skeletal malocclusion. In these patients, a Le Fort I distraction can be done in an outpatient setting that can bring atrophic arches back into Angle's class I skeletal alignment (Figs. 66–75). The maxilla can be distracted downward and forward 10 mm or more such that not only is the anterior arch relation brought into alignment but also a relative posterior crossbite is improved without expanding the palate (Figs. 76–82).

Summary

Modification of alveolar form and alveolar relation is well within the purview of distraction osteogenesis. New and improved devices and concepts continue to be developed. Practitioners should treat to the conceptual ideal of orthoalveolar form and classify osseous defects in a team approach according to a surgical/prosthetic treatment planning protocol. The most important treatment protocol to consider is whether or not distraction is used as a definitive procedure to establish orthoalveolar form or as an adjunct for follow-up bone grafting. A final concept to consider is movement of the alveolus orthognathically with segmental or total jaw distraction osteogenesis, a technique that can completely change the subsequent requirement of implant placement and the final dental restoration. Future directions in edentulous jawbone structure distraction must serve as an adjunct to esthetic dentistry whose ultimate humanitarian charge is *invenio quod defectio*.

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Atlas of the Oral and Maxillofacial Surgery Clinics

Vertical and Horizontal Mandibular Lengthening of the Ramus and Body

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For the purposes of this article, lengthening of the mandible is subdivided into vertical lengthening of the ramus as in patients with hemifacial microsomia and horizontal lengthening of the mandibular body as in patients with Pierre Robin syndrome. Unfortunately, many of the patients that present for treatment of mandibular deformities often have a combination of both vertical ramal deficiencies and horizontal body deficiencies. One of the cases presented includes an intrarch distraction of the body of the mandible illustrating how complex are some patients with skeletal discrepancies. The design of commercially available distractors may not satisfy the needs of an individual patient. This issue is addressed in greater detail elsewhere in this issue. Depending on the age of the patient and the complexity of the movement, a single vector or a multivector distractor may be needed. In very young patients or in individuals with complex movements, an external distractor may be necessary. As with orthognathic surgery, lengthening of the vertical aspect of the mandibular ramus is technically more difficult than lengthening the body of the mandible to correct sagittal deficiencies.

Indications

A number of syndromic patients may present for care either at a pediatric age where airway issues prompt intervention, or later when conventional osteotomies may not give the best results. These can include but are not limited to hemifacial microsomia (types I–III), Treacher Collins syndrome, Pierre Robin syndrome, and Stickler's syndrome. Intervention in a pediatric patient may obviate the need for a tracheostomy or allow removal of the tracheostomy (see later). In some cases, patients with severe mandibular deficiency have or are on the borderline of having obstructive sleep apnea.

There is a number of nonsyndromic patients, however, who can benefit from distraction osteogenesis. Advancement of the mandible greater than 7 mm becomes increasingly more unstable with traditional osteotomies. Large advancements of the mandible are a relative indication, but when technical difficulties with a thin ramus or relapse after a previous sagittal split are accompanied with a large movement, then distraction is a reasonable alternative. A less

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commonly seen indication is a patient with unusual mandibular anatomy that makes doing a traditional mandibular osteotomy difficult (see later). Another relative indication for advancement by distraction is a patient with temporomandibular joint (TMJ) symptoms, especially when they need a large advancement. The concept is that distraction provides a gradual lengthening of mandible and may decrease forces on the TMJ.

Vertical lengthening of the ramus

Even though distraction osteogenesis vertically to augment the mandibular ramus has been reported, there are still many variables involved in the diagnosis and treatment planning to solve all the growth and consequent asymmetry problems using the technique. The most common use of vertical distraction of the ramus is for types I and II hemifacial microsomia patients (see later). Distraction during growth, although challenging, can address some of the soft tissue and hard tissue issues that these patients have. Prediction of the growth of the opposite side and vector control, however, remains difficult. In addition, when lengthening the ramus against an intact joint, the pterygomasseteric sling is stretched. This creates a vertical force on the condylar head against the glenoid fossa compressing the intracapsular structures. The ultimate consequence may be unpredictable resorption, remodeling, or adaptation of the TMJ. These types of pressures can cause the cartilage surfaces to be flattened, putting pressure on the

Fig. 1. (*A, B*) Frontal and profile of a patient with early condylar trauma. Subsequent growth deformity. Severe mandibular deficiency, compensatory maxillary growth. (*C*) Lateral cephalogram confirming the clinical findings.

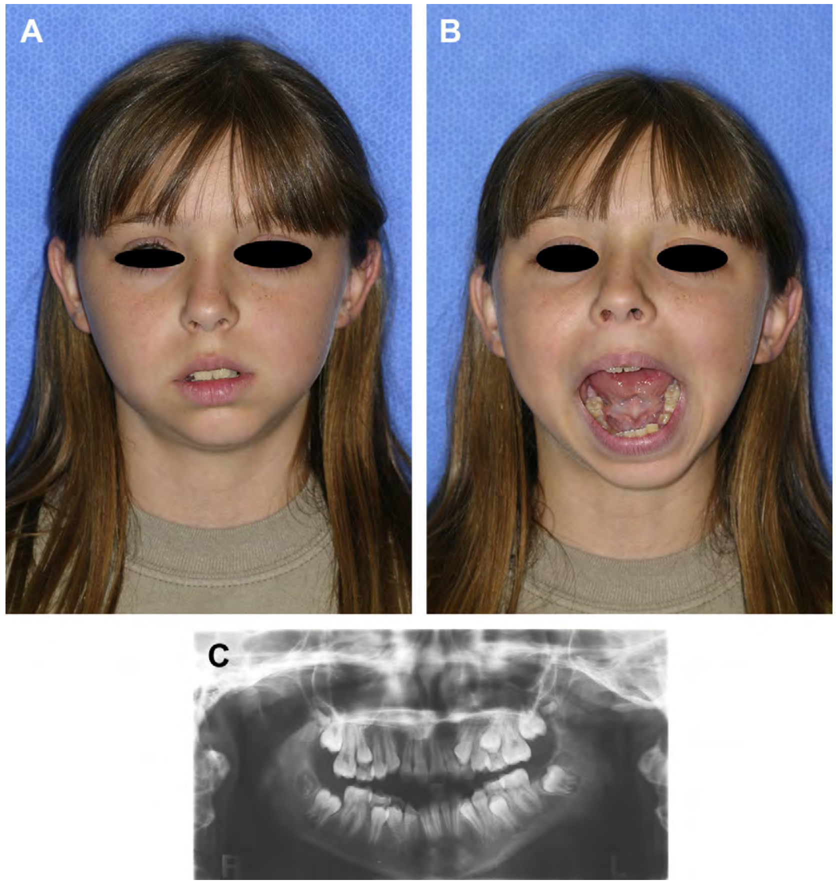

Fig. 2. (*A, B*) Frontal view, closed and open, with deviation of the mandible to the left. (*C*) Panorex showing the type IIA condyle on the left.

synovial spaces. Histologic changes occur in the subchondral bone, where there is a reparative phase with vertical condylar loss and possible damage of the articular tissues. Most authors who distract the vertical ramus during growth suggest that the patient may need a secondary surgery when growth is complete because of some of these concerns.

Fig. 3. Lateral cephalogram, showing distractor with a vertical and slightly anterior vector.

Horizontal lengthening of the body

Horizontal lengthening of the body of the mandible may be used in pediatric patients where airway is an issue. In these patients, an inverted "L" osteotomy is usually done with either an internal distractor with an extraoral port, or an extraoral distractor. In nongrowing adults, the distractor can exit intraorally, as in the case shown later. Relapse with mandibular advancement by a sagittal split osteotomy is well known. Less relapse with distraction is speculative because there are no controlled studies of advancement with traditional osteotomies versus distraction. What is not disputed is that distraction does allow large advancements not possible with traditional osteotomies without additional bone grafts.

Ankylosis of the temporomandibular joint

Ankylosis of the TMJ especially during or before growth is completed presents several challenges to the clinician. Here there may be both deficiencies in the vertical portion of the ramus and the horizontal portion of the body. In addition, there may be compensatory changes in the maxilla (Fig. 1).

For lengthening the ramus in TMJ ankylosed patients the surgical procedure is performed in two stages. The first step is the ramus and body lengthening, which allows the clinician a predictable mandibular ramus vertical augmentation, and muscle lengthening. The second surgical step is planned once the consolidation process is completed, and consists of freeing the TMJ ankylosis by a gap arthroplasty. Following this protocol, the clinician has better control of the two distracted segments. This avoids pressure against the new surgically created joint, and allows active muscle physiotherapy after releasing the joint.

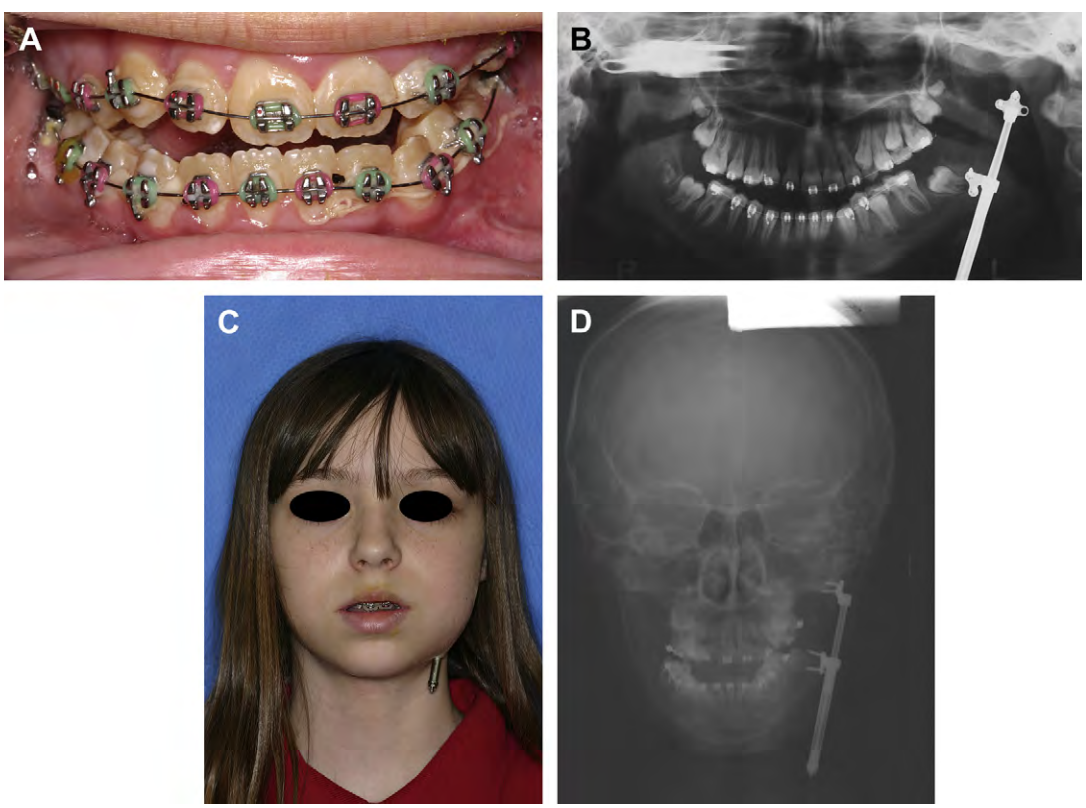

Fig. 4. (*A, B*) Occlusion and panorex showing overcorrection. (*C, D*) Frontal view and posteroanterior cephalometric radiograph showing symmetry.

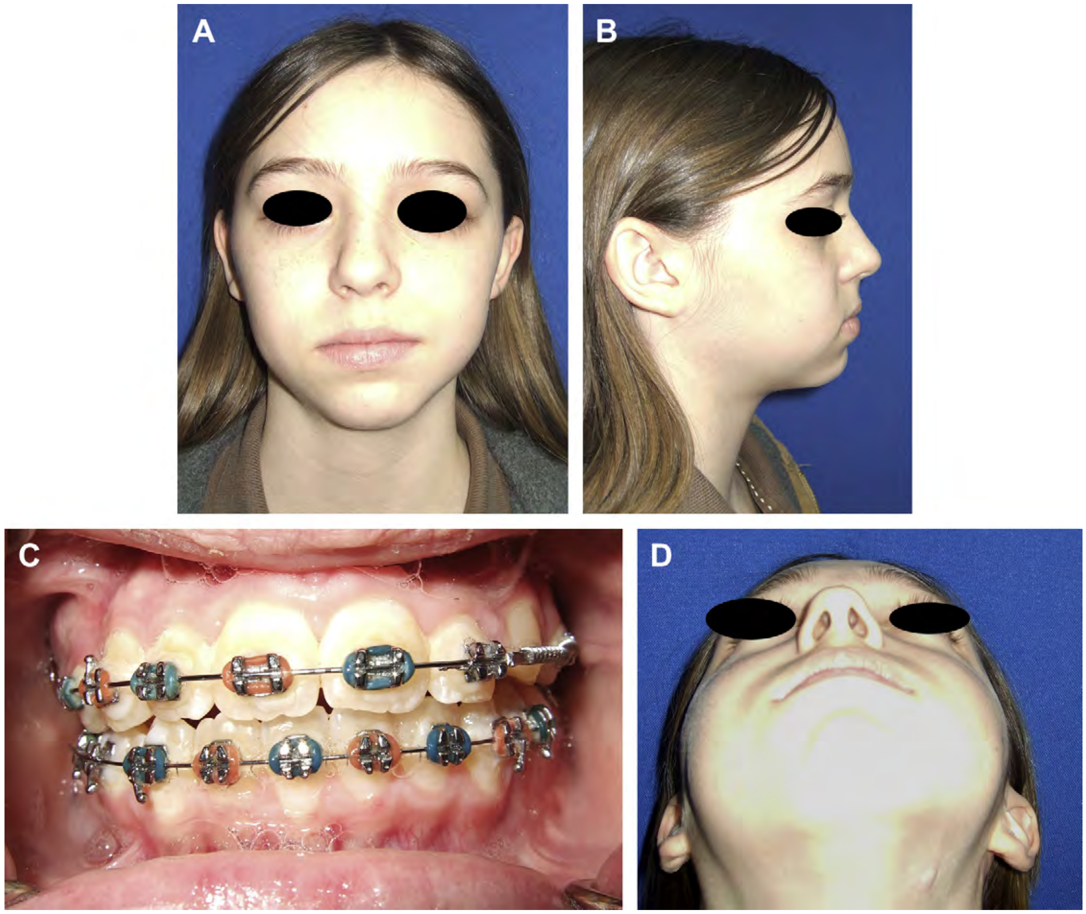

Fig. 5. (*A, B*) One year after surgery, the left side is not as full as the right, but the profile is good. (*C, D*) Occlusion class I, but still some facial asymmetry.

Cases

Case 1: vertical deficiency of the ramus with a concomitant anteroposterior deficiency

A 10-year-old girl with type 2A hemifacial microsomia presents with progressive asymmetry of her maxilla and mandible to the left (Fig. 2). She was taken to surgery, where a horizontal line was scribed on the left ramus superior to the site of the third molar. A single vector internal distractor was temporarily placed intraorally with an external port. An anteroinferior vector was chosen to anticipate growth of the mandible on the opposite side while lengthening the ramus (Fig. 3). The distractor was removed and a near complete osteotomy was made. The

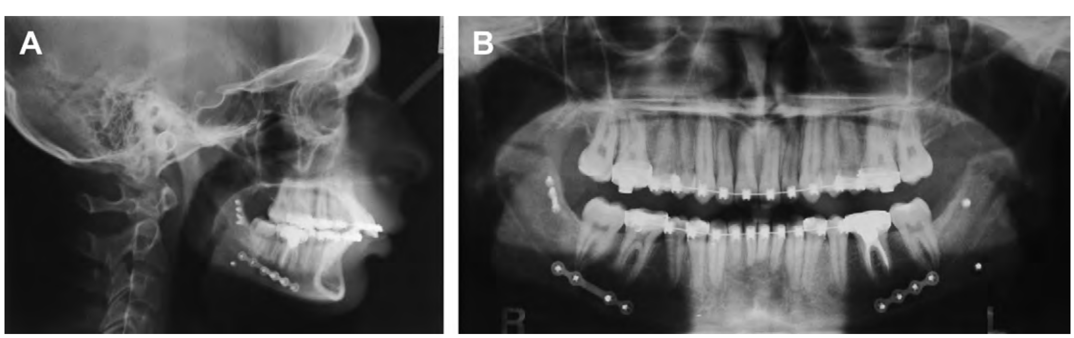

Fig. 6. (*A, B*) Lateral cephalogram and panorex showing previous attempt at a bilateral sagittal split osteotomy.

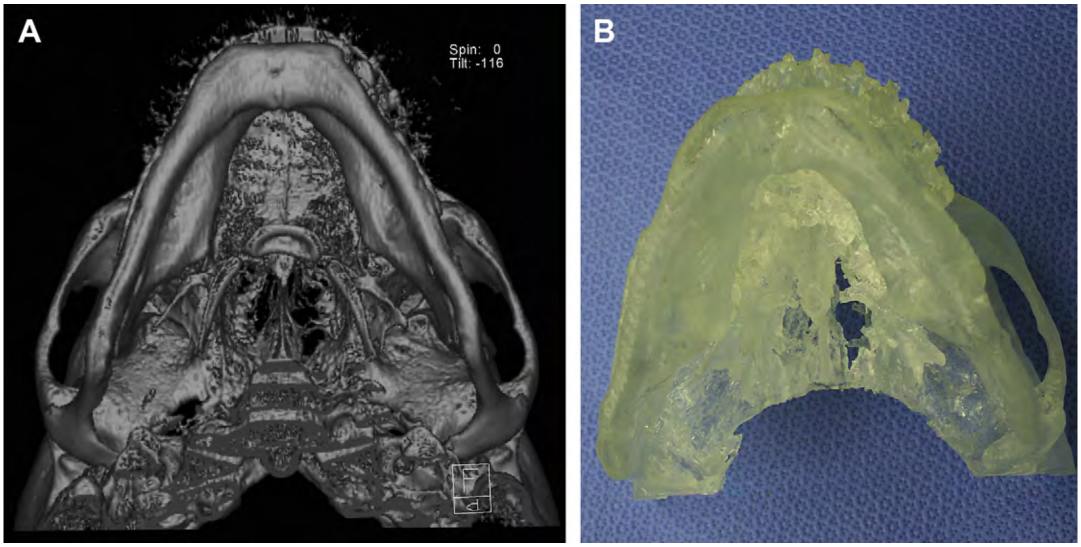

Fig. 7. (*A, B*) Three-dimensional CT scan and stereolithographic model showing very thin ramus.

distractor was replaced and the osteotomy was completed. She had a 5-day latency period followed by a twice-a-day rhythm to achieve 1 mm of distraction per day. She was distracted for 15 days to a slightly overcorrected position (Fig. 4). Frontal symmetry was achieved; however, the lower midline was approximately 2 mm to the right of maxillary midline. At 1 year, symmetry is still good, but the left side is not as full as the right (Fig. 5A, B). Occlusally, she is class I, but from the submental vertex photograph, she is less prominent on her left side (Fig. 5C, D). Although distraction during growth can help an asymmetry, often these patients need secondary osteotomies when growth is complete.

Case 2: horizontal deficiency of the mandible with unusual anatomy

A 17-year-old boy was referred for distraction osteogenesis after a failed attempt at completing a bilateral sagittal split osteotomy advancement (Fig. 6). The original surgeon

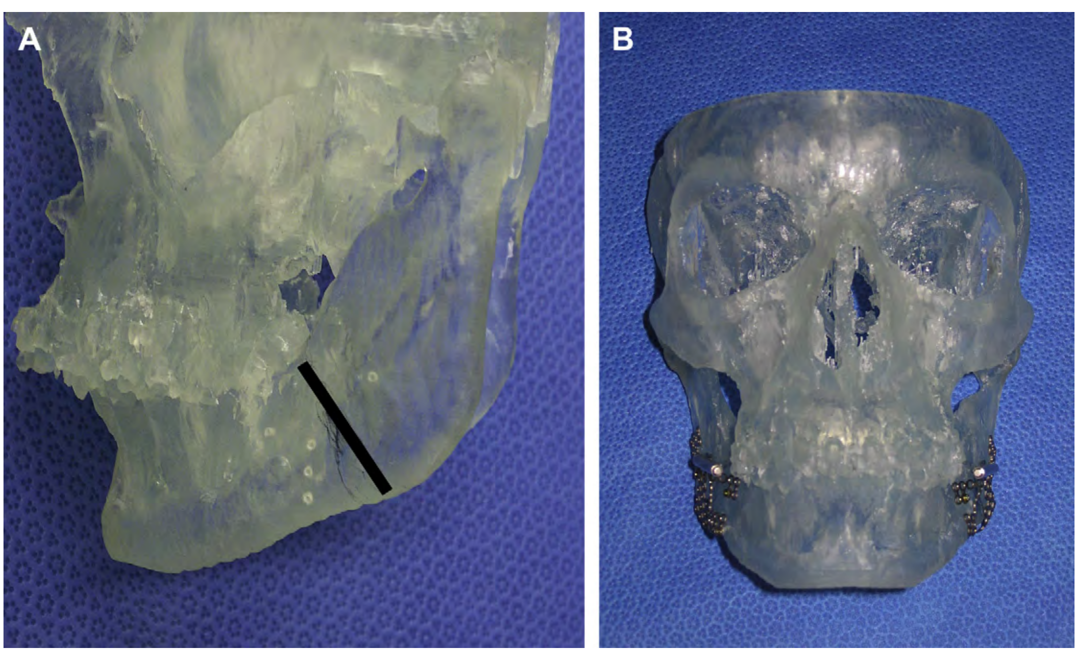

Fig. 8. (*A, B*) Model with planned osteotomy anterior to the angle (esthetic unit).

Fig. 9. Lateral cephalogram during period of consolidation.

commented that the ascending ramus was very thin and that there was an unplanned fracture of the proximal segment on one side. The segments were then fixed in place to allow healing. A three-dimensional CT was obtained and from that a stereolithographic model was made (Fig. 7). They confirmed that rami on both sides were very thin. Four months after the first surgery, an osteotomy was planned anterior to the esthetic unit of the angle, bileveled on the medial aspect of the ramus. The distractors were prebent on the model and the primary vector was chosen to parallel the maxillary occlusal plane. (Fig. 8). This slightly upward primary vector was chosen to account for the inferior pull of the suprahyoid muscular (intrinsic vectors). A 5-day latency was chosen with a twice-a-day rhythm to achieve 1 mm per day for 10 days. Consolidation time was 3 months from the time of surgery. A lateral cephalogram confirms the desired advancement (Fig. 9). The distractors were removed at 3 months. At this point orthodontic management commenced to achieve ideal interdigitation of the occlusion (Fig. 10).

Case 3: horizontal deficiency of the body of the mandible in a tracheostomy-dependent child

A 1-year-old boy with Stickler's syndrome presented with mandibular deficiency and a tracheostomy (Fig. 11). In consultation with his pediatrician and otolaryngologist it was

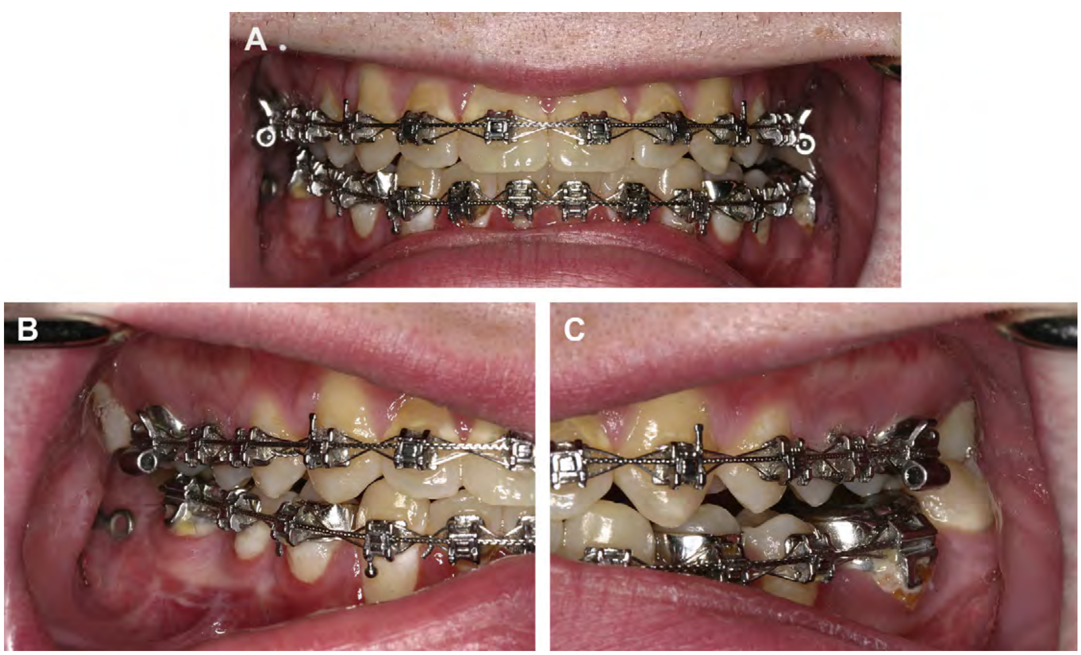

Fig. 10. (*A–C*) Occlusion just before removal of distractor.

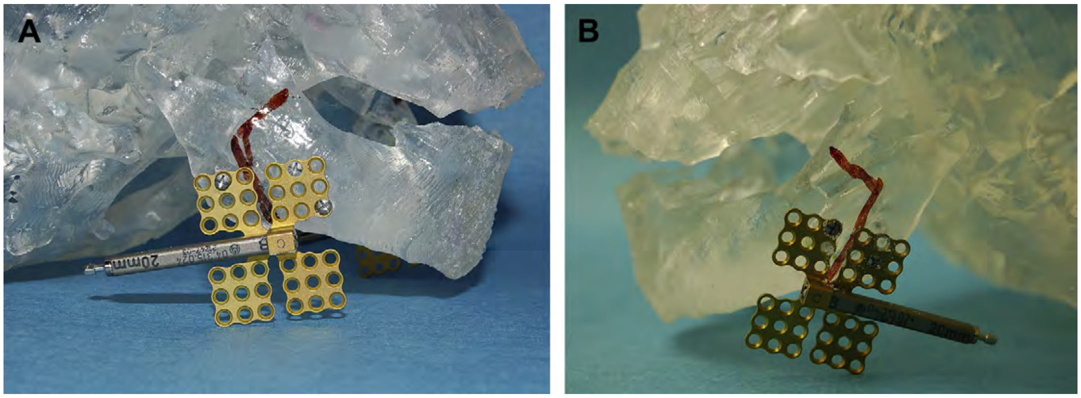

Fig. 11. (*A, B*) Stereolithographic model of left and right sides, "L" osteotomy design, distractors before lower flange being cut off.

decided to do a mandibular advancement with distraction to improve the airway. The child was taken to surgery where an extraoral incision was made at the angle of the mandible exposing the ramus and an inverted "L" was done after a distractor was placed with an extraoral port (Fig. 12). A 24-hour latency period was chosen and a twice-a-day rhythm was used to achieve 1.2 mm of distraction per day. A total of 8 mm of advancement was achieved and there was a 2-month period of consolidation after which the distractors were removed. Within 2 months of removal of his distractors, his tracheostomy was removed. The mother also noted he was able to swallow better.

Case 4: mandibular distraction in the mixed dentition

This child illustrates combined vertical and horizontal deficiency of the mandible presenting for treatment in the mixed dentition (Fig. 13). Placement of the distractors is done so that they achieve both a horizontal and vertical augmentation of the mandible (Fig. 14). At the end of 25 mm of distraction, the mandible is overcorrected (Fig. 15). Clinically, he has a stronger profile and his airway is improved from the mandibular advancement (Fig. 16).

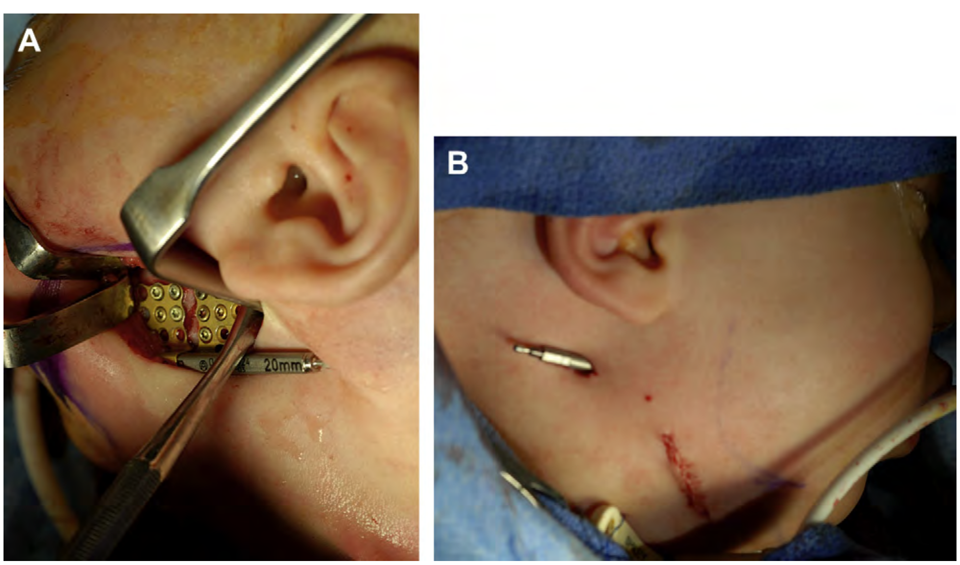

Fig. 12. (*A, B*) Osteotomy and placement of distractors on the left side, closure of wound on the right.

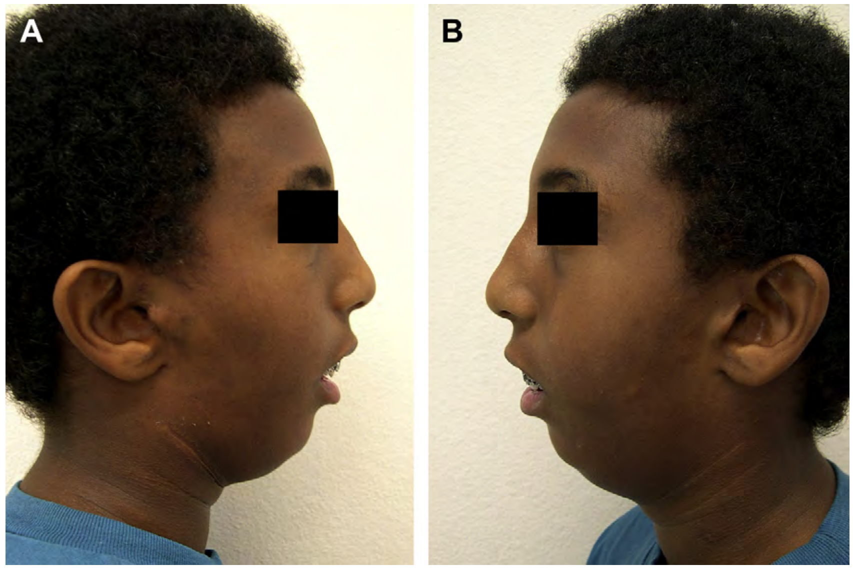

Fig. 13. (*A, B*) Right and left lateral views of a child with mandibular deficiency.

Case 5: temporomandibular joint ankylosis with vertical deficiency of the right ramus and horizontal mandibular deficiency

Preoperative frontal view of a patient with TMJ ankylosis with severe right unilateral mandibular deficiency (Fig. 17). In Fig. 18, his profile reveals a severe mandibular deficiency. With ankylosis of the TMJ and severe mandibular deficiency, many of these patients are undernourished and frequently underdeveloped. As the previous cases illustrated, they may also have airway issues. Many patients require a genioplasty to improve facial symmetry during a second surgical stage, usually 1 year later when the distractors are removed and the gap arthroplasty is performed. In Fig. 19, the right mandibular ramus has been lengthened vertically and the mandibular body has been distracted anteroposteriorly simultaneously. The activation rod can be observed extraorally in the mandibular angle; the anteroposterior activation is done intraorally.

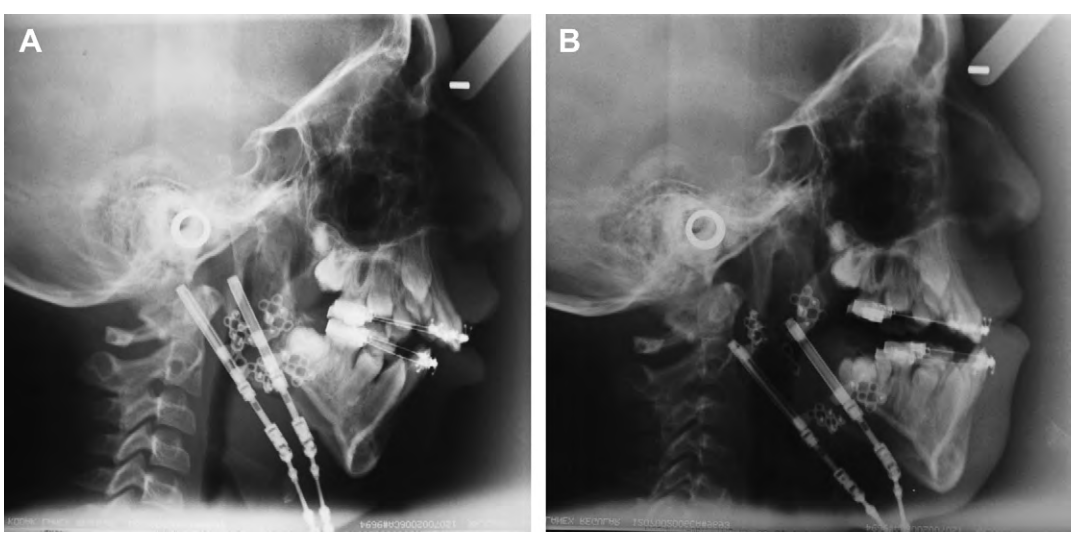

Fig. 14. (*A, B*) Distractors placed in an inferior and anterior direction, early and after 25 mm of distraction showing advancement of the distal segment.

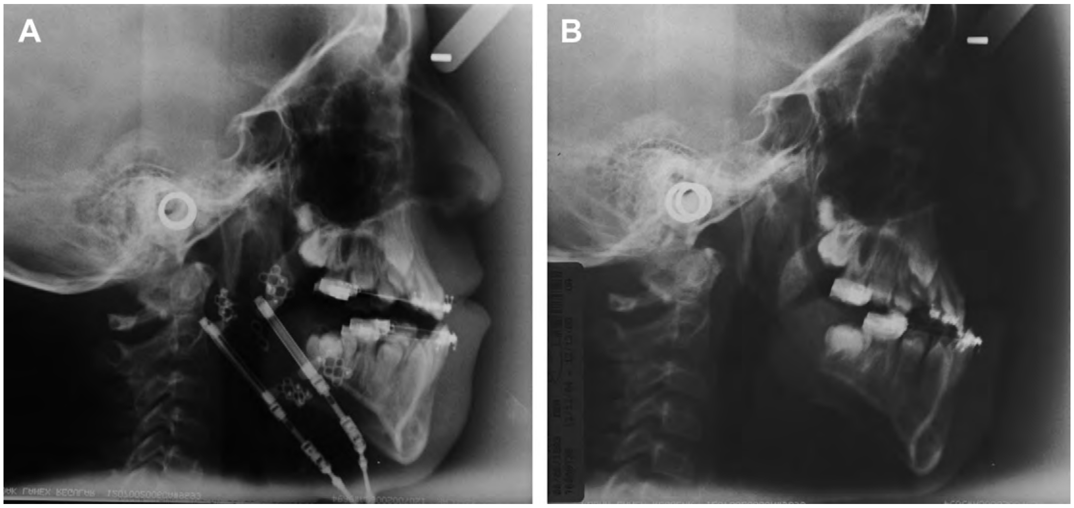

Fig. 15. (*A, B*) At the end of distraction, the mandible is overcorrected, lateral cephalometric films with distractors in place and after consolidation.

In Fig. 20, note facial symmetry, balance, and harmony. The mandible has been distracted to standard limits; some patients require 25 or even 35 mm of advancement according to the age of ankylosis onset and the moment when the child is treated surgically. Routine radiographs are taken to control the amount of activation needed to position the bony fragments properly and then wait for bone mineralization. The soft tissues are quite symmetric; however, it required an overcorrection of 15% to 20% in the bone movements. The consolidation period for this patient was 12 months at the age of 6 years.

The right TMJ fusion produced a marked three-dimensional deficiency in terms of bone and soft tissues (Fig. 21). To achieve the ultimate result, the mandible was distracted vertically and anteroposteriorly in the affected side with overcorrection, (related to the amount of distraction movement). The TMJ ankylosis was released a year later using a gap arthroplasty. Physiotherapy is indicated until normal range of motion and symmetric opening are obtained, to continue normal growth in the long-term follow-up.

The dental malocclusion is very typical, with severe class II unilaterally or bilaterally, marked crowding, inadequate axial inclinations of the teeth toward the affected side, constricted

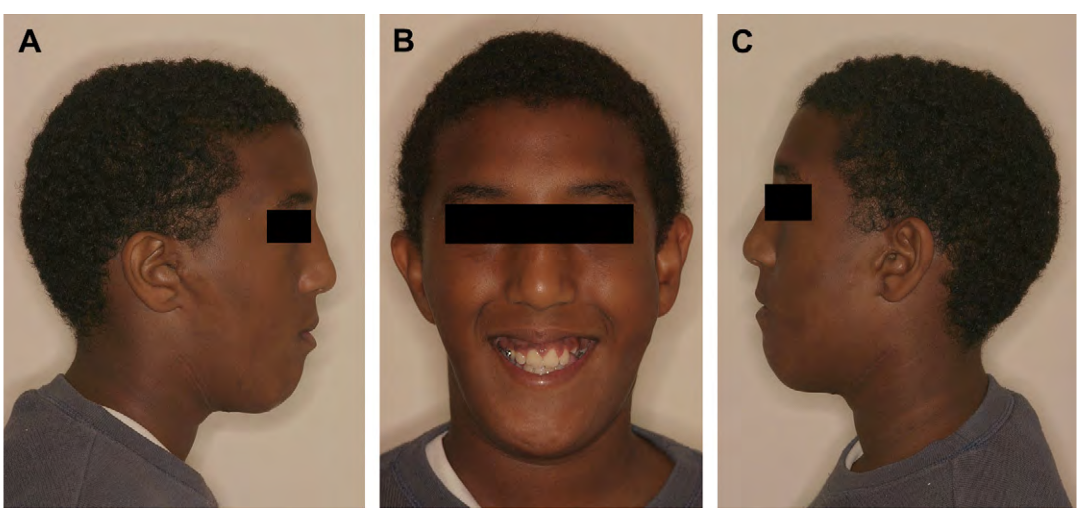

Fig. 16. (*A–C*) Frontal and right and left profiles following distraction at the age of 13, no airway obstruction.

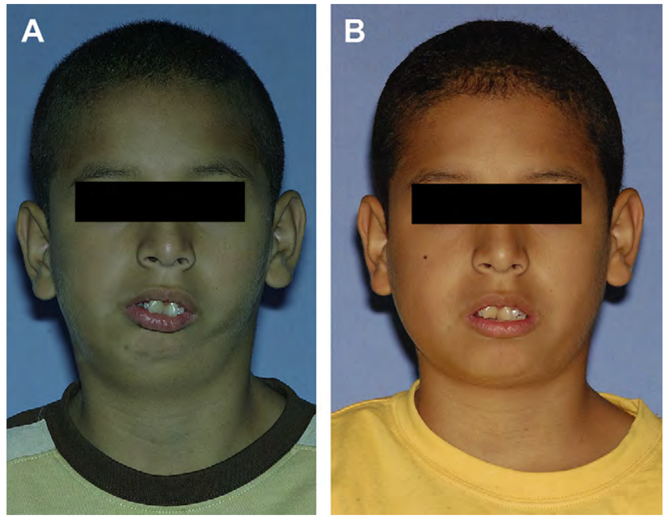

Fig. 17. (*A*) Frontal view of patient with severe ankylosis and mandibular deficiency. (*B*) Six months after treatment by mandibular distraction osteogenesis.

maxillary and mandibular arches, carious and periodontally involved teeth, and limited range of motion (Fig. 22). With the activation of the distraction appliances, the skeleton slowly and progressively shows symmetry, projection, and harmony; however, a normal dental occlusion may not accompany the facial improvements (Fig. 23). The clinical situation requires orthodontics to restore proper occlusion and some patients require a secondary orthognathic surgery. A protocol of physiotherapy is needed to obtain a full range of motion and symmetric opening (Fig. 24).

Following advancement of the mandible, the anatomic key points are marked (Fig. 25). A Risdon approach is used to visualize the entire right mandibular ramus. Channel retractors are placed anterior and posteriorly, just above the lingula, and a horizontal mandibular osteotomy is created through and through. Careful completion of the osteotomy through the lingual cortex is crucial to avoid damage to the inferior alveolar and the masseteric arteries. Maintaining the periosteal layer is important to maintain good blood supply, less scar tissue formation, and less hematoma formation. The Risdon incision permits adequate visualization of the entire mandibular ramus and maintains the integrity of mandibular branch of cranial nerve VII. The masseter muscle is elevated subperiosteally avoiding perforations or damage, which compromise

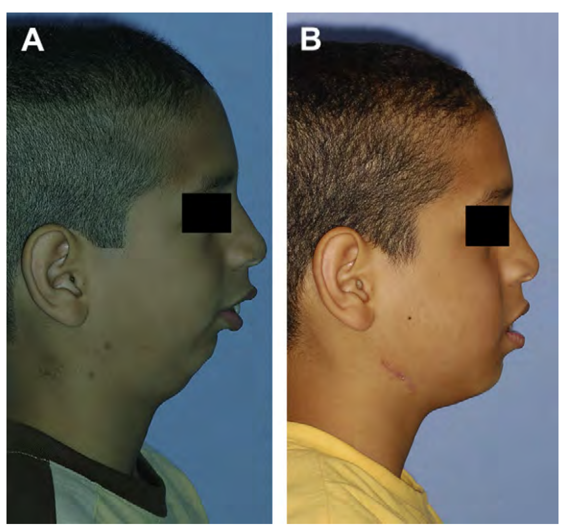

Fig. 18. (*A*) Preoperative profile view of same patient. (*B*) Six months after distraction.

Fig. 19. (*A*) Frontal view with the right ramus and body lengthened. (*B*) Six months postoperative after mandibular body and ramus lengthening.

its ability to repair because of fibrosis and scar tissues. The osteotomy and distraction appliance placement are performed through tunnels, using a 703 bur. The soft tissues are carefully protected and once the internal cortex seems transparent, a bigger chisel is used to separate both bone fragments until the mandible moves freely. At this point, the anesthesiologist may perform a laryngoscopy and intubate the patient orally, change endotracheal tubes, or go from a laryngeal mask to a naso-endo-tracheal intubation (Fig. 26). With the mandibular ramus distraction appliance in place, an externally attached rod allows the postoperative activation (Fig. 27). Ten or 12 mm $\times$ 2 mm screws are used to fix the distractor, with a minimum of two screws in the superior segment and two or three screws in the inferior. The activation of the device is checked and then closed leaving 2-mm space between the two bony segments. The distraction vector is identified before the last two screws are fixed to warrant correct distraction appliance placement. The wound is closed in layers after thorough irrigation and Steri-strips are placed over the incision.

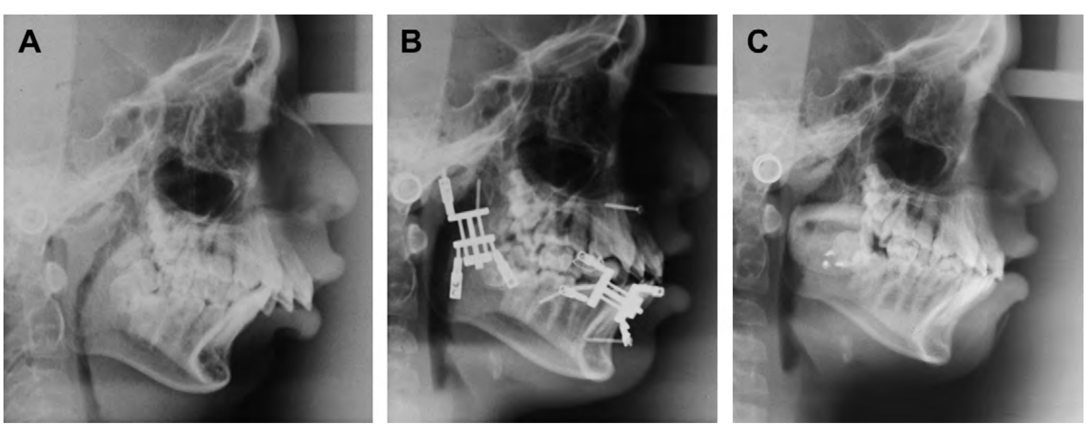

Fig. 20. (*A*) Original preoperative radiograph. (*B*) The right mandibular ramus has been lengthened vertically and the mandibular body has been distracted anteroposteriorly simultaneously intraorally. (*C*) Postoperative radiograph after consolidation and arthroplasty.

Fig. 21. (*A*) The submental vertex view shows the three-dimensional deformity. (*B*) Submental vertex view after six months of intraoral mandibular distraction.

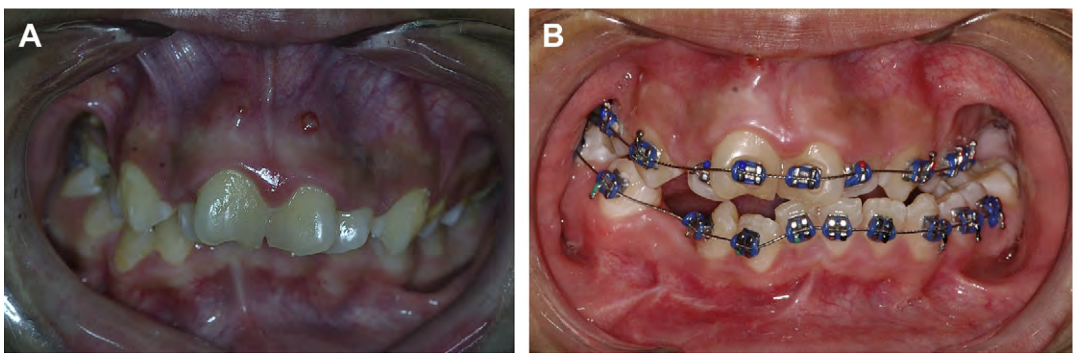

Fig. 22. (*A*) Preoperative occlusion before distraction. (*B*) Seven months after intraoral right mandibular body and ramus.

Anterior body distraction

The patient is positioned for intraoral access and local anesthetic is injected for the mandibular body surgery. A horizontal incision is made in the vestibule to expose the mandibular parasymphysis. The dissection is performed carefully to ensure that the mental nerve remains intact. The osteotomy is performed using a reciprocating saw, from the inferior

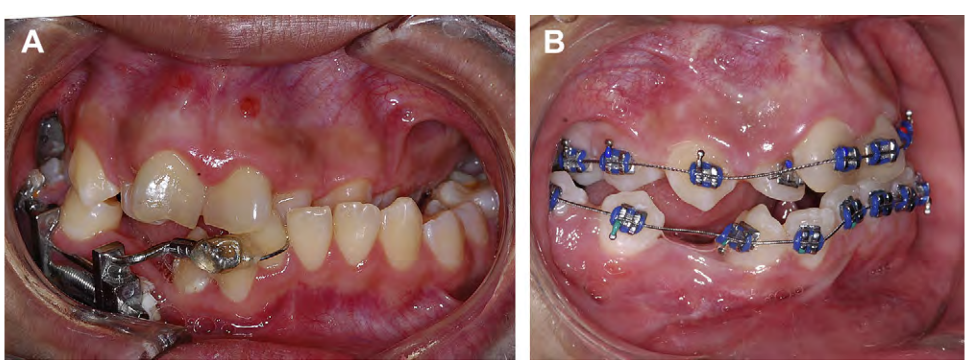

Fig. 23. (*A*) Change in occlusion following the activation of the distractors. (*B*) Seven months after intraoral distraction.

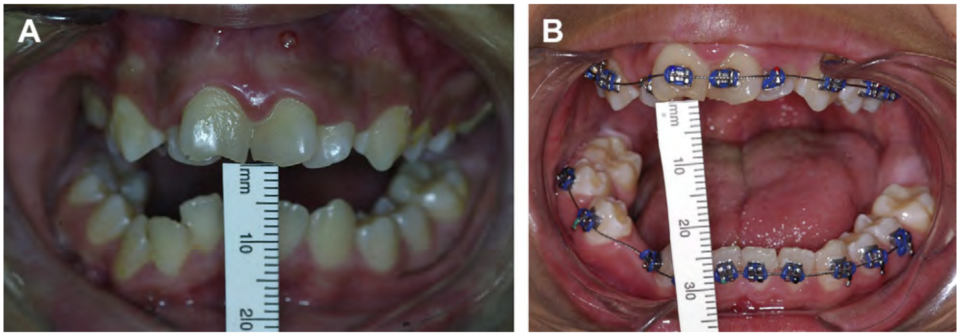

Fig. 24. (*A*) Preoperative opening. (*B*) Postoperative opening one month after gap arthroplasty.

Fig. 25. Anatomic marking of the area before surgery.

border coming up to the level of the dental roots. A tunnel is created to continue the osteotomy, continuing superiorly to the crestal bone, using a 701 bur, just in the outer cortex, not to damage the roots of the teeth. A spatula osteotome is used to complete the interdental osteotomy, and finally a bigger chisel is placed at the inferior border with a torque movement, to complete the bone separation (Fig. 28). The wound is closed in layers to avoid saliva and food contamination into the distraction chamber. The distraction appliance is placed transmucosally. The distraction device arms can be adapted to insert the bicortical screws underneath the nerve level.

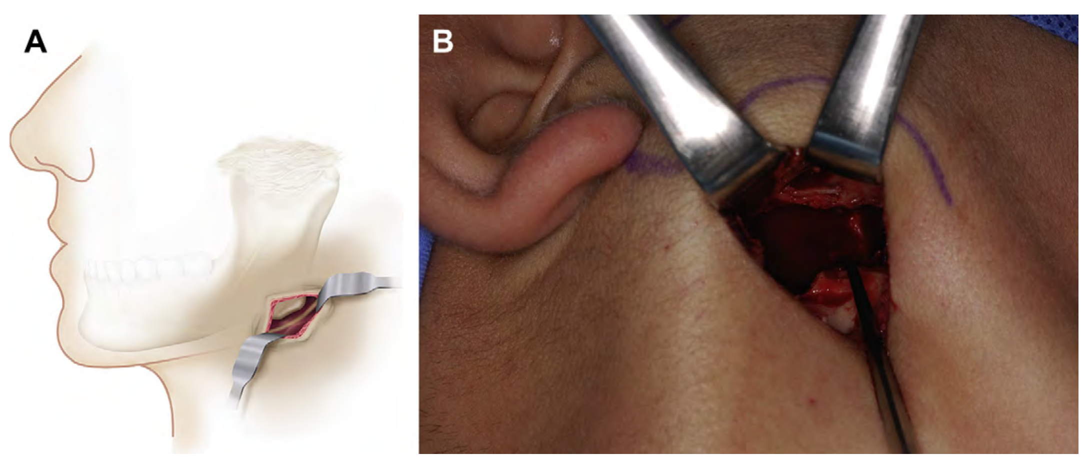

Fig. 26. (*A, B*) Dissection with placement of the distractors. The left side, dissection on the right. Submandibular approach for placement of the distractor on the ramus, and intraoral approach for the mandibular appliance.

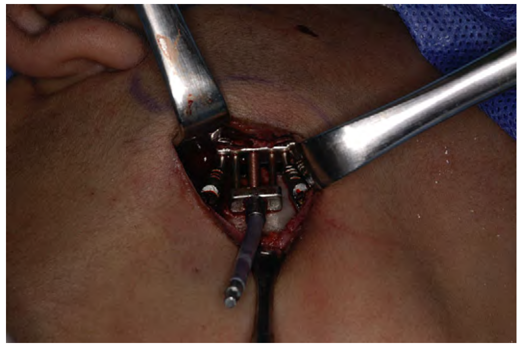

Fig. 27. Distractor in place for the ramus lengthening.

One or two screws are placed anterior and posterior to the osteotomy site. If there is no space to insert any screws at the level of the teeth without damaging them, heavy wires combined with acrylic are used to fix the distractor strongly, to permit postoperative stability during activation and consolidation. With distraction, there is development of new tissues (Fig. 29). The teeth move into the distracted region secondary to the periodontal transseptal fiber traction. The posterior mandibular fragment cannot travel back secondary to the reciprocal forces exerted by the device, because there is a TMJ ankylosis; the movement is only anteriorly. The distraction appliances are meticulously placed according to the preoperative planning. Distraction devices are selected, bent, and arranged based on the three-dimensional deficiency before the surgery. The distraction vector is carefully calculated, based on the normal side morphology and growth pattern (Fig. 30). The amount of distraction is obtained adding the deficiency measurement plus 15% to 20% overcorrection. The wounds are sutured leaving an external rod available for activation (Fig. 31). The patient is maintained on a liquid diet for 2 weeks and progresses to soft diet in the following 3 weeks. The consolidation period is followed by remodeling. The final result depends on the amount of movement, the quality and quantity of bone, and the age of the

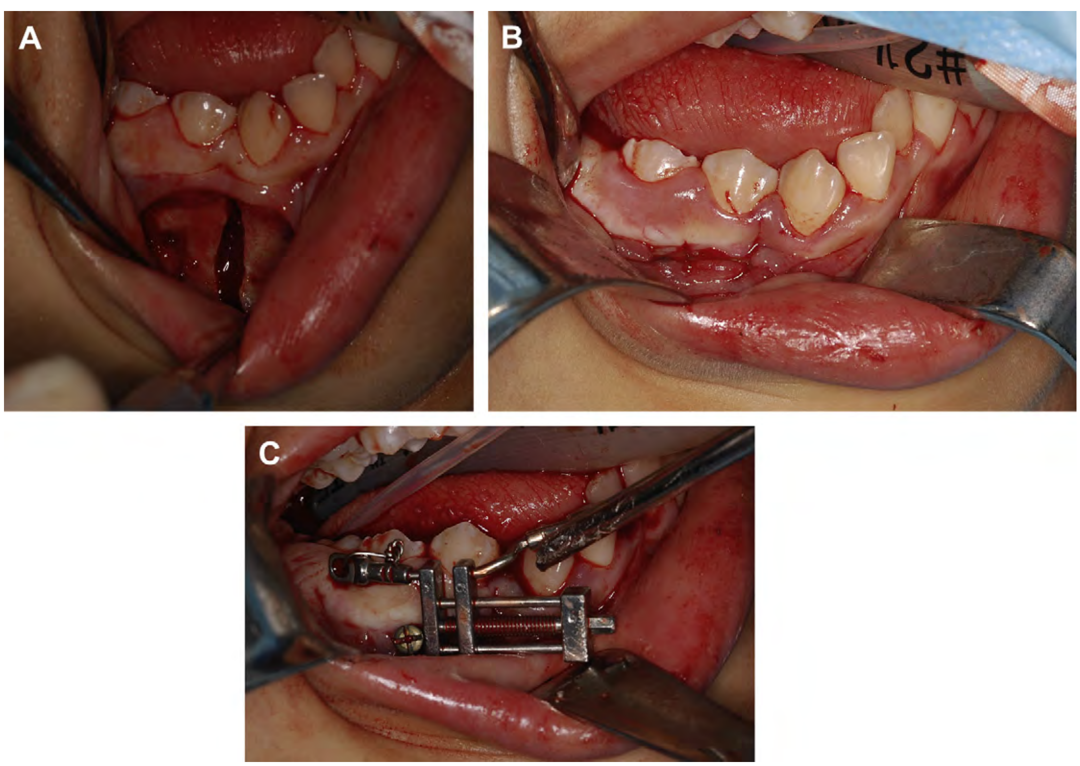

Fig. 28. (*A–C*) Intraoral dissection, and placement of distractor for the body distraction.

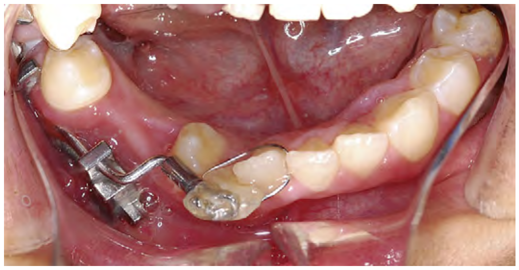

Fig. 29. Newly created bone and soft tissue after distraction.

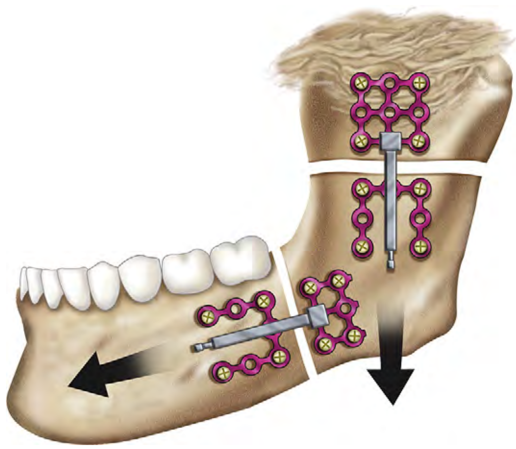

Fig. 30. Illustration of the placement of the distractors.

patient (Fig. 32). Carefully following the surgical protocol enables the patient to develop a normal mandibular shape, ideal bone and soft tissues, and good mandibular function.

Even in a severe mandibular ankylosis secondary to infection, there is marked growth asymmetry secondary to the delay in surgical treatment (Fig. 33). Two distractors were used, one in the mandibular ramus for vertical lengthening and a second on the mandibular body

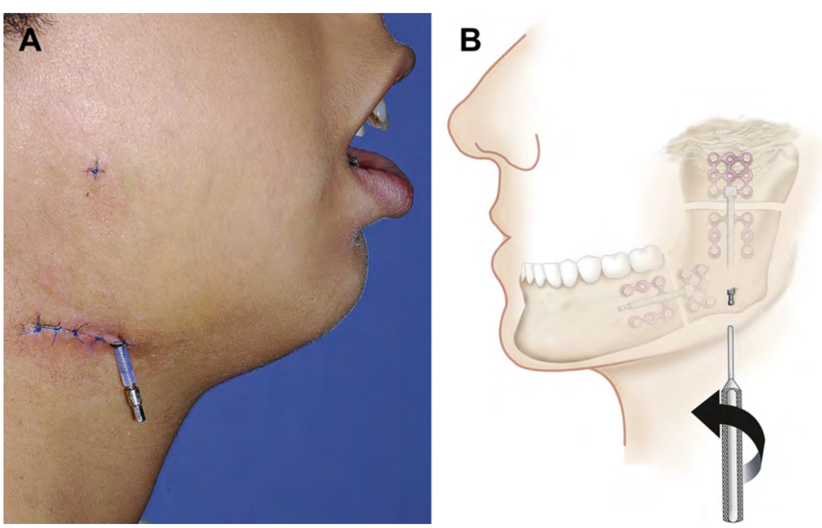

Fig. 31. (*A, B*) Closure of wound with external port visible for activation.

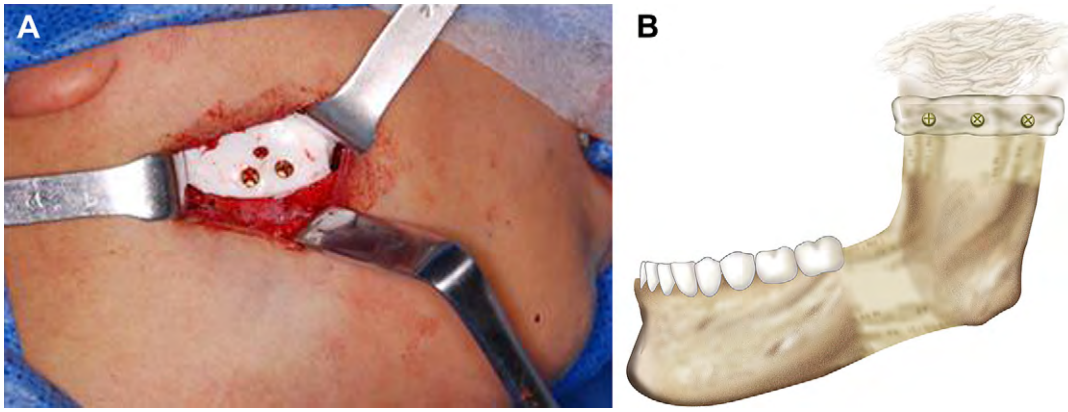

Fig. 32. (*A*) Gap arthroplasty. (*B*) Illustration of distracted bone of the ramus and the body.

for anteroposterior lengthening. The teeth are carefully avoided during the osteotomy and the insertion of screws (Fig. 34). TMJ ankylosis in the growing patient results in a severe vertical discrepancy on the affected side compared with the normal side with a marked skeletal class II malocclusion, augmented overjet, and excessively inclined lower incisors. The planning was based on the lack of vertical and anteroposterior mandibular growth. This system allows the clinician slowly and progressively to obtain an ideal symmetry and can be adapted over the 3 or 4 weeks after surgery, without the need of bone or soft tissue grafts. If there was error in

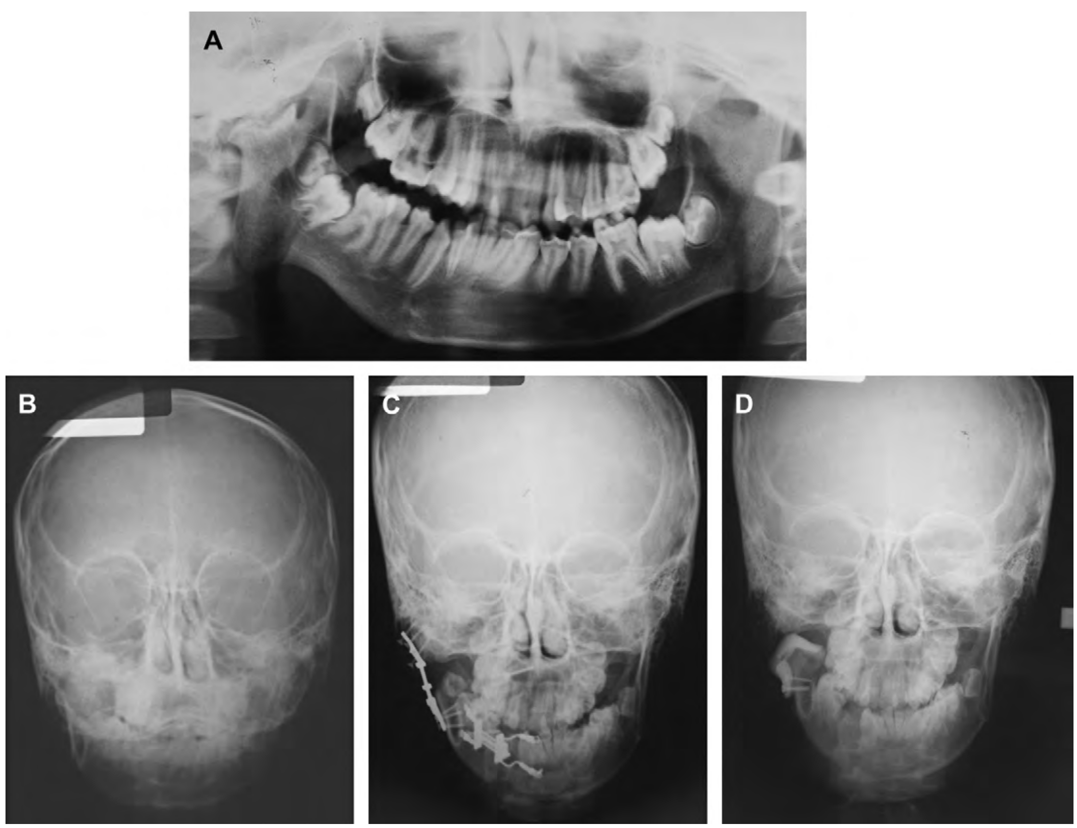

Fig. 33. (*A, B*) Radiographs illustrating the growth deficiency, panorex, and posteroanterior cedphalogram. (*C*) During distraction. (*D*) After consolidation and arthroplasty.

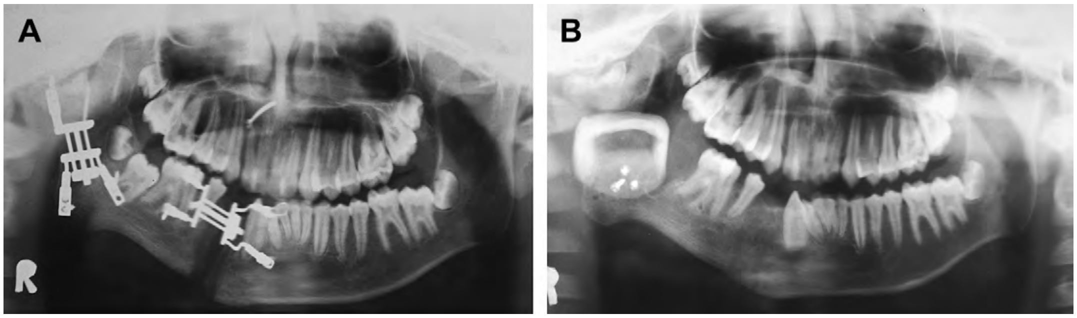

Fig. 34. (*A, B*) Radiographs illustrating the results of distraction, consolidation, and arthroplasty.

the planning of vector found in the postoperative radiographs, the appliance may be relocated by removal of some screws under intravenous sedation.

The goals of treatment in a case like this are to obtain normal range of motion and facial harmony and balance. When performing TMJ arthroplasty, several millimeters are removed to create a gap arthroplasty or to place interpositional muscle. Both of these techniques ensure a ramus shortening. The ideal scenario is to perform the TMJ ankylosed surgery in a vertically augmented ramus. The appliances are activated until ideal symmetry is obtained, then careful evaluation on age, amount of movement, and quality and quantity of soft and hard tissues variables dictate the need for overcorrection, understanding that the gap arthroplasty requires the removal of 3 to 4 mm for interpositional material.

Mandibular lengthening by distraction osteogenesis in a patient with unstable joints

A 26-year-old woman presented with arthritis of her TMJ, severe pain, and a constant change of her occlusion. The surgical plan included mandibular lengthening by intraoral distraction osteogenesis bilaterally and a maxillary Le Fort I osteotomy. The mandible was approached through a 2.5-cm vestibular incision. With minimal stripping of tissue, the inferior border of the mandible was reached where an inferior border separator was placed. A reciprocating saw is used from the inferior border going occlusally for around 5 mm, depending on the position of inferior alveolar nerve. A periosteal elevator is used to protect the lingual flap avoiding injury to the lingual nerve. A reciprocating saw is used to section the bone from the superior aspect to within a few millimeters of the inferior alveolar nerve. At this point the mandible remains intact and the wound is partially closed to allow a final sectioning after the distraction appliances have been secured with transmucosal screws.

The distractor devices were placed transmucosally after completing the osteotomies. Care was taken to ensure that they were parallel along the vector of advancement. The ideal vector was determined from the surgical tracing and dental models mounted on an articulator. The devices are fixed in three of the fixation points with multiple bicortical screws with additional support to the superoanterior aspect with a 0.024-in gauge stainless steel wire secured to an adjacent tooth for rigidity. This wire can be removed and replaced to more anterior tooth if counterclock rotation of the distal segment is desired, permitting closure of an open bite development as was done in this case.

The protocol used varies according to quality and quantity of bone, age of the patient, and amount of movement. It is based on a complete osteotomy on the day of the surgery, a latency period of 7 days, 1-mm activation a day, ideally 0.25 mm every 12 hours. Once the activation is completed, the final mandibular position is secured by placing acrylic over the distraction appliance giving extra rigidity to the distractor. The patient is kept on a soft diet. The activation

Fig. 35. (*A, B*) Frontal and profile view of patient on initial presentation. (*C, D*) Frontal and profile following distraction. (*E, F*) Preoperative occlusion. (*G, H*) Panorex preoperative and with placement of the distractors. (*I, J*) Preoperative and postoperative lateral cephalograms. (*K, L*) Distractors before placement and then in place. (*M, N*) Diagrams showing the distractors in place and the desired advancement. (*O, P*) Postoperative occlusion.

is performed and carefully explained and practiced by the patient to avoid being activated the wrong way. As the distractors are activated, reciprocal forces are exerted in both ways; the anteroposterior or vertical forces against the TMJs can be detrimental. To avoid this, class II elastics with 8 oz of force are applied bilaterally, as soon as activation is initiated. Orthodontics appliances are recommended, but arch bars securely applied over the existing dentition also can be used, including second molars. Bone screws or maxilla-mandibular screws are not used. By having control of the occlusion it is believed that damage to the TMJ can be avoided. Routine multiple radiographs as used in orthognathic surgery are indicated just after surgery, then repeated again at 2 and 3 months until the distraction chamber (bone space separation after distraction) radiopacity appears. The last region to mineralize is the fibrous inter-zone and the time required for this to occur varies from patient to patient.

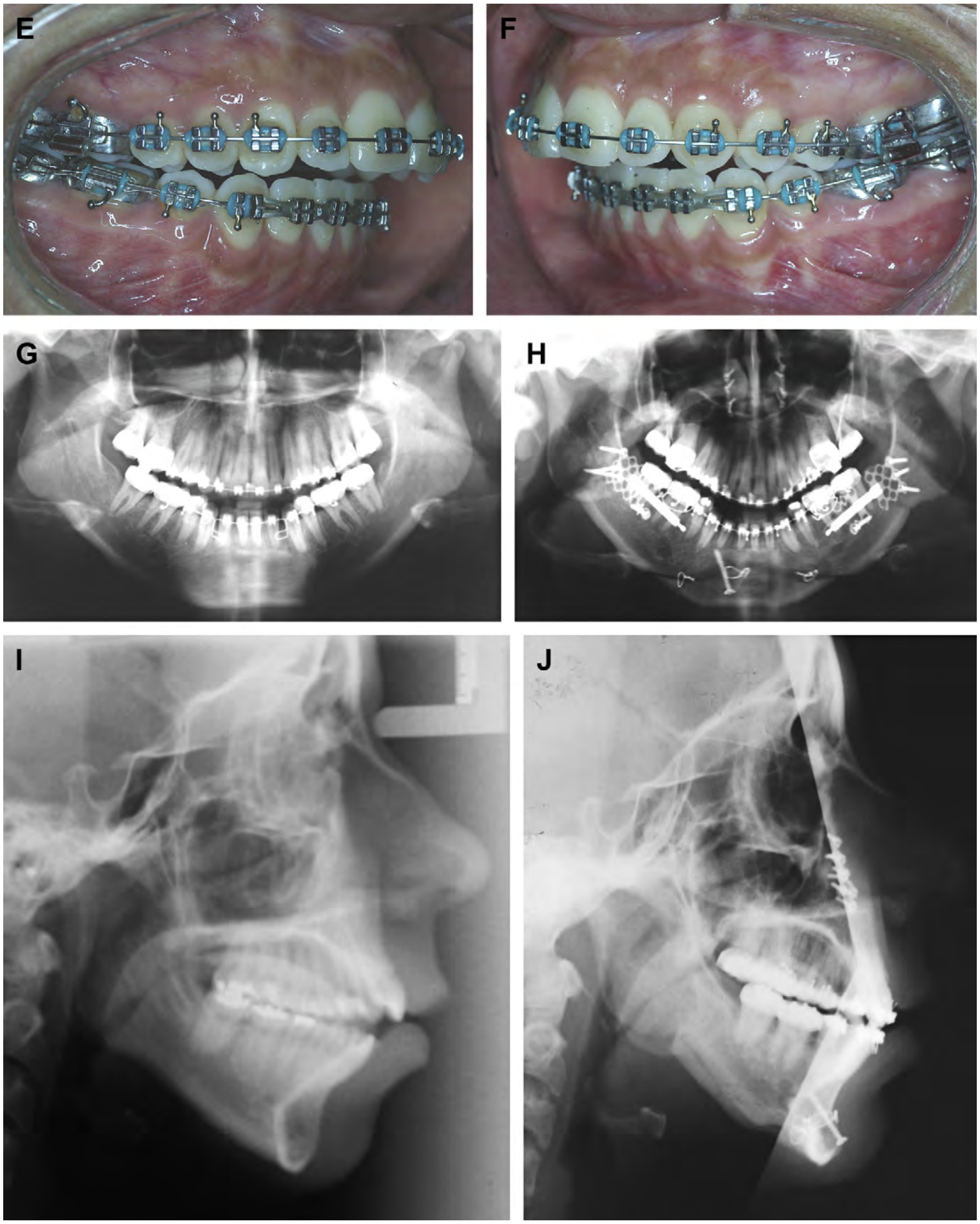

Fig. 35 (*continued*)

The appliances are not removed until complete stability is obtained. Appliances removed before the consolidation occurs causes anterior rotation of the proximal fragment, nonunions, loss of the mandibular angle, and occlusal changes. The miniaturized intraoral distracters do not limit the patient's life in any sense (work, school, or socially). The appliances are removed once proper bone mineralization is seen, which may take 3 to 5 months. Once the distraction devices are removed, the patient is referred to the orthodontist to continue treatment. Orthodontics surgical arches are removed and new lighter ones replaced. The orthodontist maintains the class II elastics if the patient complains of TMJ symptoms. The class II elastics forces are progressively eliminated. Fig. 35 shows the before and after clinical, radiographic, and surgical photographs.

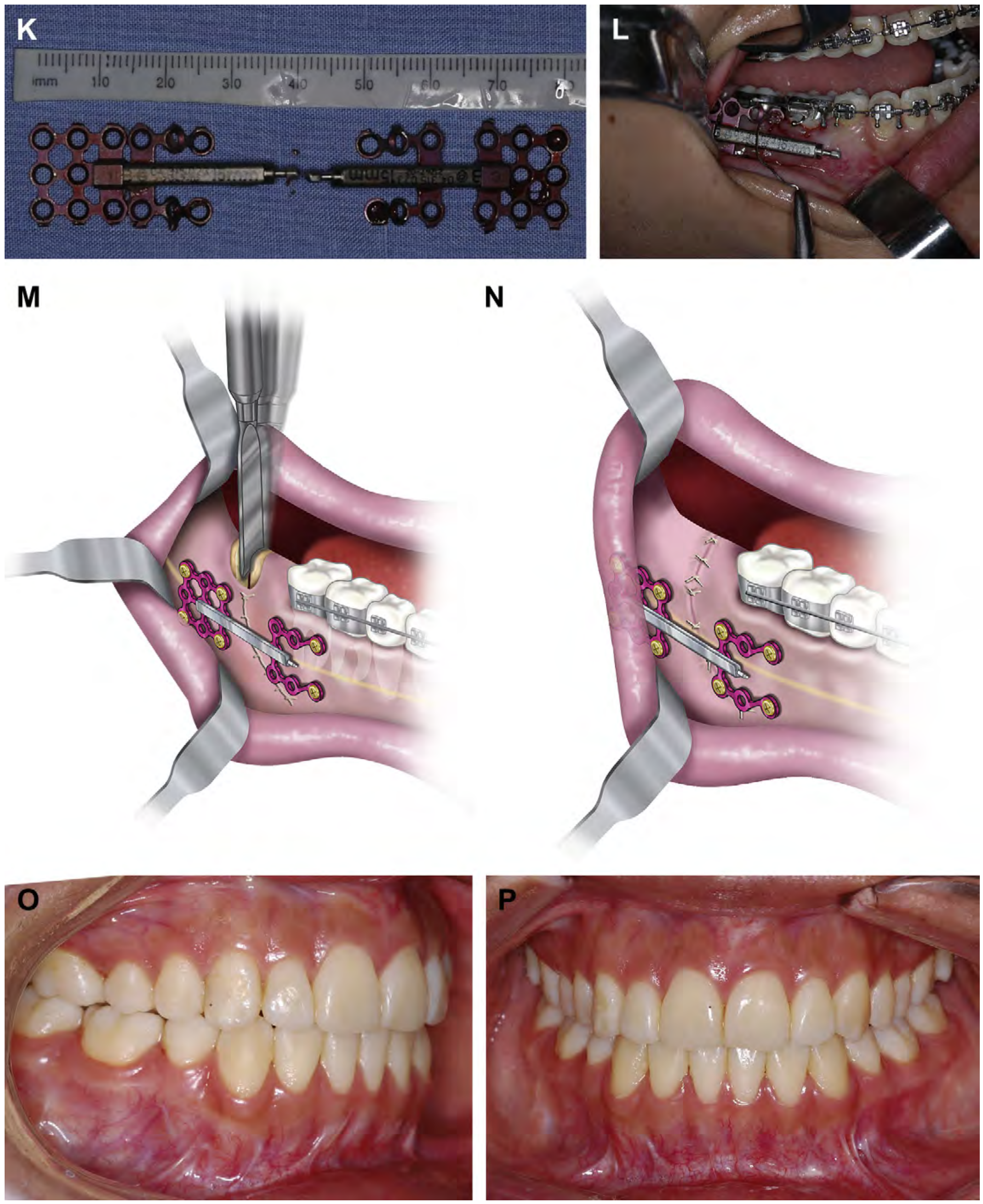

Fig. 35 (*continued*)

Summary

The technique addresses the vertical increment of facial height and anteroposterior body lengthening of the mandible by distraction followed by release of an ankylosis. Although the esthetic results are satisfactory, all of the patients in the ankylosis group were in an active growth period during both procedures. The vertical and anteroposterior dimension gained after distraction osteogenesis to lengthen the ramus and the body was predictably stable using the ankylosis to prevent undesirable positional changes or relapse by bony resorption. The current thinking of the three theories of mandibular growth is that the condylar cartilage does have some measure of intrinsic genetic programming but restricted to a capacity for continued cellular proliferation, meaning that cartilage cells are coded and geared to divide and continue to divide but extracondylar factors are needed to sustain this activity. In all of the cases, the lack of mandibular condyle and physiologic muscle function caused by the ankylosis in a growing phase compromised the three-dimensional growth of the affected side. After the functional matrix establishes its new equilibrium, secondary procedures, such as genioplasty, may be considered to correct the remaining bony and soft tissue deficiencies. The longer the patient with TMJ ankylosis waits to seek surgical treatment, the more complicated the three-dimensional deficiencies become, requiring an elaborated orthodontic-surgical plan.

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Maxillary Advancement by Distraction Osteogenesis

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Distraction osteogenesis (DO) is a surgical technique for reconstruction of bony deformities. It involves making osteotomies in the bone and gradually displacing the two bony segments apart. This results in new bone formation that fills the gap and stretches the overlying soft tissue envelope. DO was first used in orthopedics to lengthen long bones. The technique was not well understood until Ilizarov, a Russian orthopedic surgeon, laid down its foundation in 1952 through his work in rural Siberia. Distraction of the maxilla was first performed in monkeys in 1965 by expanding the midpalatal suture. The first application of DO in the craniofacial region was a mandible distraction reported by McCarthy and colleagues in 1992. Since then, application of DO to the craniofacial skeleton has increased exponentially. Traditionally, maxillary hypoplasia has been treated by Le Fort I osteotomy but today DO at the Le Fort I level has become the workhorse for managing maxillary retrusion in difficult cases because of soft tissue limitations and large advancements.

Indications for maxillary distraction osteogenesis

There are a variety of indications for maxillary distraction. The majority of cases are patients who have craniofacial deformities. Those who have maxillary deficiency include patients who have Apert's, Crouzon's, or Pfeiffer's syndrome and maxillary cleft lip and palate, to name a few. DO can improve their facial esthetics and in those who have airway issues resolve them by increasing the size of the airway. Patients who have facial clefts usually have severe maxillary hypoplasia. Although they may undergo a traditional Le Fort I osteotomy with bone grafting, there is a variable amount of relapse as a result of palatal scarring and soft tissue resistance. Obstructive sleep apnea commonly is seen in many of the children who have craniofacial syndromes. They and select adults who have deficiency in their upper airway dimension can benefit from DO. Patients who have hemifacial microsomia are the second most common congenital craniofacial malformation after cleft lip and palate. They may need a combination of maxillomandibular distraction. Deficient maxillary alveolar ridge secondary to traumatic avulsion of teeth and their accompany bone segments can be treated by distraction as can patients who have facial deformities secondary to incompletely managed complex midfacial fractures.

Contraindications for maxillary distraction osteogenesis

The only true contraindication is a noncompliant patient. As long as there is adequate bone for placement of the distraction device, there is no contraindication. Younger patients are a relative contraindication due to their bone being quantitatively and qualitatively insufficient for the device placement.

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Advantages of maxillary distraction osteogenesis

The underlying physiology of DO is that bone grows when stretched. This new bone formation is a result of membranous ossification. There are three phases of DO: latency, activation, and consolidation. DO also causes a gradual increase of the soft tissue volume because of stretch forces applied with bony distraction, termed *distraction histiogenesis*. (See Chapter one for a more in-depth discussion of DO and histiogenesis.) Increase in the soft tissue through distraction histiogenesis is believed an advantage of DO over traditional midface advancement techniques. Traditional midface advancement osteotomies cause immediate bony correction but do not allow for gradual compensatory soft tissue changes. As a result, scarring and memory in the soft tissue occur in the preoperative period. These negative soft tissue forces on the advanced bone segments are the main reason for relapse after traditional midface advancement surgeries. From a stability point, a traditional Le Fort I osteotomy is limited as to how much advancement can be achieved. Many surgeons consider 10 to 15 mm to be the maximum advancement attainable. Relapse of a Le Fort I osteotomy in the range of 4% to 40% has been reported by several investigators. In contrast, the more gradual stretching of the soft tissue seen with distraction is believed to prevent bone relapse. This is important especially when large advancements are needed, such as in the many individuals who have midface hypoplasia caused by cleft lip and palate. In many instances, the class III skeletal relation is so severe a compromise is chosen where the maxilla is advanced and the mandible is set back. With DO, the amount of advancement is unlimited obviating a bilateral sagittal split osteotomy setback (Fig. 1). With large maxillary advancements, a bone graft harvested from a secondary site is used to increase stability. With distraction, however, the need for a bone graft is eliminated. DO at the Le Fort I level can be performed as a same-day procedure especially when using an external distractor. It also eliminates the need for blood transfusion or permanent hardware.

In summary, there are five significant advantages to DO: large advancements; low relapse rates resulting from simultaneous soft tissue expansion; decreased operative time and, hence, morbidity; the ability to vary the height of the osteotomy when internal bone devices, such as bone plates, are not needed; and decreased incidence of velopharyngeal insufficiency in cleft patients.

Fig. 1. Maxillary advancement and proportions obtained by distraction.

Disadvantages of distraction osteogenesis

There are several disadvantages of DO when used to correct skeletal discrepancies. It is technically demanding and imprecise compared with orthognathic surgery. Its imprecise nature is primarily a problem of vector control. When orthognathic surgery is executed, segments of bones and their accompanying soft tissue are precisely translated in space as dictated by model surgery and splints. With distraction, segments are moved more slowly but are influenced by the attached tissues (secondary vectors) during the movement. Additionally, even when distractors are prebent on stereolithographic models, application of them in an operating room is less precise than with model surgery. Significant patient compliance is required and many office visits are necessary, which increases overall treatment time. Finally, the procedure is more expensive as a result of the cost of the individual distractors.

Vectors for maxillary distraction osteogenesis

There are primarily three vectors: anterior-posterior—severe class III skeletal malocclusion due to maxillary hypoplasia, as in cleft patients and majority of dentofacial deformities; vertical—anterior open bite cases mainly in combination with the anteroposterior deficiency seen in syndromic patients; and horizontal or transverse discrepancy with narrow maxilla leading to V-shaped palate and teeth crowding. Finally, there may be a combination of all of the deficiencies. The same distraction devices can be used to achieve maxillary advancement and vertical height, whereas transverse widening of the maxilla is achieved by a separate device applied to the palate. Currently, there are no devices to achieve correction of a skeletal problem in all three dimensions.

Types of distractors

There are two types of distractors based on anchorage for the anteroposterior and vertical advancement of maxilla: internal and external devices. (See the article by Van Sickels and Reddy elsewhere in this issue for a more in-depth discussion of the types of distractors.)

Internal distractors

Internal distractors are submerged under the soft tissue with a small rod for distraction protruding through the oral cavity or through the skin (Fig. 2). The device is placed with anchoring plates on either side of the osteotomy. They are best used for larger bones and require a second-stage surgery for their removal. There also are modular types of devices, which are custom made. The advantages of internal distractors are better patient acceptance, direct adaptation to bone reducing the distance from the callus to the activating axial screw, and better wound management.

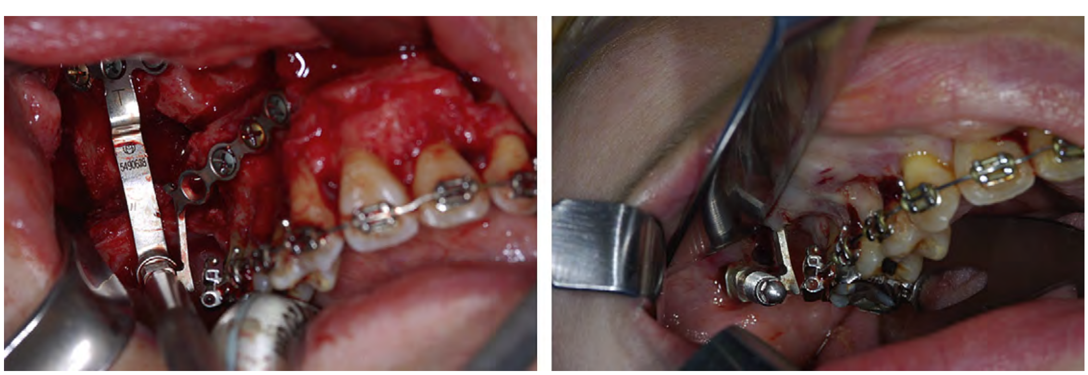

Fig. 2. Internal maxillary distractor.

The disadvantages of internal distractors are a need for second-stage surgery for removal, therefore increased morbidity. Once placed, there is an inability to change the primary vector of distraction and it is difficult to achieve parallelism between the distractors and the occlusal plane because of the need to bring the tram/lever arm through the opening of the oral cavity.

External distractors

These are located outside the oral cavity and held through the skin with transcutaneous pins. They are anchored to the skull and attach to a tooth or bone appliance with wires. They often are removed in an office under local anesthesia saving patients a second general anesthetic and surgical dissection to remove them. The halo external distractor was described first by Polley and Figueroa in 1997 (Fig. 3).

Its advantages are that the primary vector can be changed during distraction, allowing correction of a skeletal deformity in several dimensions. Additionally, osteotomy cuts can be made as high as possible as minimal internal fixation is required. A more apical osteotomy has the advantage of avoiding the roots of teeth with internal appliances and provides concomitant midface advancement. Because of the external attachment, there is less operative time fixing the framework to the maxilla and when it is necessary to remove it, it can be done in the office under local anesthesia.

The disadvantages are several and include psychologic stress on patients and special care needed to prevent traumatic injury while wearing the equipment. External devices rely on intraosseous pins to transmit the force. The longer the distance from the axial screw of the distractor to the callus, the less effective the distraction. Several require adequate dentition (primary or secondary) for fixation of an intraoral splint.

Technique

Preoperative planning and imaging studies

Patients undergoing distraction require a photographic and radiographic assessment throughout the distraction to assess their progress (Fig. 4). Radiographic studies, such as lateral cephalogram and panorex, are a prerequisite for surgery. Cephalometric analysis is needed pre and post distraction and is helpful in planning the primary vector of distraction (Fig. 5). Quantifying the degree of exorbitism is important especially in syndromic patients. Some surgeons recommend CT scan with 3-D models/stereolithographic models. The 3-D models help

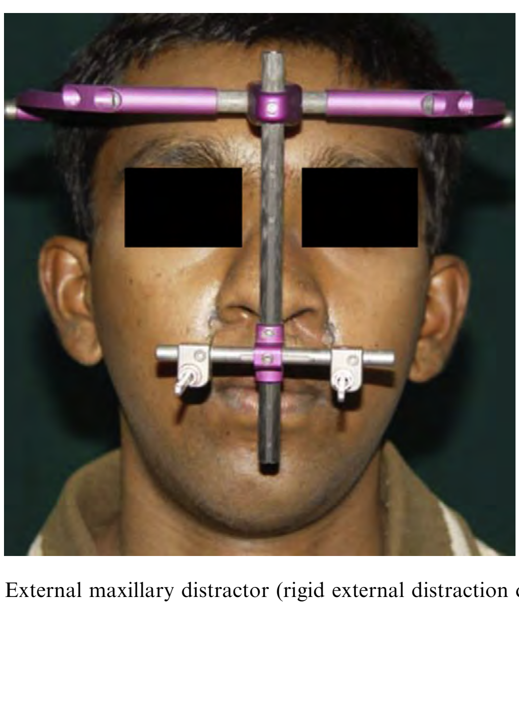

Fig. 3. External maxillary distractor (rigid external distraction device).

Fig. 4. Photographs of patient before (*A, C*) and after (*B, D*) maxillary distraction.

understand the skeletal discrepancy and, hence, the needed vectors to place the devices. Models also facilitate adaptation of the footplates for the internal distraction and cut-down time needed in an operating room to place them. These models are particularly beneficial for novice surgeons.

Surgical technique

General anesthesia is required for the osteotomy and device placement. The maxilla is exposed via a vestibular incision and a subperiosteal dissection is performed. The pyriform rim of maxilla, nasal septum, and the zygomatic buttress and the infraorbital foramen and nerve are appropriately exposed (Fig. 6). The level of Le Fort I osteotomy is dictated by the desired movement of soft tissue and bone, availability of bone stock, and the type of distractors. This is determined preoperatively. For the internal or submerged devices, the distractors are adapted

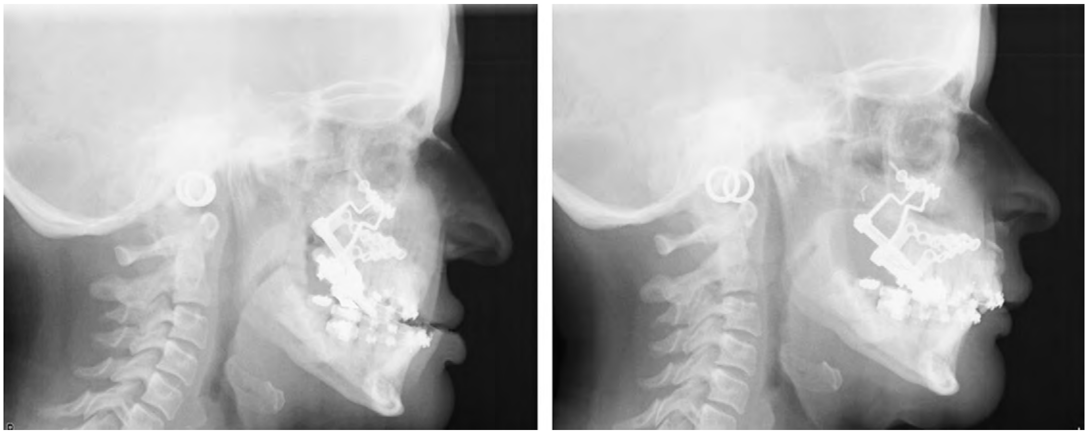

Fig. 5. Cephalograms demonstrating the distance and vector during the maxillary distraction.

to the maxilla at the level of the zygomaticomaxillary buttress before the osteotomies are performed. The bone at the buttress region may need to be contoured in preparation for the device to allow for the best vector alignment (Fig. 7). After adaptation of the distractors, the holes are drilled in the maxilla and the osteotomy level is marked between the upper and lower footplates. The distractors then are removed and the osteotomy performed at the Le Fort I level (Fig. 8). The osteotomy must be below the infraorbital nerve. In patients who have severe exorbitism, a Le Fort III may be necessary. The maxilla is downfractured and mobilized sufficiently. The maxilla should not be mobilized excessively so that it is floating completely. The distractors then are fixated to the bone at the same holes that were drilled before (Fig. 9). The distractors should be parallel to each other in addition to the desired occlusal plane. Some distraction devices come with parallel bars/guides that help in the placement. Activation of the distractors is done by approximately 5 mm and is checked for interferences and vector, then returned to zero position (Fig. 10).

Latency and distraction period

The latency period is the time delayed before the distraction phase. This period varies widely among surgeons, although most recommend approximately 4 to 7 days. In general, younger patients require shorter latency periods. If the latency period is too long, patients may have premature fusion of the bones. Children are especially susceptible to premature fusion because of their higher metabolic rates. A short latency period may predispose to fibrous union of the two distracted bones, inadequate osteogenesis, and decreased callous volume. Early distraction is theorized to disrupt new capillary formation by not allowing the capillaries to mature enough to withstand the distraction forces.

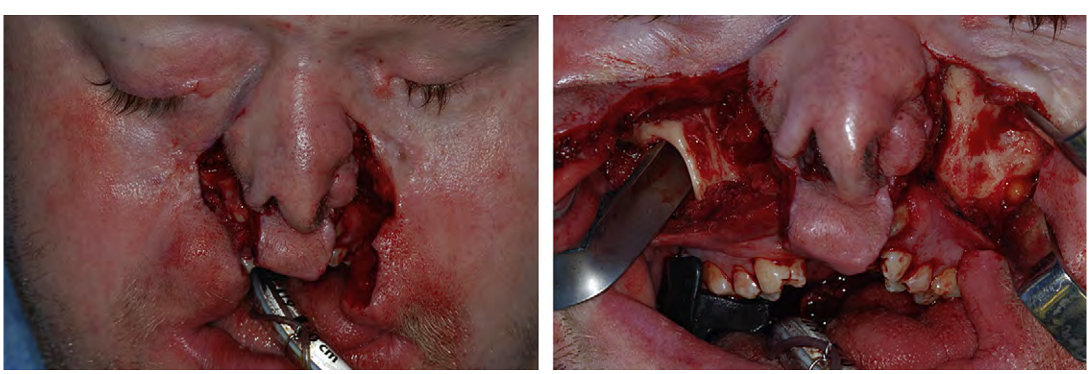

Fig. 6. Maxillary buttress, pyriform rim, and infraorbital nerve are exposed with vestibular incision Note: The craniofacial cleft sites also were used along with the vestibular incision as the clefts were being revised in this patient.

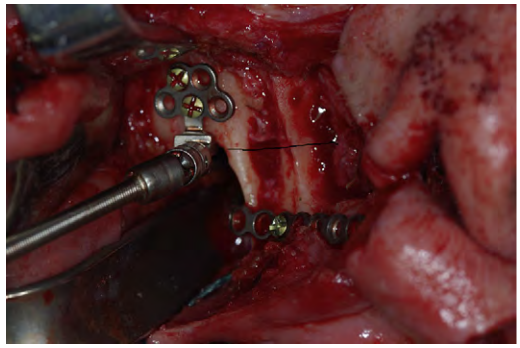

Fig. 7. The maxillary distractors are placed before osteotomy and secured with few screws and the osteotomy site is marked. Note: The zygomatic buttress is contoured to facilitate the placement of the distractor.

Distraction then is begun at a rate of 1 mm per day. Distraction rates that are too aggressive can lead to fibrous union whereas too slow distraction leads to early fusion. Patients are followed at regular intervals to ensure compliance and proper distraction. At the end of the activation phase, the appliance is kept in place for the consolidation phase, which is usually twice as long as the activation.

Consolidation

The consolidation period is the period of bone remodeling. It should be approximately 2 to 3 times the length of the distraction phase. The device remains in place as a fixation device. Consolidation generally takes approximately 10 weeks to develop (Fig. 11). Decreased stability of bone segments may lead to the formation of cartilage then to delayed bony formation or possibly fibrous union (Fig. 12). Maxillomandibular fixation or elastic traction is used if needed for the callous molding and fine occlusal adjustment. A second-stage surgery is needed for removal of the buried devices and if the maxilla is mobile it could be adjusted into occlusion and fixated with traditional titanium plates and screws. A traditional Le Fort I osteotomy with fixation by plates can be performed if needed for the occlusion for fine adjustment of the occlusion.

External distractors require similar steps with minor differences. These systems use an external halo device that is attached to the bone directly by plates or screws, orthodontic devices, or the maxillary splint (Fig. 13). This splint and the orthodontic devices are prepared ahead of time. The halo is placed in the operating room after the osteotomies are performed and surgical site is closed. The halo typically is placed parallel to the Frankfort horizontal plane. The osteotomy cuts can be made as high as possible if needed because no internal fixation is needed (Fig. 14). The custom-made maxillary splint acts as a link between the maxillary skeleton and the distraction apparatus. The splint is cemented to the molar teeth. At the end of the consolidation phase the splint and halo are removed in the office without a second-stage surgery.

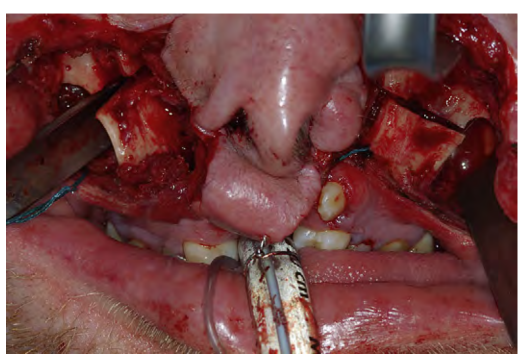

Fig. 8. Maxillary Le Fort I osteotomy.

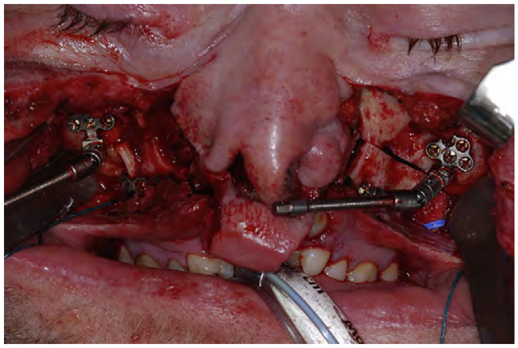

Fig. 9. Bilateral maxillary distractors in place with maxillary osteotomy.

Horizontal maxillary distraction

Horizontal or transverse maxillary widening is needed in cases of narrow maxilla with deep palatal vault and anterior crowding. Maxillary constriction in growing children can be corrected with slow or rapid maxillary expansion devices. In adults, however, nonsurgical expansion results in alveolar bone bending with teeth tipping and periodontal compromise. This is because maxillary widening in adults is resisted by the midpalatal suture, the zygomatic buttress, and the pterygomaxillary junction. Two techniques are used for maxillary widening in adults. These are surgically assisted rapid palatal expansion (SARPE) and segmental multipiece Le Fort I osteotomy. SARPE can be achieved through tooth-borne or bone-borne appliances (Fig. 15). Maxillary expansion can be combined with expansion of the symphysis.

Disadvantages of tooth-borne appliances include orthodontic rather than orthopedic expansion, resulting in tooth tipping and mobility of the teeth. They can compress the periodontal ligament, and buccal root resorption with bone fenestration has been seen. In contrast, bone-borne devices allow orthopedic expansion, better speech, and more room for the tongue as they are placed higher up in the palate.

Traditional SARPE appliances are tooth borne with fixation to the molar teeth. Sari and colleagues describe a bone-borne device called the transpalatal distractor (TPD).

The TPD comprises a splint, which is attached to two abutments, and an expansion module as a single piece. The abutments are placed as high up in the palatal vault as possible. The TPD is secured with transmucosal screws. Another bone-borne distractor, described by Koudstaal and colleagues, is the Rotterdam palatal distractor. Its biggest advantages are that it is small in size and requires no screws for fixation. The surgical technique involves a traditional Le Fort I osteotomy with pterygomaxillary disjunction but not a downfracture. The distraction protocol is the same as described previously.

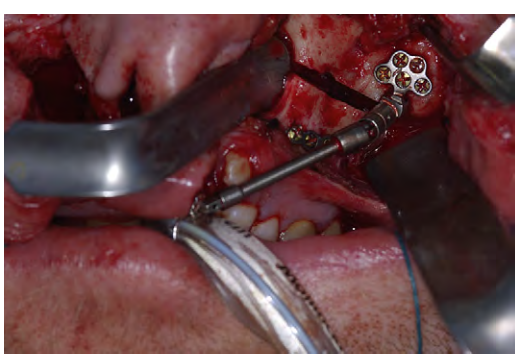

Fig. 10. Verifying the vector and interferences for distraction immediately in the operating room by activation.

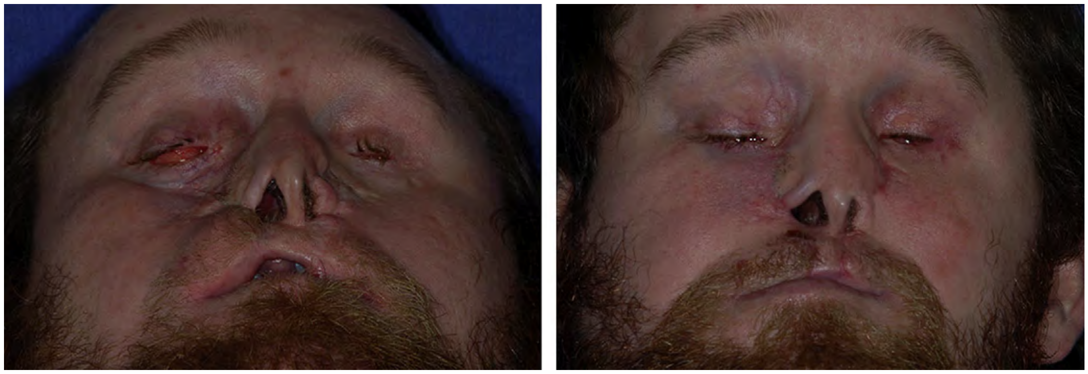

Fig. 11. Pre and post-surgical results of Le Fort I maxillary advancement after consolidation.

Fig. 12. Formation of cartilagenous and fibrous union during consolidation due to mobility.

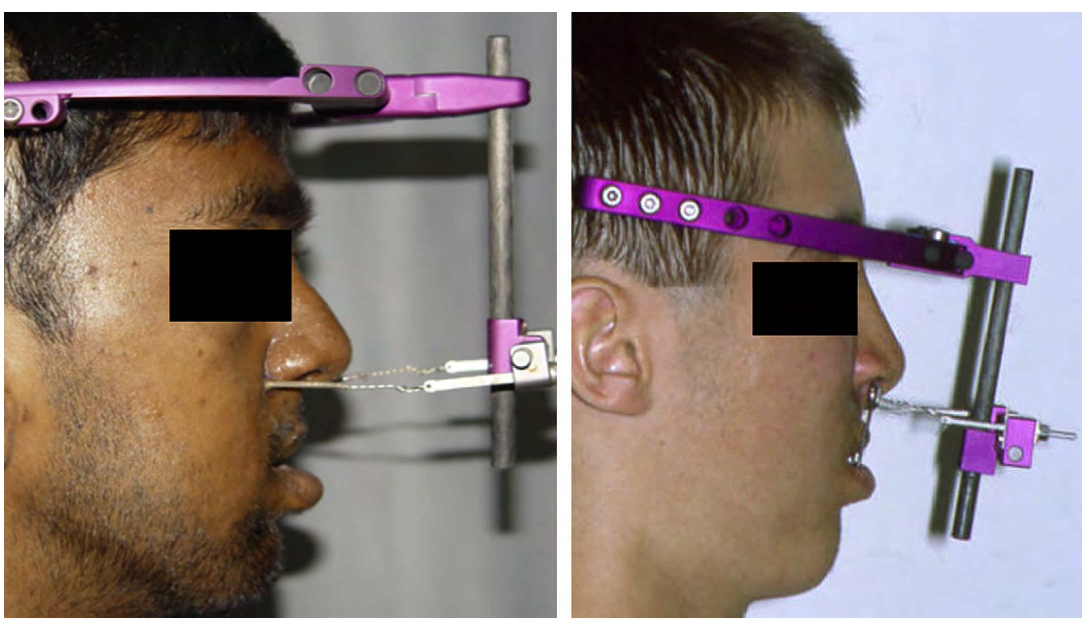

Fig. 13. Attachment of external halo device to maxilla by direct wire to a plate and to an orthodontic maxillary splint.

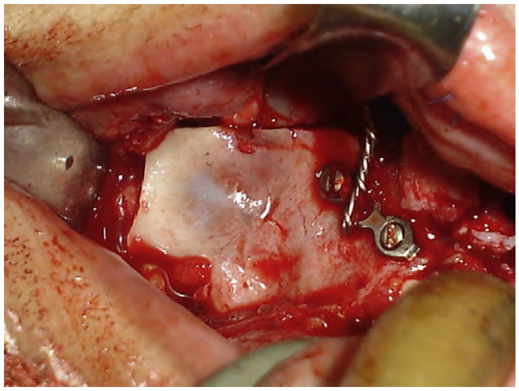

Fig. 14. High Le Fort I maxillary osteotomy at the level of infraorbital nerve with plate and wire attachment for the external halo device.

Complications of maxillary distraction osteogenesis

Guyette and colleagues examined changes in speech after maxillary DO and found that there was a 16.7% increase in hypernasality but concluded that overall the risk for velopharyngeal insufficiency after DO is similar to that of traditional Le Fort I advancement. Device failure or fracture of the anchoring plates is not uncommon. Premature fusion of the segments can occur especially if there is noncompliance by patients. Device extrusion can occur sometimes with wound infection. Relapse occurs but does not seem as severe as that seen with large advancements with traditional osteotomies. Distraction in growing patients runs the risk for possible interference with tooth buds and damage to vital structures. Finally, with distraction the segments may not move in the desired direction.

Future

Future approaches to DO of the maxilla may involve the following devices or techniques: implantable devices made of bioresorbable materials, multivectorial internal devices, minimally invasive placement by means of endoscopic techniques, computer-assisted distraction with automated or motorized devices (to improve and quicken distraction techniques), and flexible distraction rods that allow for concurrent occlusal adaptation.

Fig. 15. Tooth-borne and bone-borne devices for maxillary widening.

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Atlas of the
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Midfacial Distraction Osteogenesis

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Although distraction osteogenesis (DO) of the midface in theory is no different from DO performed at other sites, the surgical application of DO in the midfacial region is different. As discussed in the article by Jensen and Block elsewhere in this issue, DO is a biologic process that promotes bone formation between the cut surfaces of bone segments that is initiated when traction is applied to separate the bony segments. This process also initiates histiogenesis of the tissues surrounding the distracted bone: cartilage, ligaments, muscle, blood vessels, gingival, and nerve tissue.

DO as it applies to the midface is not a new concept. According to Balaji, Fauchard described the use of an expansion arch as early as 1728, applying it to widen the arches to a more physiologic form. Wescott attempted to correct a crossbite by placing two double clasps on the maxillary bicuspid teeth and a telescopic bar to apply transverse force and Angell expanded a maxillary arch by using a transverse jackscrew and clasps on the bicuspid teeth. Goddard is credited with standardization of the palatal expansion protocol with activation twice daily for 3 weeks followed by a period of stabilization.

Codivilla is credited with using an external skeletal traction apparatus after performing an oblique femoral osteotomy to accomplish the first lower extremity lengthening. Although Gavril Ilizarov was the first to describe a tissue-sparing osteotomy and a reliable distraction protocol that involved the long bones of the lower extremity in 1951, modern clinical DO of the facial bones developed once McCarthy and colleagues applied the concept to mandibular lengthening in 1992. This led to an explosion of clinical and research activity in craniomaxillofacial DO over the past decade. As in other sites, midfacial DO involves five distinct periods: osteotomy, latency, distraction, consolidation, and remodeling.

Adapting distraction osteogenesis from tubular long bones to irregularly shaped membranous bones

DO can be applied to multiple sites in the midfacial skeleton in pediatric and adult populations. The application of the concepts described in limb lengthening and the distraction of tubular long

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Box 1. Midfacial distraction osteogenesis device classification

External—bone-borne
Internal—subcutaneous
Intraoral
- Extramucosal
  - Tooth-borne
  - Dental implant-borne
- Submucosal
  - Bone-borne
  - Hybrid

Classification according to distraction direction
- Unidirectional
- Bidirectional
- Multidirectional

Classification according to site of midfacial distraction
- Le Fort I, II, III
- Nasal bones
- Zygomatic bones
- Healed bone grafts
- Maxillary alveolus
  - Transverse
  - Vertical
  - Horizontal

Data from Sándor GKB, Ylikontiola LP, Serlo W, et al. Midfacial distraction osteogenesis. Oral Maxillofacial Surg Clin North America 2005;17(4):485–501.

(endochondral) bones, however, must be modified when applied to the irregularly shaped membranous bones of the midfacial skeleton. There are several anatomic sites in the midfacial skeleton where DO may have an application. These include the maxilla at the Le Fort I, II, and III levels; the nasal and zygomatic bones; and the bones of the cranium. In addition, DO can be applied to healed bone grafts in the craniomaxiofacial skeleton and to vertical and horizontal defects of the maxillary alveolus (see the article by Spagnoli elsewhere in this issue).

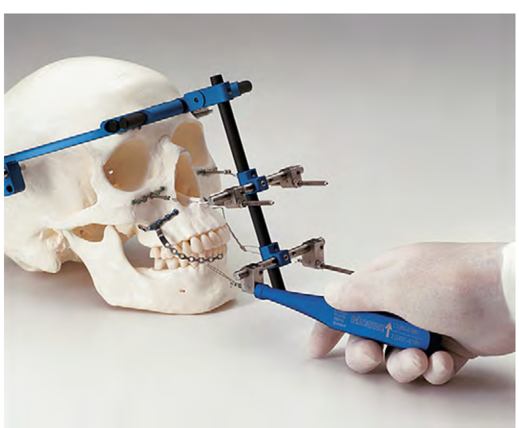

Fig. 1. An external frame device resembling a halo can be used to distract the retrusive midface (Biomet-Microfixation, Jacksonville, Florida). Such devices have become simple to apply, lightweight, and based on transcutaneous pin fixation to the skull. This device can be adapted to provide distraction vectors in more than one plane of space.

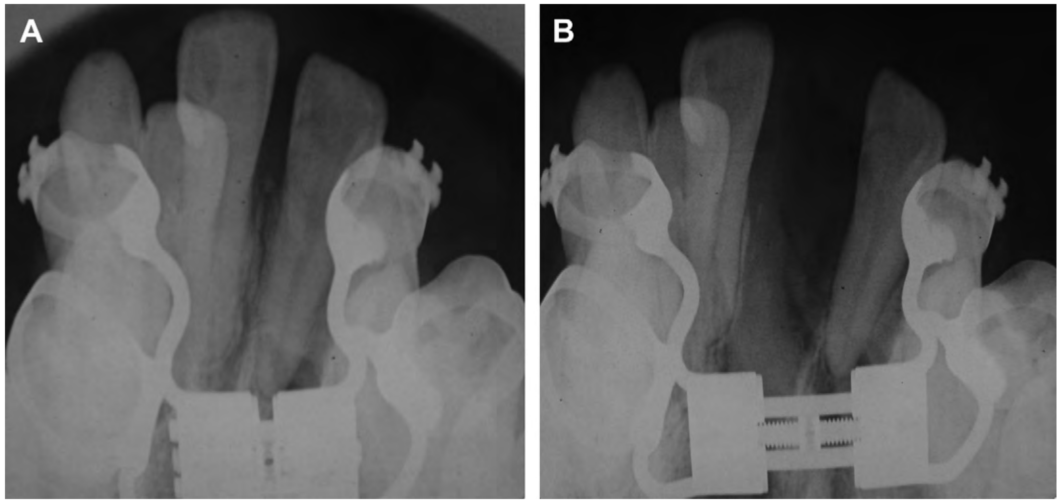

Fig. 2. (*A*) An occlusal radiograph of a patient who had a right-sided unilateral cleft palate and alveolus and a transverse deficiency of the maxilla. A traditional tooth-borne palatal distractor was applied to the maxilla and an osteotomy performed in the midline between the two central incisors. (*B*) Note the diastemma that has developed between the maxillary central incisors, which is the site of the palatal DO in this patient who had cleft lip and palate. This intersegmentary gap is visible before the consolidation phase.

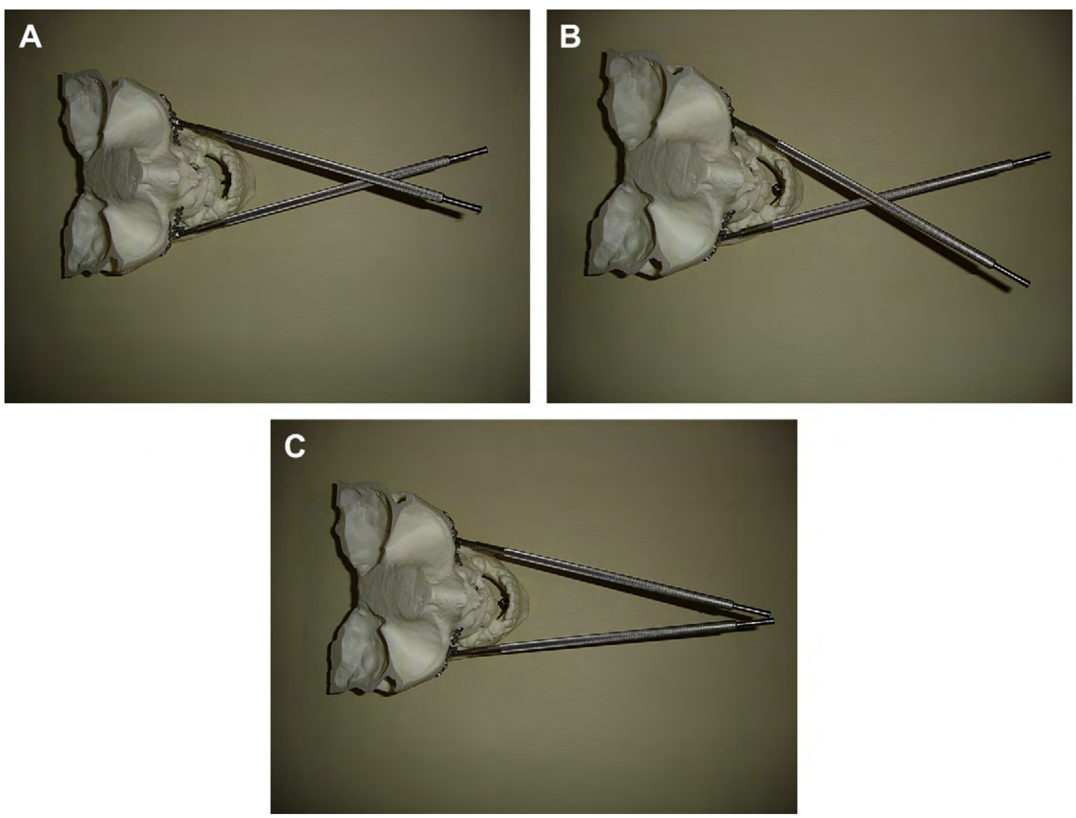

Fig. 3. (*A*) Occasionally two devices must be used simultaneously as shown with these two Le Fort I level submucosal maxillary distractor devices. The vectors of distraction of the two devices must not interfere with each other. Slight convergence as seen in this figure is tolerable. (*B*) The same distraction devices from do not function ideally when the vectors of distraction are too convergent. (*C*) These ideally placed devices show minimal convergence of the vectors of distraction.

As discussed in the article by Reddy and Elhadi elsewhere in this issue, the hardware required for distraction of each region may vary as much as the distraction protocols differ from themselves (Box 1). Hardware may range from large external halo-like devices (Fig. 1) to jackscrews that attach to the teeth (Fig. 2). The goals of treatment and the ideal vectors used in each of these regions also are distinct. Certain devices allow distraction in more than one plane or

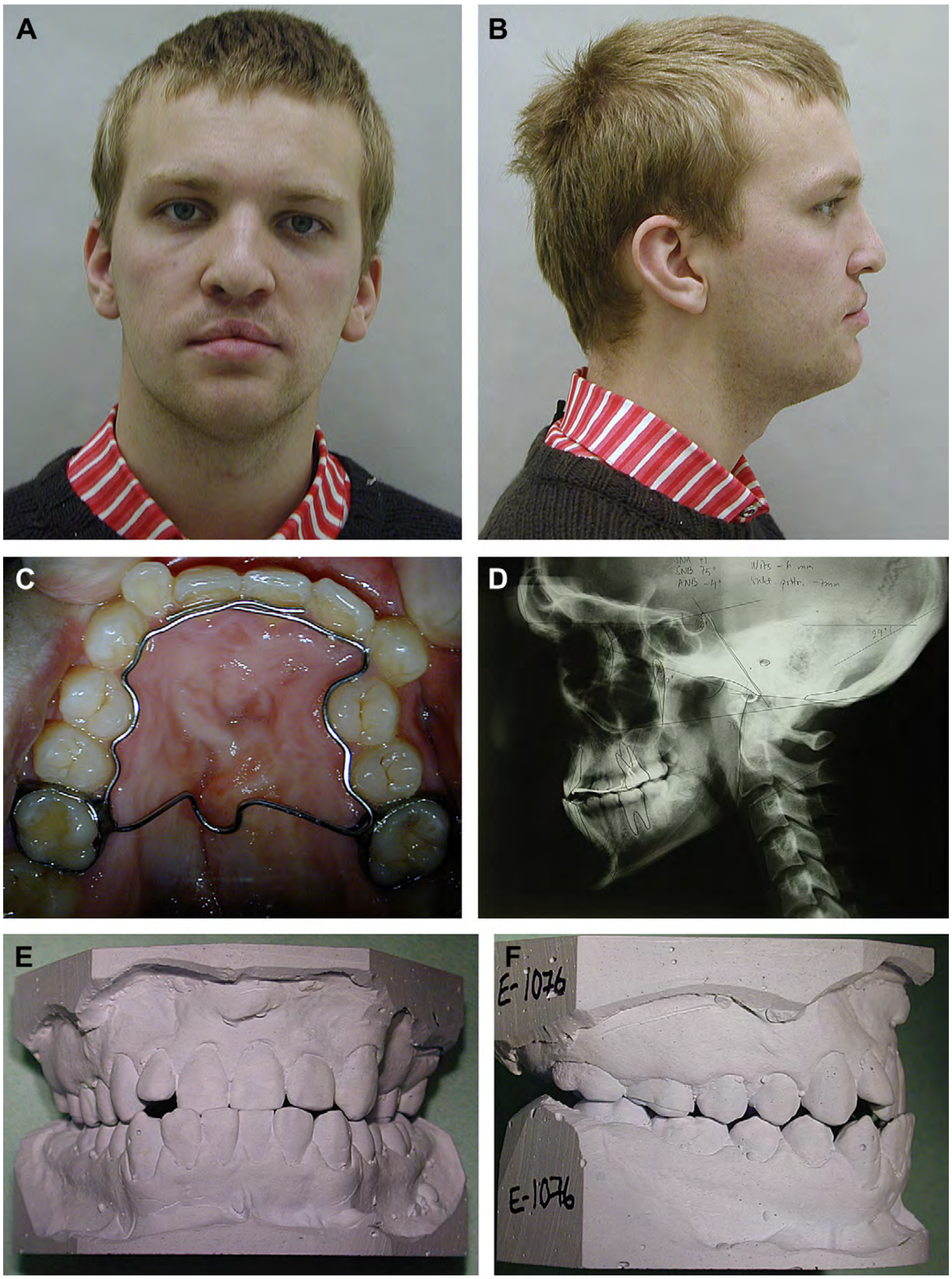

Fig. 4. (*A*) Frontal view of an 18-year-old man who had bilateral cleft lip and palate with maxillary deficiency. (*B*) The lateral view of the patient. (*C*) Extremely scarred palate visible on this photograph. This patient was at risk for developing velopharyngeal insufficiency with a traditional Le Fort I level maxillary advancement osteotomy. (*D*) Preoperative lateral cephalogram of patient. (*E*) Frontal view of models with a negative overjet. (*F*) Right lateral view of occlusion.

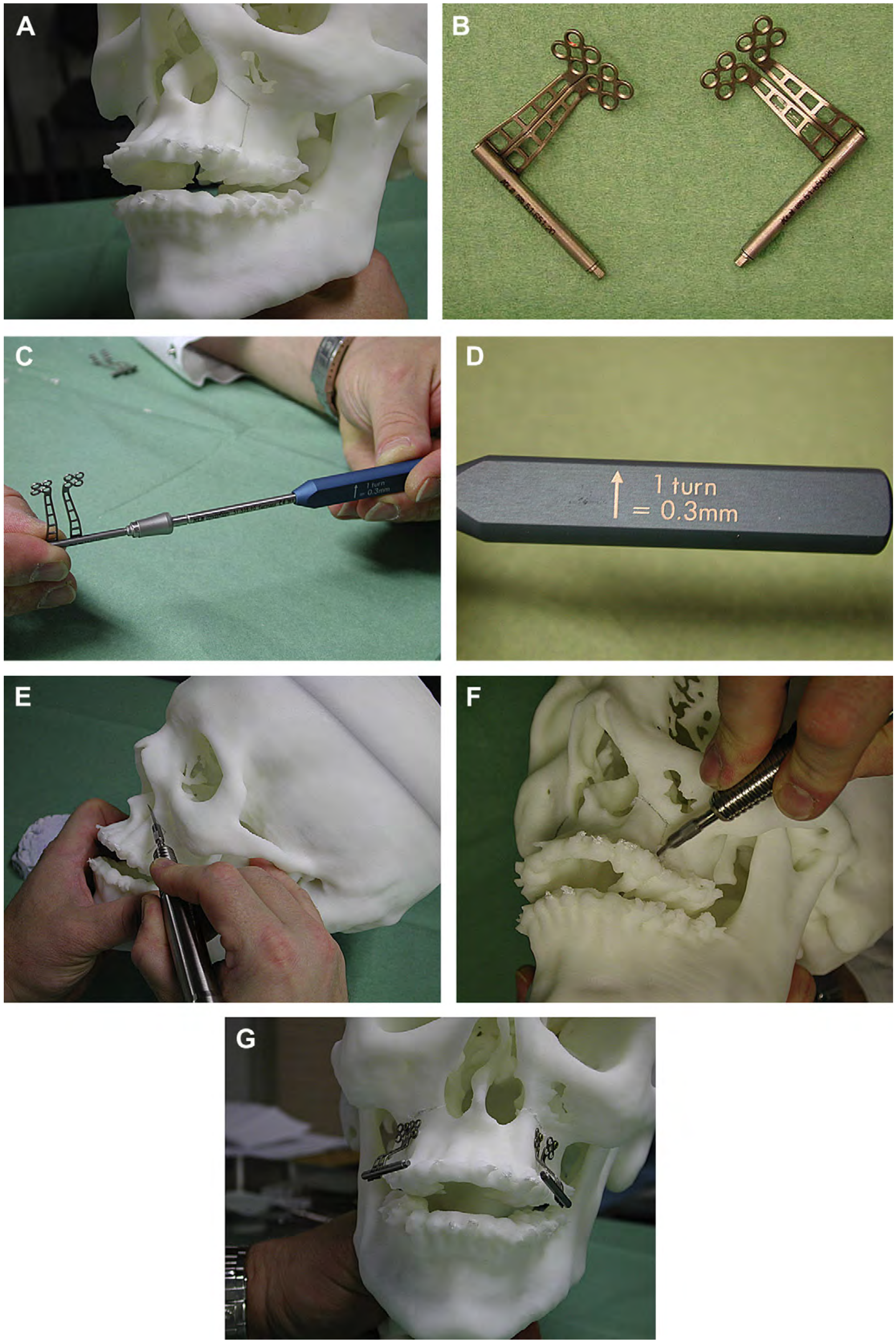

Fig. 5. (*A*) Osteotomy lines have been scribed onto a stereolithic model of the patient. (*B*) The distraction plates are selected prebent and the screw holes are predrilled (KLS Martin, Jacksonville, Florida). (*C*) The distraction screwdriver is used to test the activation of the distractor. (*D*) The clinician must be aware of the magnitude of movement with each turn of the distraction screwdriver. Manufacturers usually mark this clearly on each device. (*E*) The horizontal cut of the anterior maxillary cut of the osteotomy is performed. (*F*) The vertical cut of the osteotomy is made. (*G*) The distraction plates are secured to the osteotomized model.

direction (see Fig. 1). At times two devices may be used simultaneously; however, neither the devices nor their vectors of distraction should be allowed to interfere with each other (Fig. 3).

Indications

Midfacial DO is labor intensive and technique sensitive as a treatment modality and should be reserved for specific indications. Midfacial DO has two main advantages over traditional osteotomies of the midface. First, DO can produce larger movements than traditional osteotomies. Second, DO seems to be associated with less relapse than traditional osteotomies. DO, therefore, should be reserved for significant bony movements in the treatment of conditions known to have high relapse rates after traditional osteotomies.

DO can be repeated during different phases of life. In some cases, the application of a halo to the skull and a few simple titanium plates screwed into the bones of the craniomaxillofacial skeleton may be less invasive than certain osteotomies of the midface. Moreover, developing tooth roots of the maxilla can be avoided and left undamaged by the design of osteotomies used in DO of the midface.

Cleft lip and palate patients often require significant advancement of their midface at one or more Le Fort levels. Maxillary advancement using traditional osteotomies may place these patients at risk for the development of velopharyngeal insufficiency. It has been reported that this debilitating complication may be avoided for some of these patients if DO is used to advance the maxilla perhaps because it leaves the posterior dentition and velopharyngeal relationships undisturbed.

DO of the midface also may be applied in situations requiring emergent care. It can ameliorate obstructive sleep apnea in Crouzon's syndrome, for example, possibly avoiding the need for tracheostomy. DO also is used to provide urgent ocular protection in Pfeiffer's syndrome.

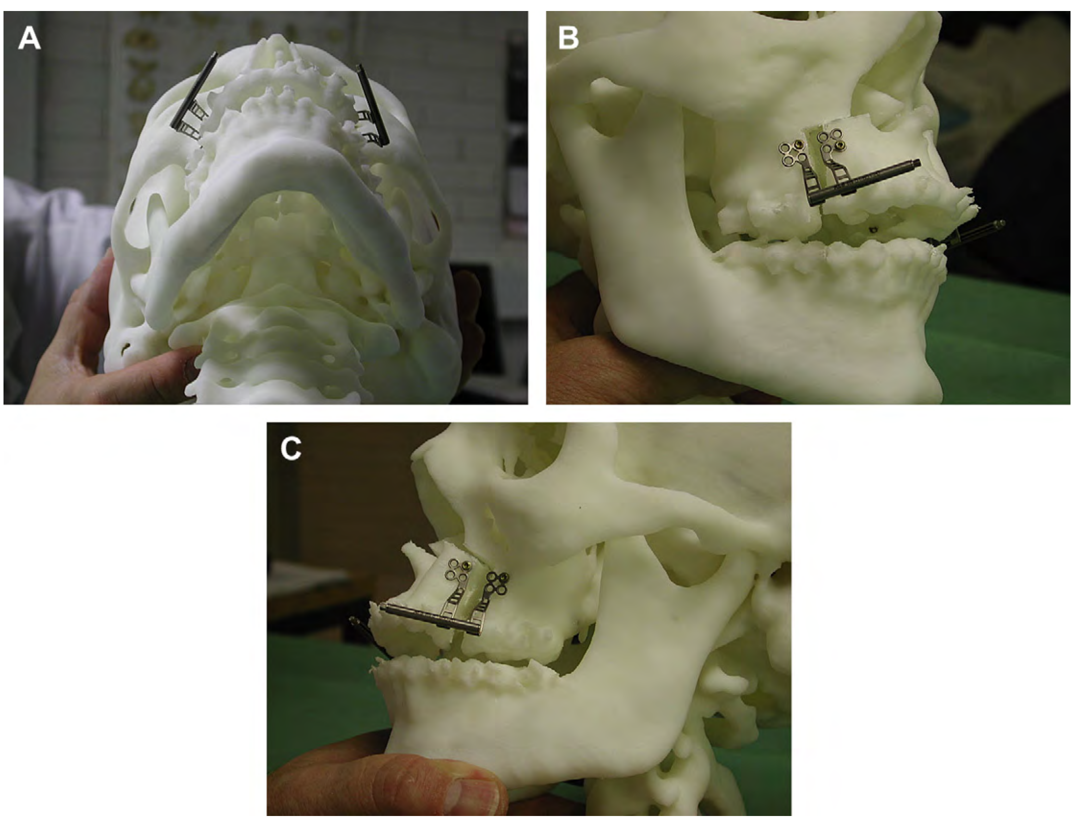

Fig. 6. (*A*) The vectors of distraction should not be too convergent to allow forward distraction of the maxilla. (*B*) The distractors on both sides are activated to test the forward movement of the maxilla through its full range. Here the right side is shown. (*C*) Left side of the model showing the forward distraction of the maxilla.

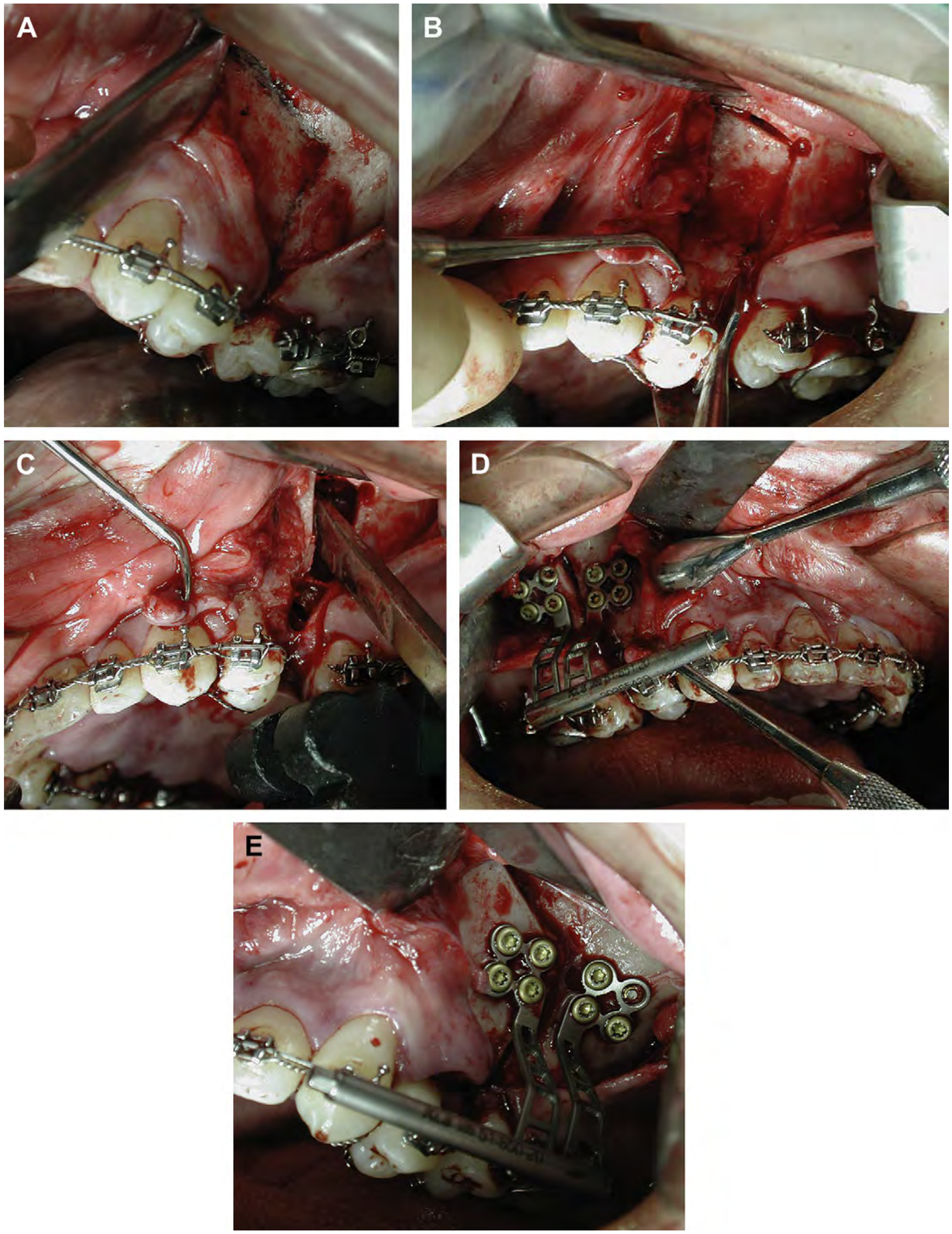

Fig. 7. (*A*) Osteotomy lines scribed onto the maxilla. (*B*) Osteotomy cuts completed. (*C*) Anterior maxillary segment stretched and mobilized despite extensive surrounding scar tissue. (*D*) Distractor applied to the right side of the maxilla. (*E*) Distractor applied to the left side of the maxilla.

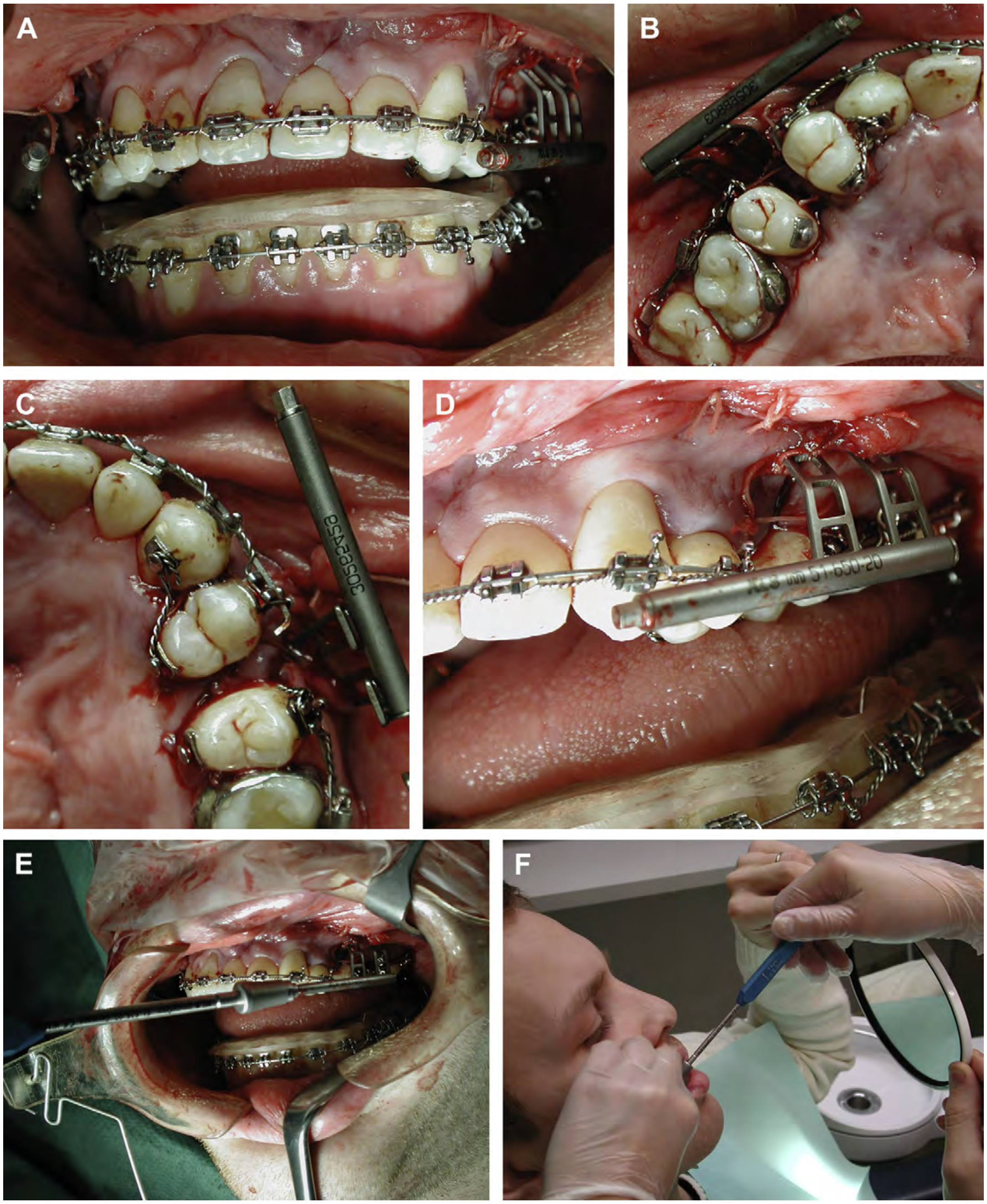

Fig. 8. (*A*) Frontal view of maxilla with distractor wounds closed. A smooth interocclusal splint has been wired to the mandibular dentition to permit the anterior relocation of the maxillary segment without interferences. (*B*) Occlusal view of the right maxillary distractor. (*C*) Occlusal view of the left maxillary distractor. (*D*) Lateral view of the distractor positioned to be in a neutral location in the buccal vestibule or sulcus. If the distractors are positioned too far laterally then they are uncomfortable as they impinge excessively on the soft tissues of the cheek. (*E*) The distractor can be tested using the screwdriver intraoperatively. (*F*) Careful teaching of the patient ensures compliance and successful use of the appliance during the distraction phase.

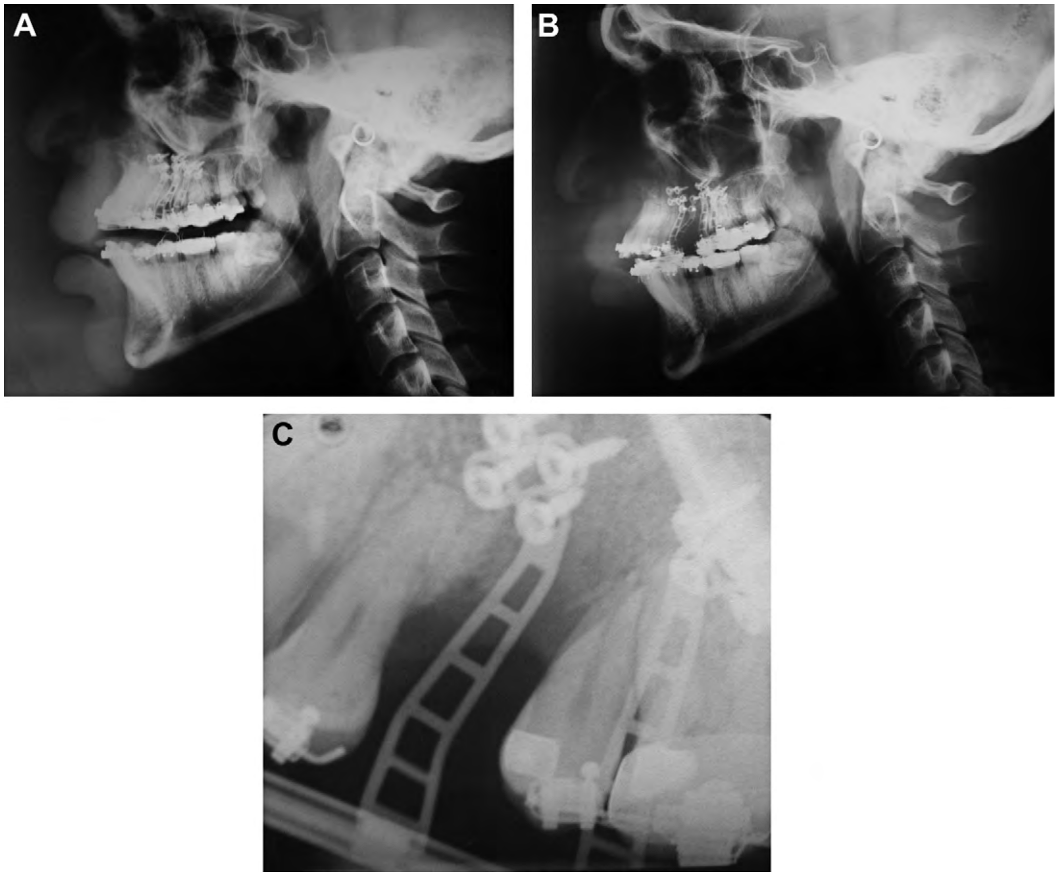

Fig. 9. (*A*) Lateral cephalogram taken immediately after the surgery. (*B*) Lateral cephalogram taken at the end of the distraction phase, at the start of the consolidation phase. Note the presence of the bone gaps between the roots of the bicuspid teeth. (*C*) Periapical radiograph showing the bone fill in the distracted bone between the tooth roots during the consolidation phase. Dental implants are used to restore these spaces.

Distraction osteogenesis in cleft lip and palate

DO offers several advantages over conventional osteotomies in the treatment of cleft lip and palate patients. There is a reduced tendency for significant relapse after distraction of the maxilla than after traditional maxillary osteotomies. The soft tissue changes associated with maxillary advancement may be superior after DO when compared with traditional Le Fort I level advancement surgery. It also is possible that deterioration of velophayngeal function may be avoided in patients at risk for the development of velopharyngeal insufficiency.

The midfacial deformities seen in cleft lip and palate patients include transverse maxillary deficiency, midfacial retrusion, and significant alveolar cleft defects. Transverse maxillary deficiency in unilateral cleft lip and palate patients can be corrected with corticotomy and distraction in a modified procedure similar to the surgically assisted rapid palatal expansion procedure in which distraction is performed across the midpalatal suture. Despite the presence of a palatal cleft, transverse deficiency of the unilateral cleft maxilla can be corrected reliably using DO (see Fig. 2). It is the opinion of the authors that transverse discrepancy should be corrected first, before anteroposterior discrepancies are treated with DO.

Midfacial retrusion may be treated at the Le Fort I, II, or III levels. Le Fort I level distraction may involve advancement of segmentalized maxillary fragments or of the entire maxilla. Experimental advancement of anterior maxillary segments osteotomized at the Le Fort I level in sheep and in primates has been shown to be followed by bone healing typical of DO.

Distraction hardware developed for anterior maxillary segmental advancement (Figs. 4 and 5) has been used successfully in patients who have cleft lip and palate. A stereolithic skull reconstructed from a 3-D CT scan can aid planning of such osteotomies by permitting preoperative selection and bending of plates, thus reducing expenditures on distraction hardware and operating room time (Figs. 6 and 7). Preoperative planning also ensures that a certain configuration and arrangement of the selected distraction hardware actually produce the vectors of distraction desired (Figs. 8–10).

Distraction hardware also has been developed for Le Fort I level osteotomies (Figs. 11 and 12) in embodiments designed to be used submucosally and subcutaneously. The selection of a specific device is determined by the goals of the distraction procedure, anatomic constraints, and the amount of room available to accommodate placement of the hardware. Care must be taken to avoid damaging the developing dental follicles or tooth roots in pediatric patients when applying such devices to the lateral wall of the maxilla.

DO and traditional osteotomies can be combined at multiple levels. The authors present a case of a patient who had Crouzon's syndrome using combined Le Fort II osteotomy and DO at the Le Fort I level as a step-by-step illustration (see Figs. 11 and 12).

Large alveolar cleft defects may be reduced in size using DO to transport bone segments across the cleft. Such a decrease in size of the cleft and associated oronasal fistula may enhance the outcome and predictability of bone grafting techniques.

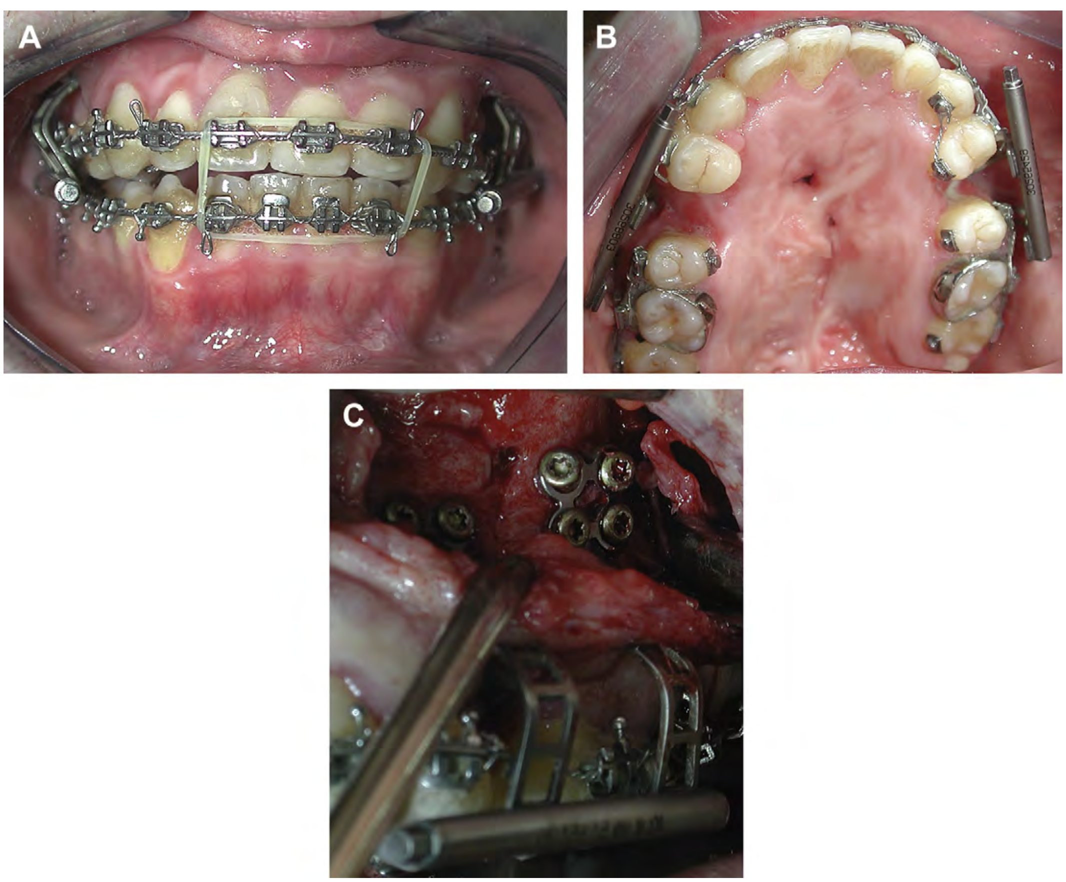

Fig. 10. (*A*) Fontal view of occlusion at the end of the consolidation phase. Elastics are used to bend the distraction regenerate and close the anterior open bite. (*B*) Palatal view of the distractors in place. Note that a small fistula has opened on the palate since the start of the distraction process. (*C*) View of the regenerated bone at the time of distractor removal after the consolidation phase.

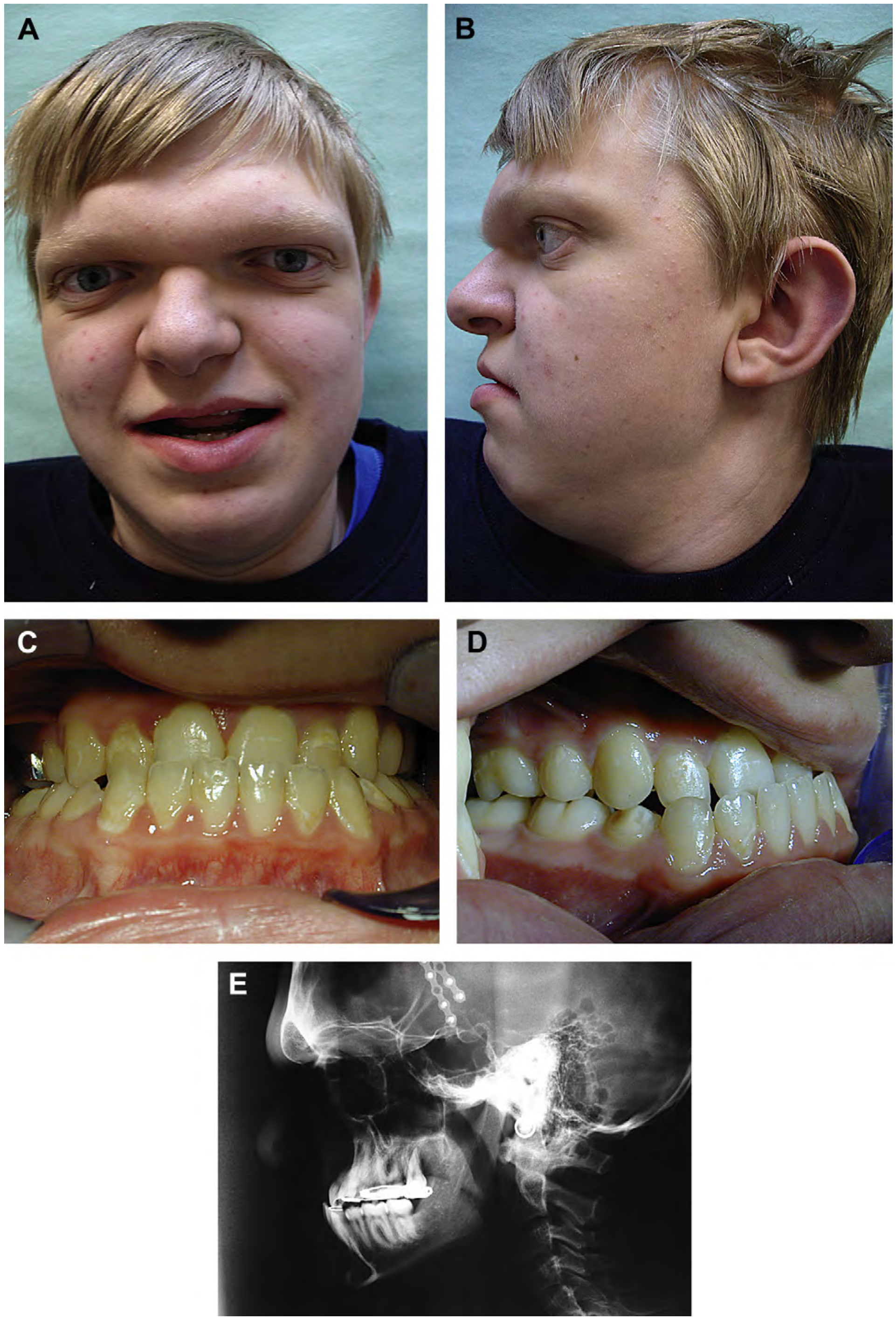

Fig. 11. (*A*) Frontal view of a 17-year-old man who had Crouzon 's syndrome with short facial height, prominent supraorbital rims, an unusual nasofrontal angle and midfacial retrusion. (*B*) The lateral view of the same patient. (*C*) Occlusion from the frontal view showing an anterior crossbite. (*D*) Right lateral view of the occlusion. (*E*) Note the retruded midface on the preoperative lateral cephalograms and the extremely well pneumatized frontal sinuses, which make simple trimming of the supraorbital rims impossible. (*F*) Anterior view of submucosal distractors for Le Fort I level DO on a stereolithic skull model (Synthes, Oberdorf, Switzerland). This device is designed to advance the entire maxilla at the Le Fort I level in one piece. (*G*) Lateral view of Le Fort I level intraoral submucosal distractor adapted and applied on the stereoloithic model before the mock skull surgery. (*H*) The Le Fort I and II osteotomies are scribed onto the stereolithic skull model. (*I*) The horizontal maxillary osteotomy is performed between the two components of the distraction plates. The distraction plates are then resecured to the osteotomized model. (*J*) The distractors on both sides are activated to test the forward movement of the maxilla through its full range to ensure that there were no bony interferences between the selected osteotomy cuts and the vector of distraction.

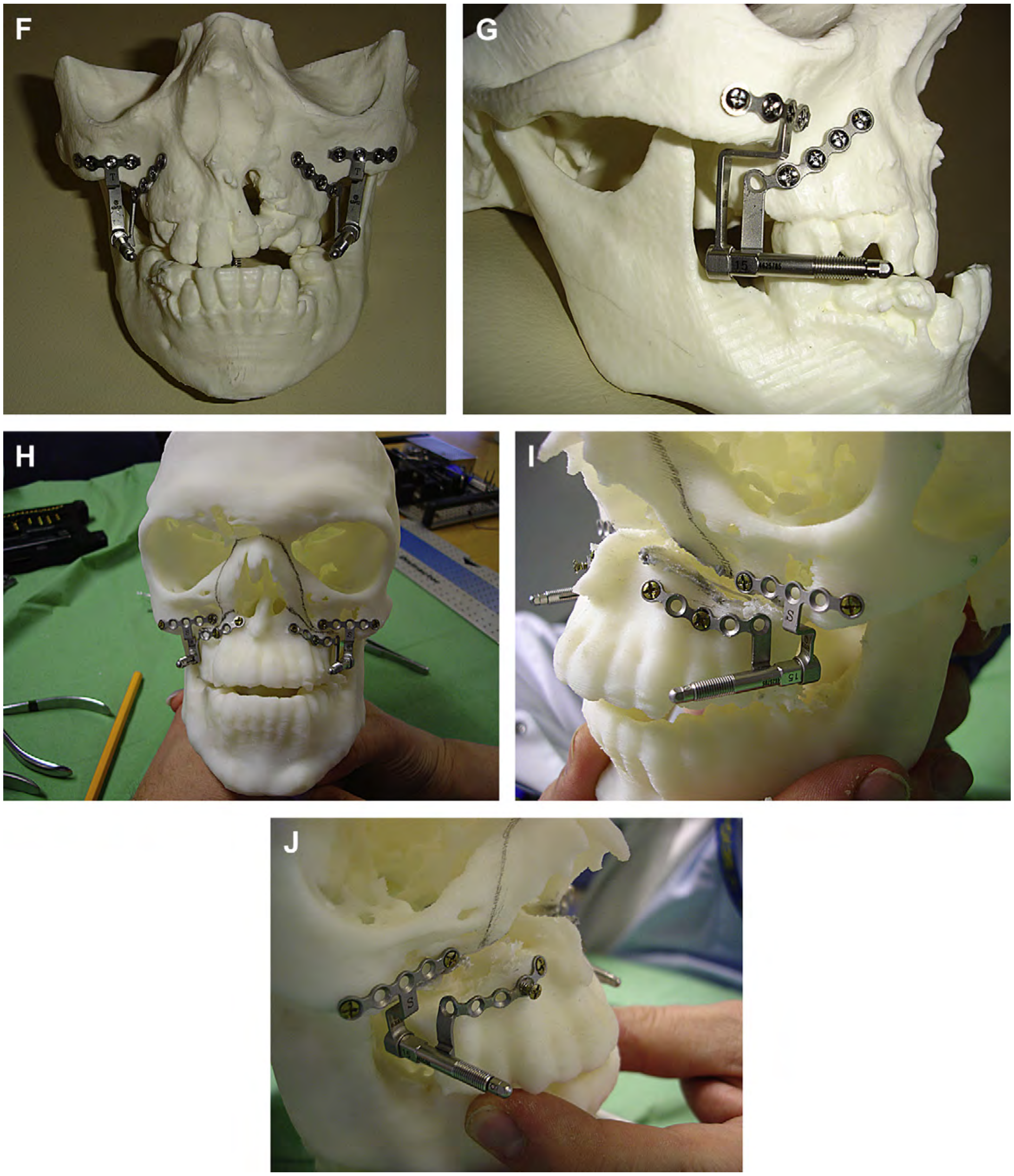

Fig. 11 (*continued*)

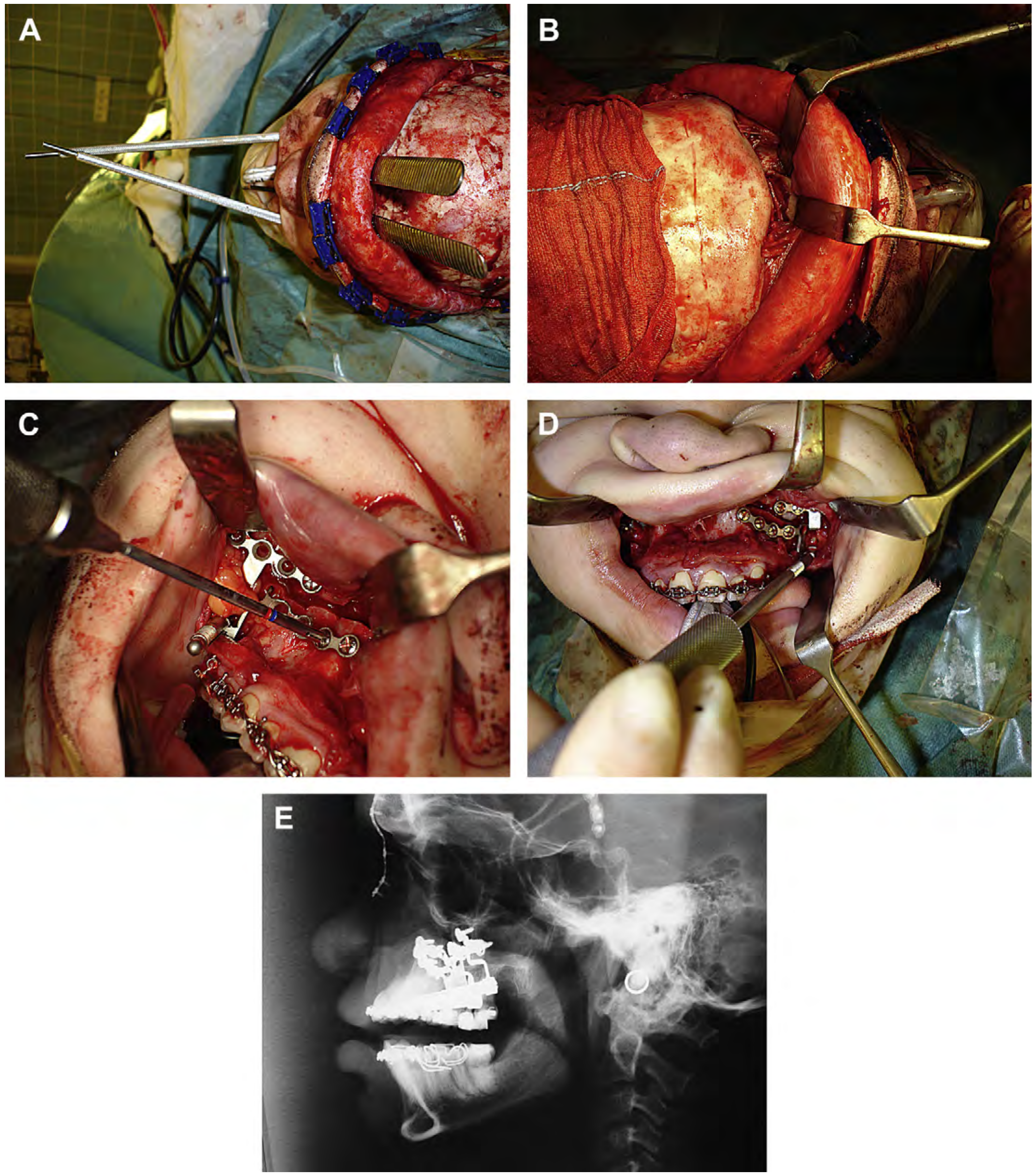

Fig. 12. (*A*) Exposure of the maxilla at the Le Fort 1 and Le Fort 2 levels. (*B*) An interpositional bone graft is used at the Le Fort 2 level to advance the upper part of the midface. (*C*) The distractor is applied to the maxilla. (*D*) The preoperative lateral cephalograms. (*E*) Lateral cephalograms taken immediately postoperatively. (*F*) Lateral cephalograms taken at the end of the distraction phase. (*G*) One year postoperative lateral cephalogram. Note that the distractors have been replaced by bone plates. (*H*) Postoperative frontal view of the 17-year-old man who had Crouzon's syndrome (see Fig. 11A) who had improved facial height, less prominent supraorbital rims, and improved nasofrontal angle. (*I*) Postoperative left lateral view of the patient. (*J*) Postoperative occlusion from the frontal view showing correction of the anterior crossbite. (*K*) Postoperative right lateral view of the occlusion.

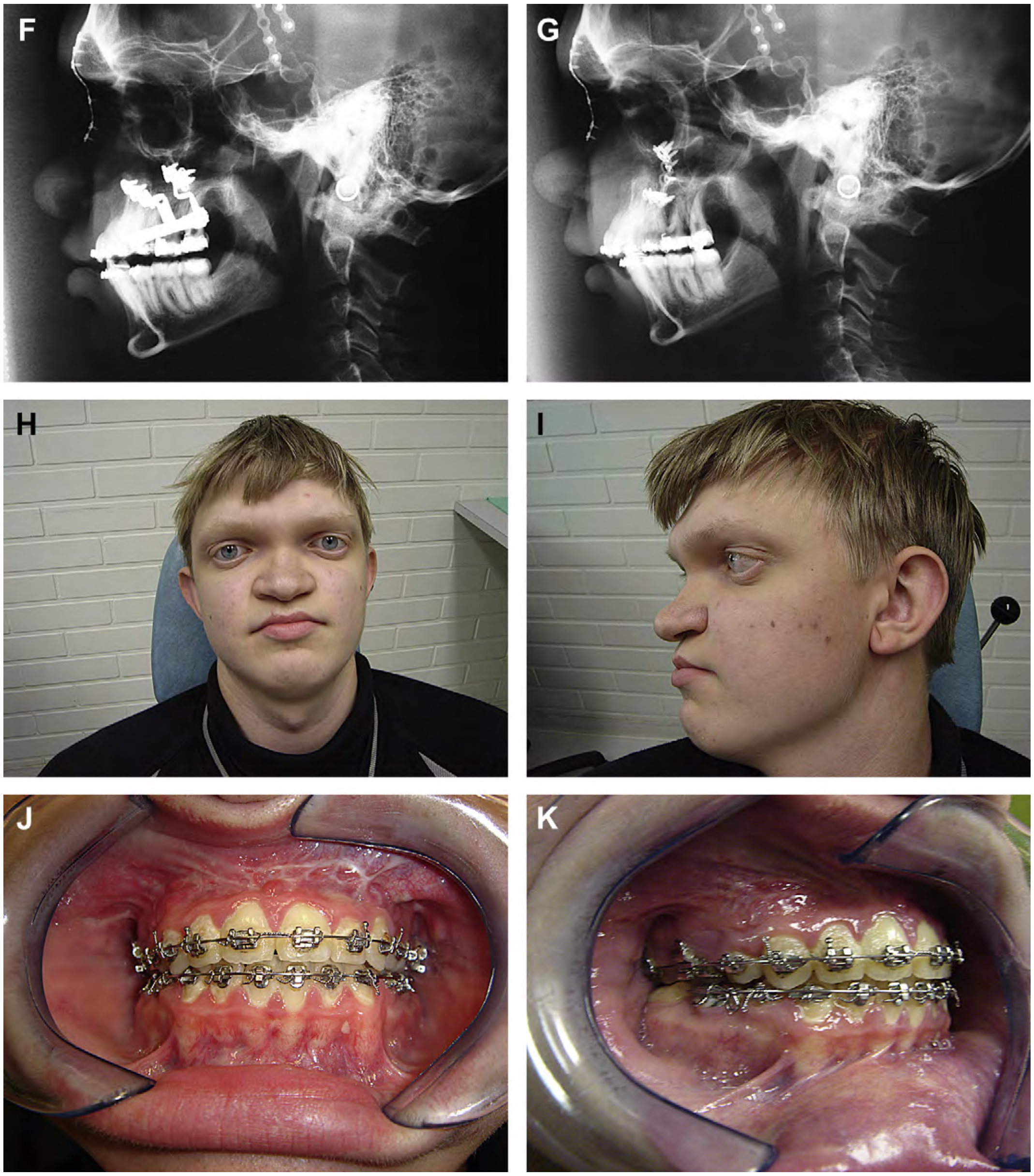

Fig. 12 (*continued*)

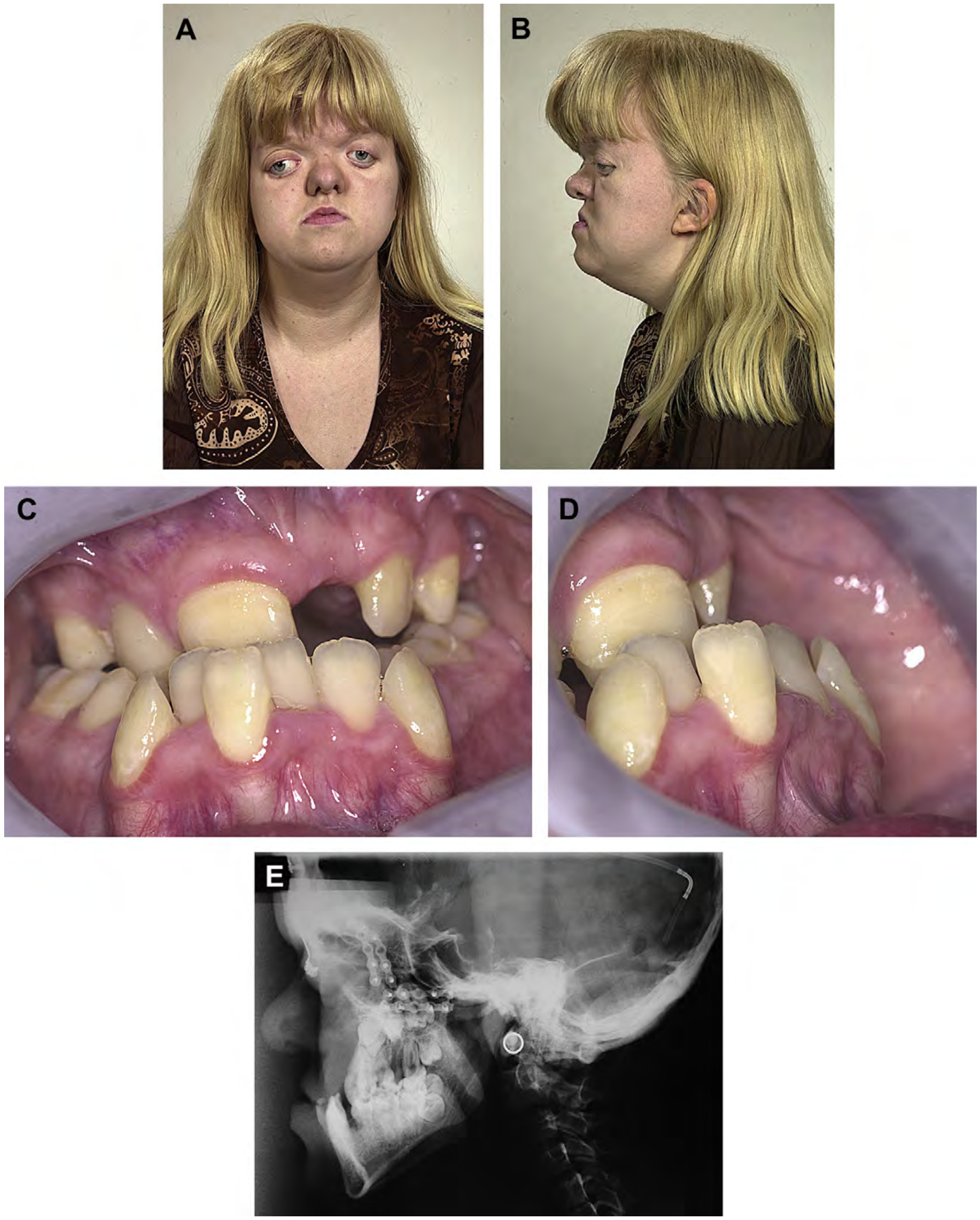

Fig. 13. (*A*) Frontal view of a 16-year-old girl who had Crouzon's syndrome. (*B*) Left lateral view of patient who had Crouzon's syndrome and severe midface retrusion. (*C*) Frontal view of dentition in occlusion with severely retrusive maxilla and crowded malocclusion. (*D*) Right lateral view of significant negative overjet. (*E*) Lateral cephalogram showing significant midfacial retrusion despite previous osteotomy to advance the midface. (*F*) Sterelolithic skull with Le Fort III osteotomy scribed onto model. (*G*) Right and left internal distractor devices (Leibinger, Mülheim-Stetten, Germany) are temporarily secured to the temporal, zygomatic, and maxillary bones on the clear model. The osteotomies then are designed to be in harmony with distractor positioning. (*H*) The devices are removed and the osteotoimies are performed. (*I*) The distractors are reapplied with the maxilla in the neutral or starting position. (*J*) Right internal distractor activated. (*K*) Left internal distractor activated and taken through the range of possible distraction to ensure that there are no bony interferences with the distraction procedure.

Fig. 13 (*continued*)

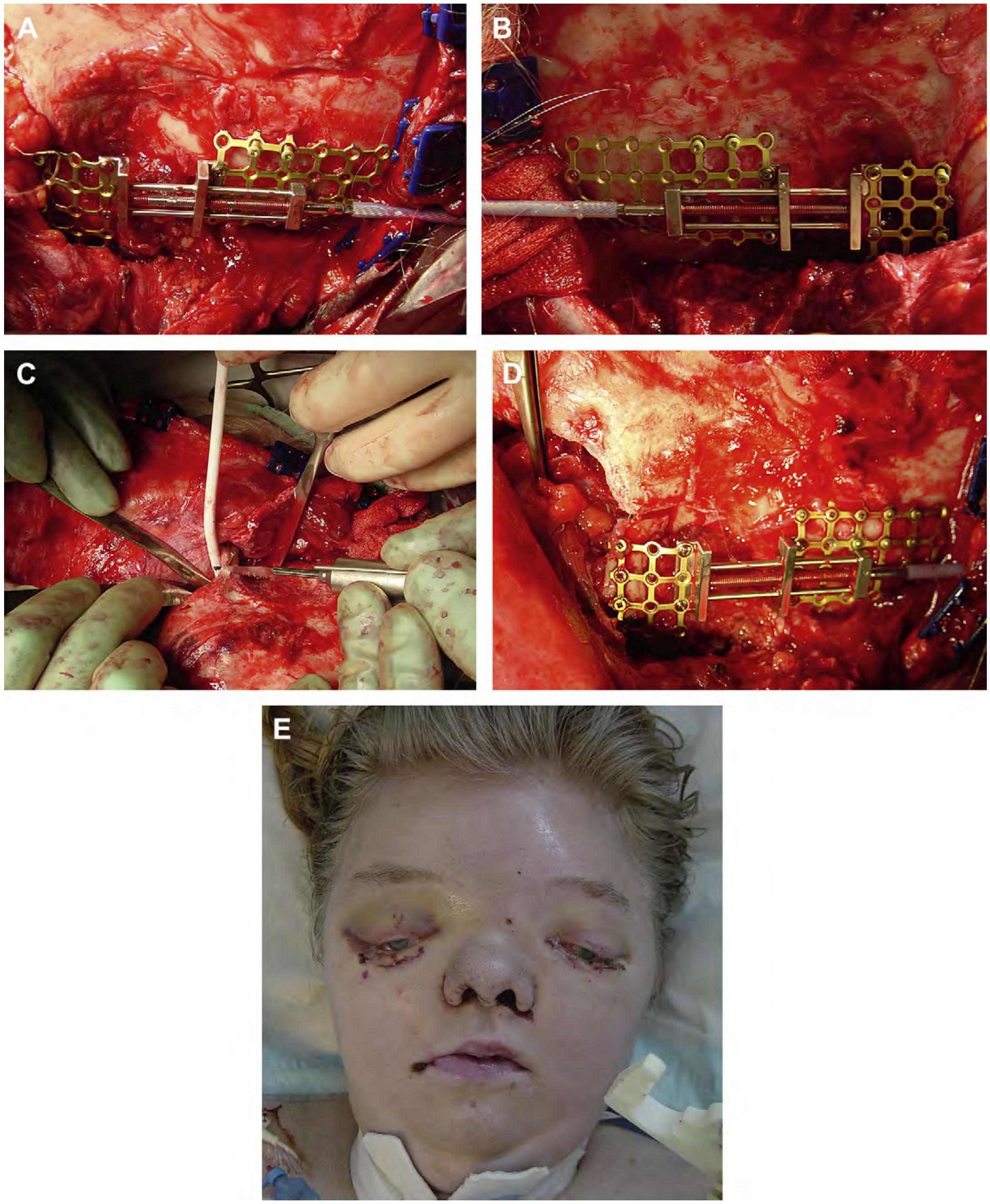

Fig. 14. (*A*) Left internal distraction device temporarily applied. (*B*) Right internal distraction device temporarily applied. Osteotomy lines then are designed to harmonize with the distractor. (*C*) Osteotomy performed at the Le Fort III level. (*D*) Distractor activated and tested to ensure there are no obstacles through the range of distraction. (*E*) Postoperative view of patient ready to commence distraction after 5-day latency period.

Higher-level Le Fort distraction osteogenesis

The treatment of craniofacial dysostoses, such as Crouzon's (Fig. 13), Apert's, Pfeiffer's, and Saethre-Chotzen syndromes, is critically dependant on advancement of the midface. DO can be performed in the midface at the Le Fort I, II, or III levels; the zygomatic bones; healed facial bone grafts; the frontal bones; and the other bones of the cranium. A variety of distractor designs are available but they can be grouped into two basic categories: external halo-like devices (see Fig. 1) and miniaturized internal devices (Fig. 14). A step-by-step ''how our team does it'' illustration of a Le Fort III level DO in a patient who had Crouzon's syndrome is presented (Figs. 13–16).

The proponents of external devices point out that although these devices are rigid they are easily adjustable, often in more than one plane of space. External distraction devices permit easy control of the force and direction of distraction. External devices can be applied easily to growing children, and they obviate rigidly fixing devices on the lateral walls of the maxilla using screws where developing dental follicles and roots of the permanent dentition can be damaged. The use of external halo-like devices is associated with the risk for penetrating the cranium with the fixation pins of the halo, especially in children. Moreover, the skin around the fixation pins of the halo can become infected. The social stigma associated with wearing an external device may deter its use because of its perceived psychologic effect. Furthermore, external devices are prone to being accidentally dislodged.

The proponents of internal devices point out that such devices can be worn out of plain sight and have minimal impact on the daily activities of patients (see Fig. 16). Internal devices often are unidirectional so that distraction may be possible in only one plane of space (see Fig. 15). Often two internal devices must be used simultaneously on either side of the maxilla to obtain a symmetric distraction. The cost associated with the use of two appliances must be borne in mind. Metal internal distraction devices are the most rigid but require removal after the distraction process. Removal of distraction devices can be difficult and complicated. Resorbable distraction devices that do not require removal recently have become available. Just as the skin around the fixation pins of an external distraction device can become infected, the tissues surrounding the transcutaneous distraction rods of the internal devices also can become infected.

The results of maxillary distraction at the Le Fort III level are impressive when compared with the results of a traditional Le Fort III osteotomy. Fearon describes a study of 12 children who underwent Le Fort III level distraction compared with an age-matched cohort of 10 children treated by osteotomy at the same level. The average horizontal advancement

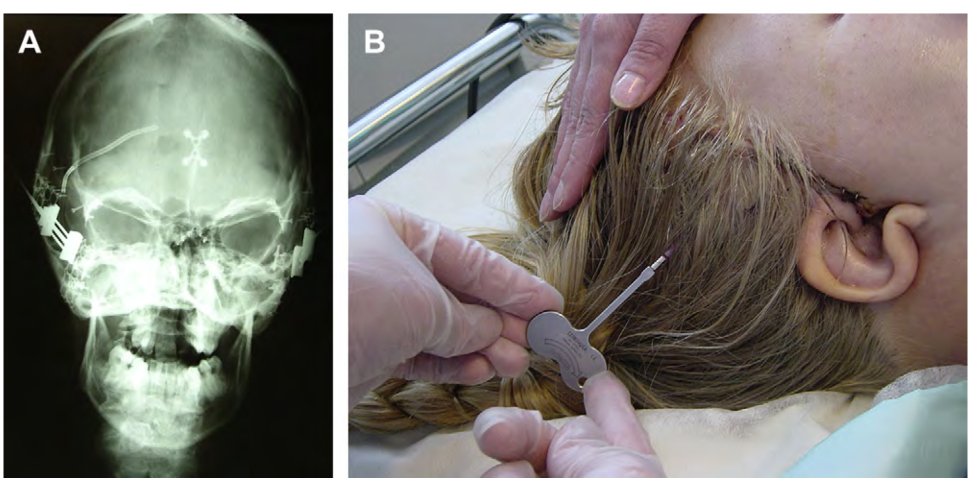

Fig. 15. (*A*) Anteroposterior cephalogram radiograph taken to confirm distractor positioning before onset of distraction phase. (*B*) Distractor key used to activate internal distractor that is accessible by a trancutaneous rotation arm.

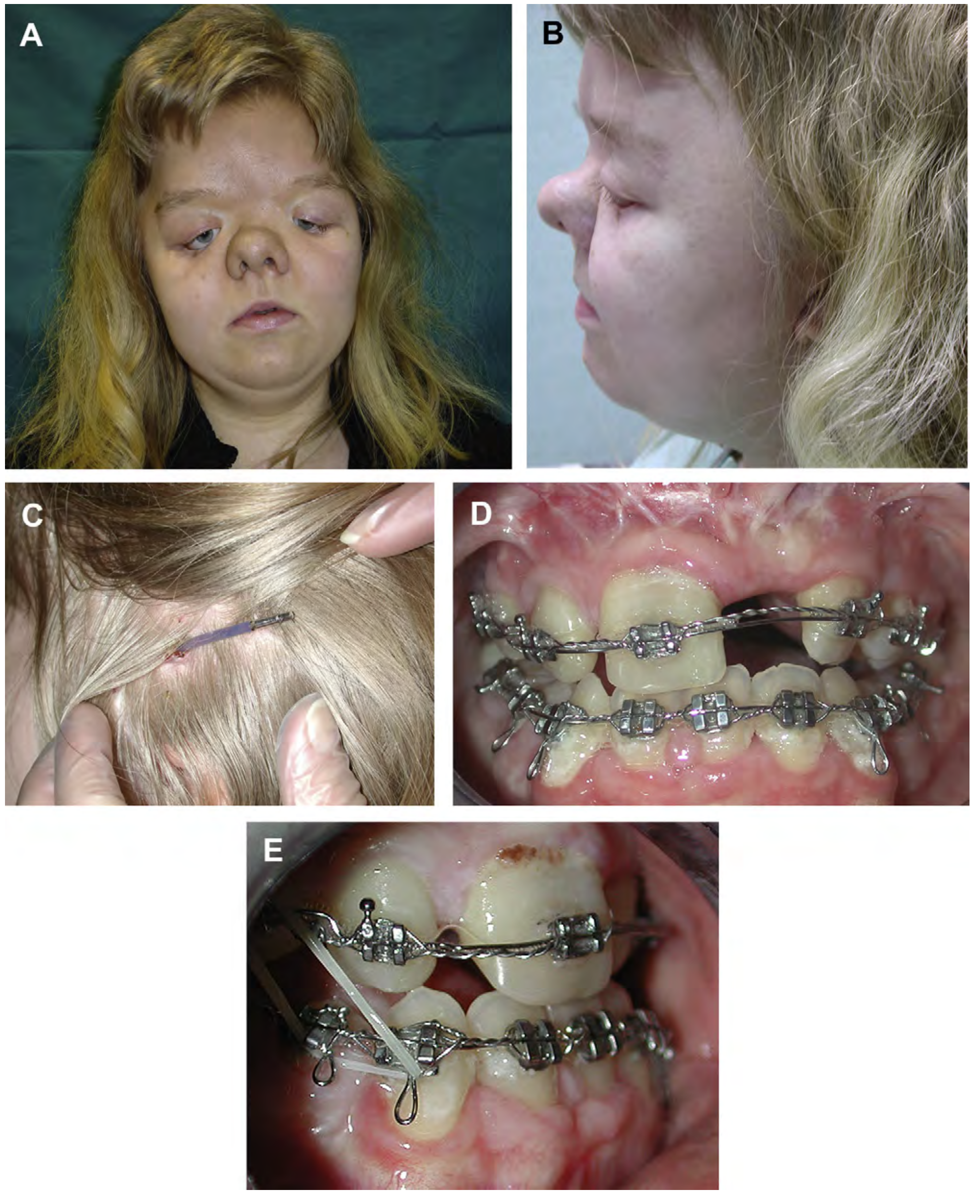

Fig. 16. (*A*) Frontal view of patient at the end of the consolidation phase of distraction. (*B*) Right lateral view of patient at the end of the consolidation phase of distraction. (*C*) Transcutaneous wound at end of consolidation phase with excellent tolerance of the internal distractor device by the surrounding soft tissues. (*D*) Anterior view of the corrected occlusion at the end of the consolidation phase. (*E*) Right lateral view of the corrected occlusion at the end of the consolidation phase. (*F*) Composite photo of final facial appearance and occlusion postoperatively. (*G*) Preoperative lateral cephalogram. (*H*) Postoperative lateral cephalogram at end of consolidation phase. The advancement at level of the incisors was 19 mm whereas at the frontonasal region it was 8 mm.

achieved in the Le Fort III distraction group was 19 mm compared with 6 mm in the Le Fort III osteotomy group. Two patients in the distraction group demonstrated quantifiable improvement in sleep apnea: sleep studies for these patients yielded more normal values, specifically their respiratory disturbance indices. Two patients experienced amelioration of sleep apnea, which permitted their tracheotomies to be decannulated. Fig. 16H shows the result of one patient who had a Le Fort III level DO with a 19-mm advancement at the level of the incisor teeth and an 8-mm advancement at the frontonasal region.

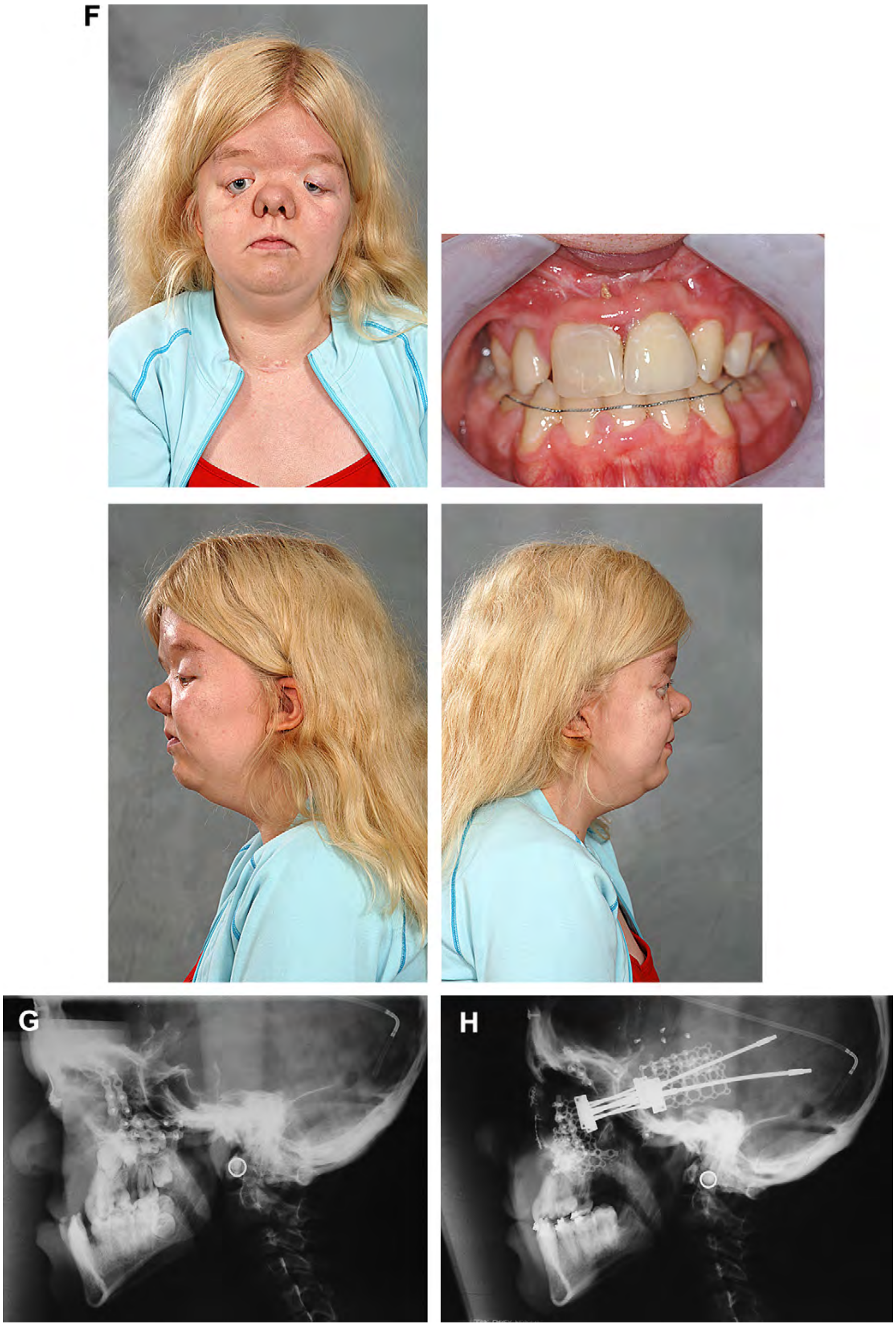

Fig. 16 (*continued*)

Unlike Le Fort III level distractions, the results of distraction at the Le Fort II level may not differ appreciably from distraction at the high Le Fort I level. Some investigators recommend that DO be executed at multiple levels to correct the occlusion and the midfacial retrusion independently using separate vectors (see Fig. 11). This is because the teeth, the nasofrontal region, and the orbital rims may not all advance the same distances (see Fig. 16G, H). In such cases, Satoh and colleagues advise that the final position of the midface should be governed subjectively by the positions of the nasal bones, malar complexes, and orbital rims relative to the rest of the face, whereas the occlusion should be governed by an occlusal splint. Satoh and colleagues recommend osteotomizing the midface into two portions and distracting the two portions separately using independent vectors and different amounts of distraction.

The future of midface distraction osteogenesis

In the future, all levels of DO in the midface may benefit from automation of the distraction technique by the incorporation of a micromotor controlled by a microprocessor, allowing smooth and continuous distraction. Automated DO would liberate patients from having to comply with protracted distraction schedules requiring multiple clinical sessions held over several weeks. Moreover, success of the distraction procedure no longer would depend on patients to activate the distraction device. Dental implants also may be combined with distraction hardware to provide anchorage for pulling or distracting forces (Fig. 17). Endoscopy may be another future adjunct to the distraction procedure facilitating minimally invasive

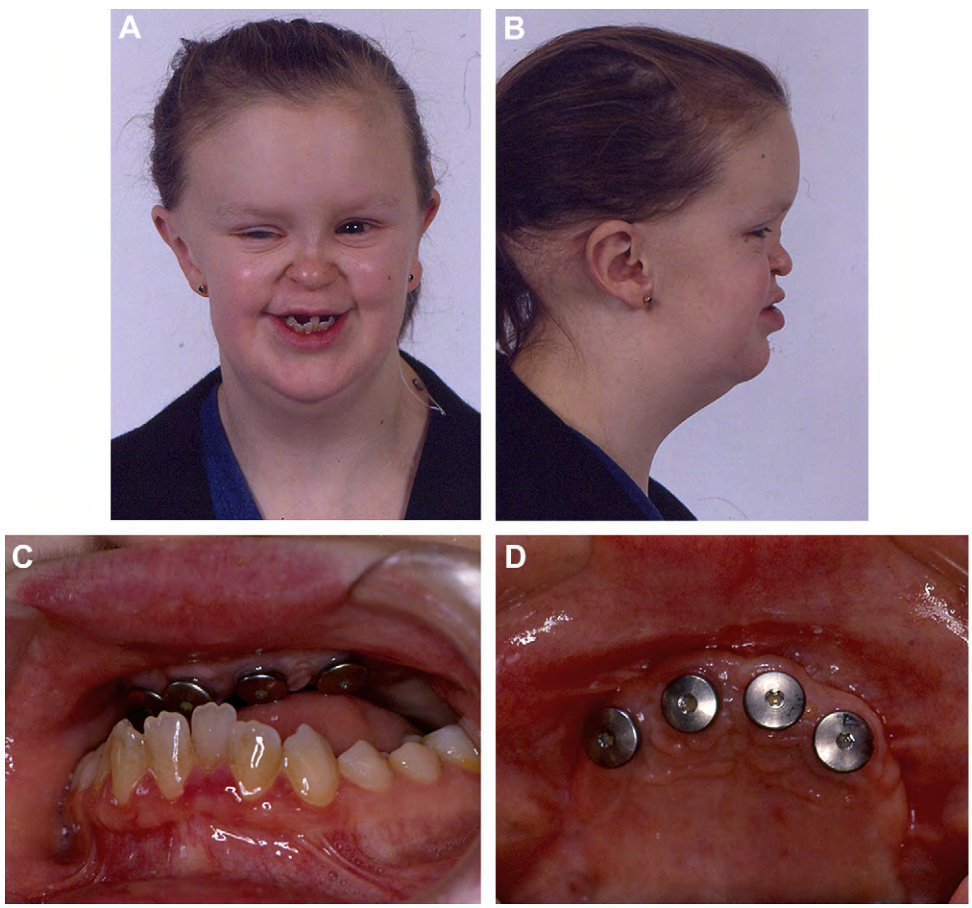

Fig. 17. (*A*) Frontal view of patient who had extreme midfacial hypoplasia after radiation of the face to treat a maxillary rhabdomyosarcoma in infancy. (*B*) Lateral view of same patient. (*C, D*) Dental implants may offer the opportunity to provide anchorage for distraction devices to pull on the midface using an external halo appliance.

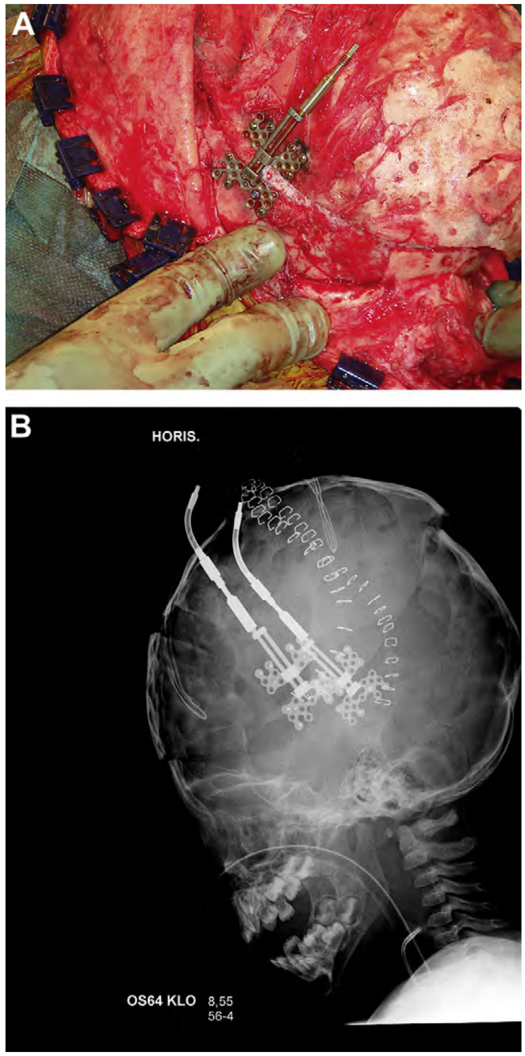

Fig. 18. (*A*) Cranial distractor applied to temporoparietal region of the skull to permit progressive cranial expansion by DO. (*B*) Paired cranial distractors positioned with complimentary vectors of distraction.

surgery with improved visualization of the osteotomy sites. Cranial DO is another possibility (Fig. 18) to allow progressive cranial enlargement in cases of recurrent craniosynostosis. It also may be combined with DO at multiple levels of the midface.

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Orthopedic and Orthodontic Management of Distal Segment Position During Distraction Osteogenesis

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Long-bone distraction osteogenesis as developed by Ilizarov, Codvilla, and others used a circumferential distraction device that provided controlled linear bone elongation. The distraction device could be applied directly parallel to the bone's long axis, which was the desired vector of distraction. The varying curvilinear form of the facial bones and their relationship to the soft tissues and specialized structures of the face create limits on device placement and vector realization. Difficulty has been experienced in designing devices for craniofacial distraction that offer the same control and stability that circumferential distraction devices provide in lengthening long bones. Although designs for craniofacial devices have been improved substantially, the limitations for corticotomy/osteotomy placement and device placement imposed by the complexity of human facial anatomy probably never will be overcome completely. For this reason orthodontic/orthopedic control of the distal segment is important to the quality of outcomes achieved with distraction osteogenesis.

The principal concern addressed in this article is the position of the distal segment during and following the activation and consolidation phases of distraction. Once consolidation is complete, the position of the distal segment, good or bad, is fixed. The goal, therefore, is to maximize the capabilities of the distraction device to deliver the desired vector(s) by selecting the correct device, applying it at a proper orientation, and taking advantage of whatever adjustability the device offers. In addition, having control of the dentition allows manipulation of the distal segment position to optimize occlusion, facial esthetics and function.

Although not inclusive, situations requiring special consideration in control of the distal segment include (1) delivering bilaterally symmetric advancement of the mandible, maxilla, and/or midface, (2) correcting asymmetry with unilateral vertical and anteroposterior distraction of the mandible, (3) recognition of premature consolidation as the source of distal segment misdirection and its management, (4) providing a level of precision in distal segment position that is comparable to traditional jaw osteotomies when used as the definitive procedure on skeletally mature patients, and (5) compensating for inadequacies in osteotomy and/or device placement.

Distal-segment positional issues observed with bilateral advancement of the mandible, maxilla, or midface include incomplete correction, unintended asymmetric advancement, anterior open-bite formation, or other malocclusion. These issues may be result from incomplete presurgical preparation, improper treatment planning, dental interferences during activation, inadequate corticotomy/osteotomy implementation, errors in device position, hardware limitations, and/or inadequate control of the occlusion.

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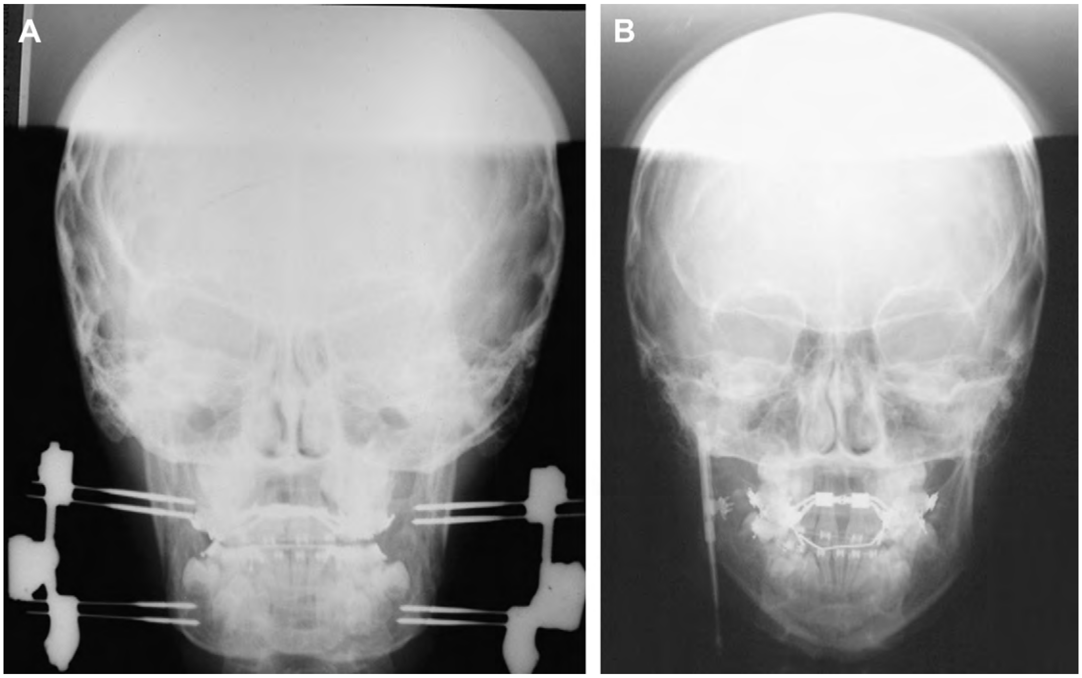

Fig. 1. (*A*) An external distraction device that is a significant distance from the bone. (*B*) An internal distraction device in close proximity to the bone.

If the distraction device is not long enough, the desired position of the distal segment cannot be achieved. The ratio of skeletal lengthening to device activation is not 1:1 but instead varies based on the distance from the device to the bone surface (along with other factors): the closer the device is to the bone, the closer the ratio is to 1:1, and the ratio decreases as the device is distanced from the bone surface (Fig. 1). Distance from the device to the bone must be taken into consideration when selecting the device length. For an ''average'' device placement, a conservative rule of thumb is to select a device that has twice the lengthening capacity of the desired result. For example, if the desired linear anteroposterior correction at the incisors is 15 mm, a device with a length of 30 mm or more should be selected. It also is important to understand that additional length is needed in a device that offers three-dimensional adjustment if the angular component will be activated.

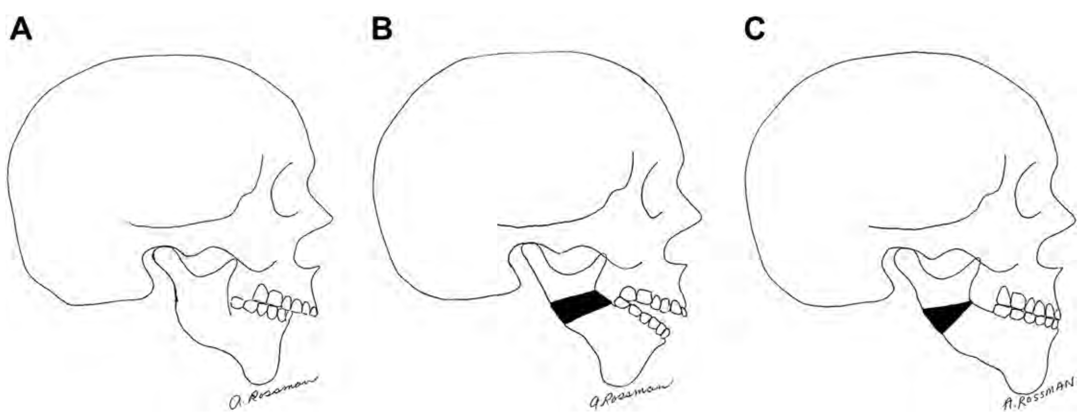

Fig. 2. Bilateral mandibular distraction of a hypoplastic mandible. (*A*) With linear lengthening, posterior dental interference results in an anterior open bite. (*B*) Linear distraction results in equal distances between the proximal and distal segments on the medial and lateral surfaces of the ramus. (*C*) Angular distraction results in a convergence between the distal and proximal segments on the medial surfaces of the ramus. A minimum of 10 mm of linear lengthening must precede angular activation to prevent consolidation of the medial aspects of the ramus. Note the open bite is corrected.

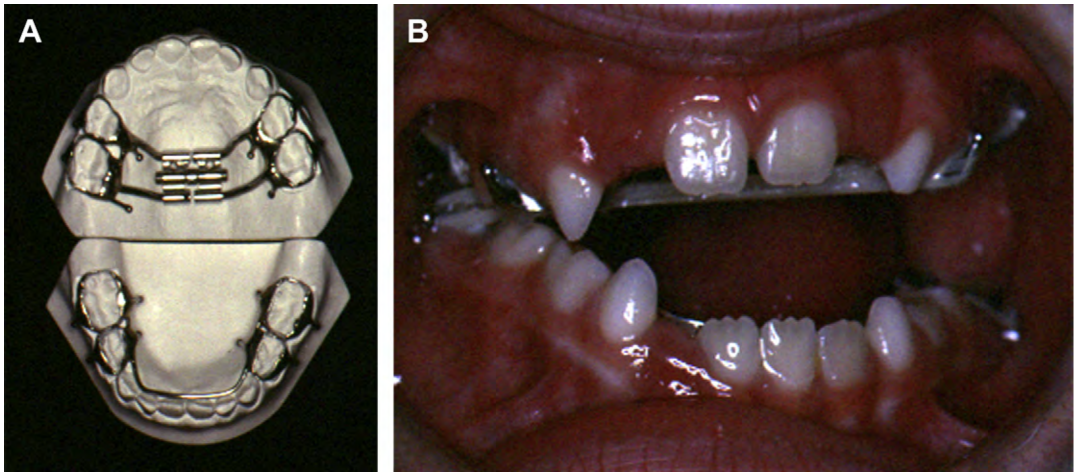

Fig. 3. (*A*) The distraction stabilization appliance: a double-banded maxillary expansion appliance and mandible lingual holding arch with ball hooks buccal and lingual on all bands. (*B*) Interarch elastics attached to stabilization appliances to maintain midline position of the mandible during unilateral vertical ramus distraction for the management of vertical mandible asymmetries. (*From* Hanson PR, Melugin MB. Orthodontic management of the patient undergoing mandibular distraction osteogenesis. Semin Orthod 1999;5(1):25–34; with permission.)

When the angular component of a multidimensional device is activated in the mandible, the lateral surface of the mandible maintains or increases the distance between the distal and proximal segments. Conversely, the medial surface of the ramus sees a convergence of the proximal and distal segments as the angulation dialed into the distraction device is increased (Fig. 2). To prevent convergence and interference of the proximal and distal segments at the medial surface, a distraction gap must be established before the angular component of the device is activated. It is widely accepted that a 10-mm distraction gap is necessary before angular activation to avoid this interference. When angular activation is added, a net loss of linear length is observed. Hence additional linear activation is required to achieve the desired anteroposterior result, and therefore the device must be longer.

Multidirectional mandibular distraction devices offer the ability to correct emerging asymmetry with transverse adjustments. This capability is not used frequently, as illustrated

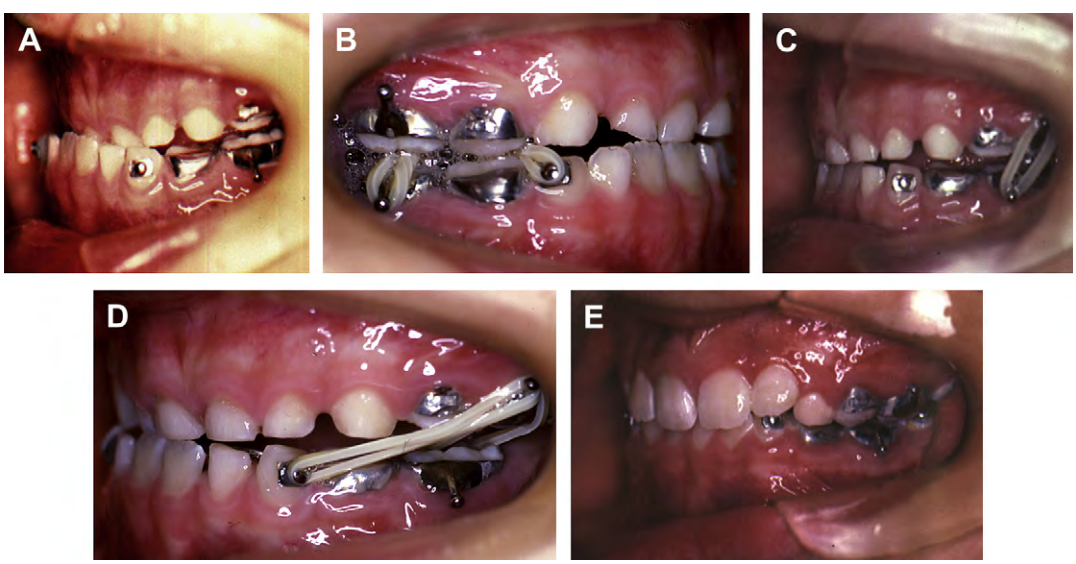

Fig. 4. (*A*) Unwanted class III development during unilateral mandible distraction osteogenesis planned for the vertical ramus correction in craniofacial microsomia. (*B–D*) Class III elastics to correct class III dental relationship and to improve OJ. (*E*) Final occlusion showing improved overbite/overjet.

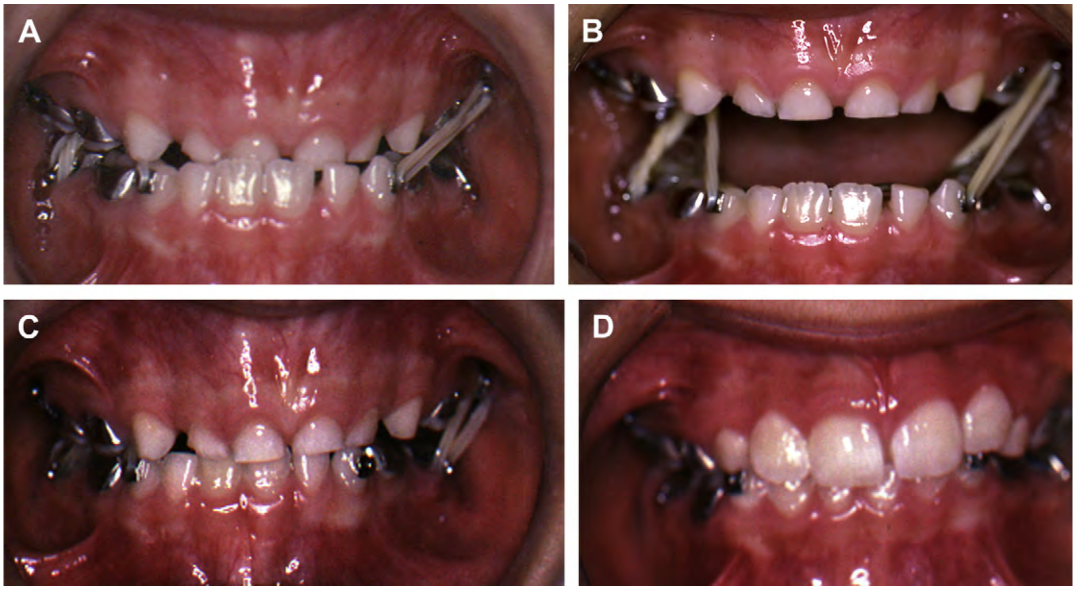

Fig. 5. (*A*, *B*) Unilateral class III elastics and protraction headgear to correct midline deviation and class III malocclusion that developed during unilateral mandible distraction osteogenesis. Protraction headgear placed posterior force on the chin to redirect the distal segment. (*C*) The class III malocclusion is improved, but the midline still is deviated. (*D*) The class III correction is maintained with growth and dental maturation.

in the following example. If the distal segment is moving asymmetrically to the right, one intuitively would consider activating the device to the left to correct this asymmetry. Unfortunately, the result of left-transverse adjustment is not movement of the distal segment to the left. Instead, the condyle segment, offering less resistance to force than the distal segment, moves left with the left-transverse adjustment. This movement of the condyle segment results in a counterintuitive movement of the distal segment to the right in accord with left-transverse adjustment. More predictably, interarch elastics may be used to manipulate the distal segment orthopedically during active distraction to improve the sagittal relationship of the distal segment and to control misdirection. This manipulation is accomplished with heavy elastic traction on distraction-stabilization appliances or similar rigid tooth-borne appliances to ''guide'' the mandible to the desired position (Fig. 3).

In addition to elastic traction, distal-segment control may be achieved in many ways. Adequate predistraction arch preparation (removing potential dental interferences), including

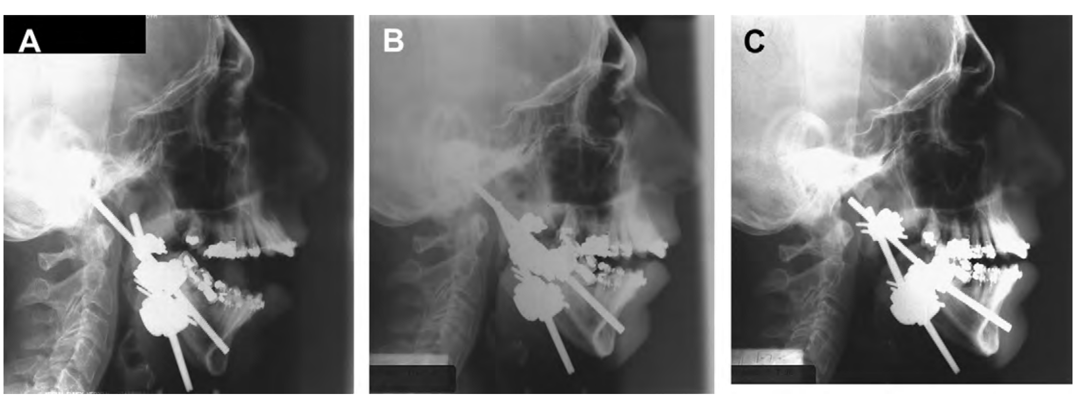

Fig. 6. A 47-year-old man who had severe mandibular hypoplasia and associated obstructed sleep apnea. (*A*, *B*) Posterior dental interference resulting in open-bite formation. (*C*) After 1 week of vertical and class II elastics to close the anterior open bite, presumably molding the regenerate and dental and skeletal segments to close the anterior open bite.

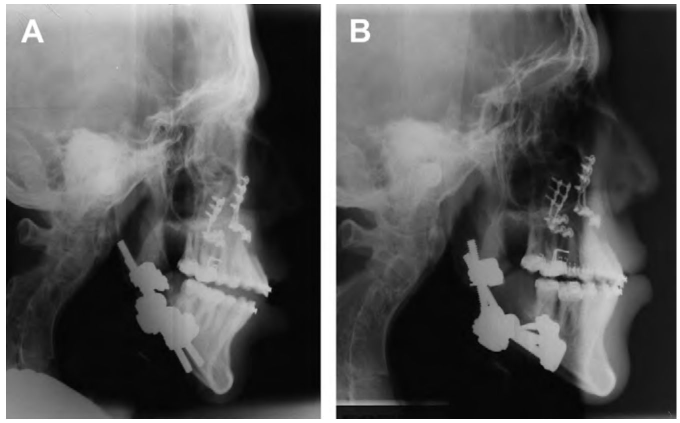

Fig. 7. (*A*) Bilateral mandibular distraction osteogenesis with the development of unwanted open bite secondary to posterior dental interference. (*B*) The open bite is controlled with a combination of elastic traction and angular activation of the distraction devices.

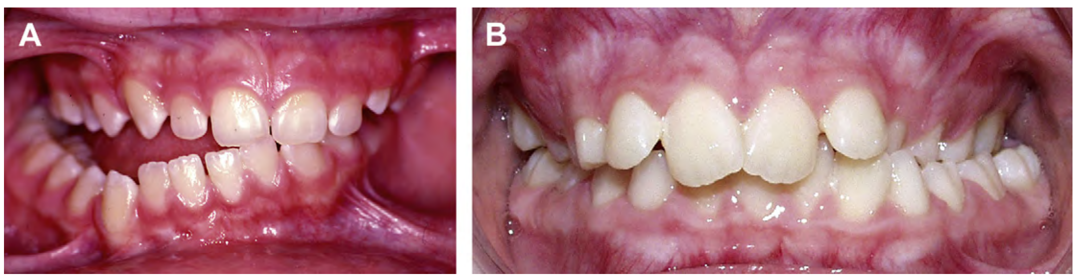

Fig. 8. (*A*, *B*) Two examples of laterognathism: an unwanted outcome of unilateral vertical lengthening of the ramus during correction of mandibular vertical asymmetry if the device is not placed perpendicular to the occlusal plane and/or if midline position of the mandible is not maintained with elastic traction. With some component of unwanted anteroposterior advancement, the mandible and mandibular dental midline deviate laterally away from the distraction side, a crossbite develops on the contralateral side, a buccal cross bite develops on the distracted side, open bite may result on the contralateral side, and the distracted side fails to lengthen vertically. The desired open bite on the deficient side is not realized. For image *A*, distraction was completed for the left ramus with right laterognathism developing and for a different patient in image *B*, right side distraction caused left laterognathism.

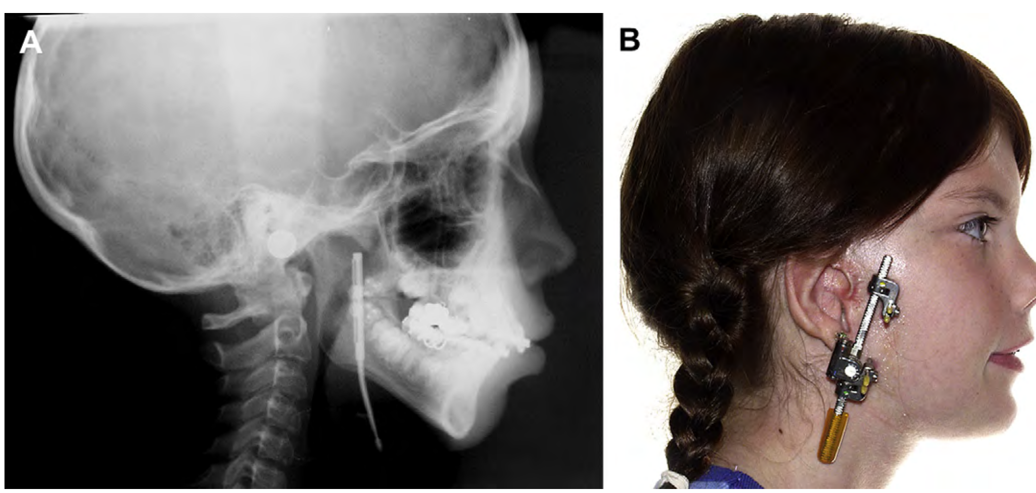

Fig. 9. (*A*) An internal distraction osteogenesis device parallel with long axis of the ramus. Activation results in angle and body elongation with a net effect of anteroposterior advancement, failure of desired vertical lengthening of the ramus, failure of the desired open-bite formation. (*B*) An eternal distraction osteogenesis device perpendicular to the occlusal plane results in vertical lengthening of the ramus, correction of the mandibular occlusal cant, and the desired unilateral open-bite formation.

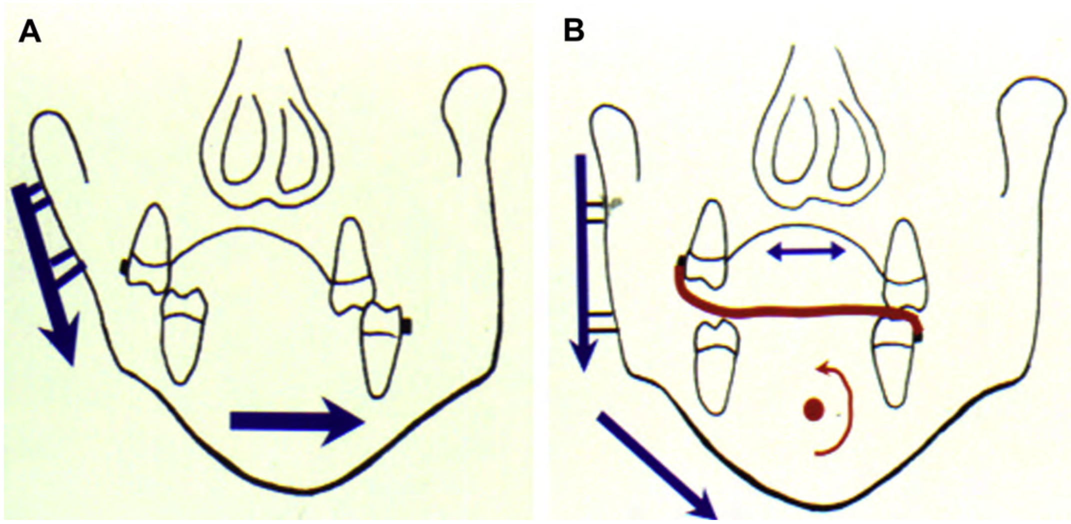

Fig. 10. The biomechanics of Hanson's distraction stabilization appliance. (*A*) Laterognathism: the mandible and chin point shift away from the distraction side, cross bite on the distraction side, buccal cross bite on the contralateral side, failure of desired open-bite formation on the distraction side. (*B*) Maxillary expansion to address cross bites. The mandible midline position is restored by interarch elastic wear: cross arch/cross palatal, class III on the distraction osteogenesis side, class II on the contralateral side, and cross bite on both sides. (*Courtesy of* Barry Grayson, DDS, Craniofacial Orthodontist, New York University Medical Center, Institute of Reconstructive Plastic Surgery; with permission.)

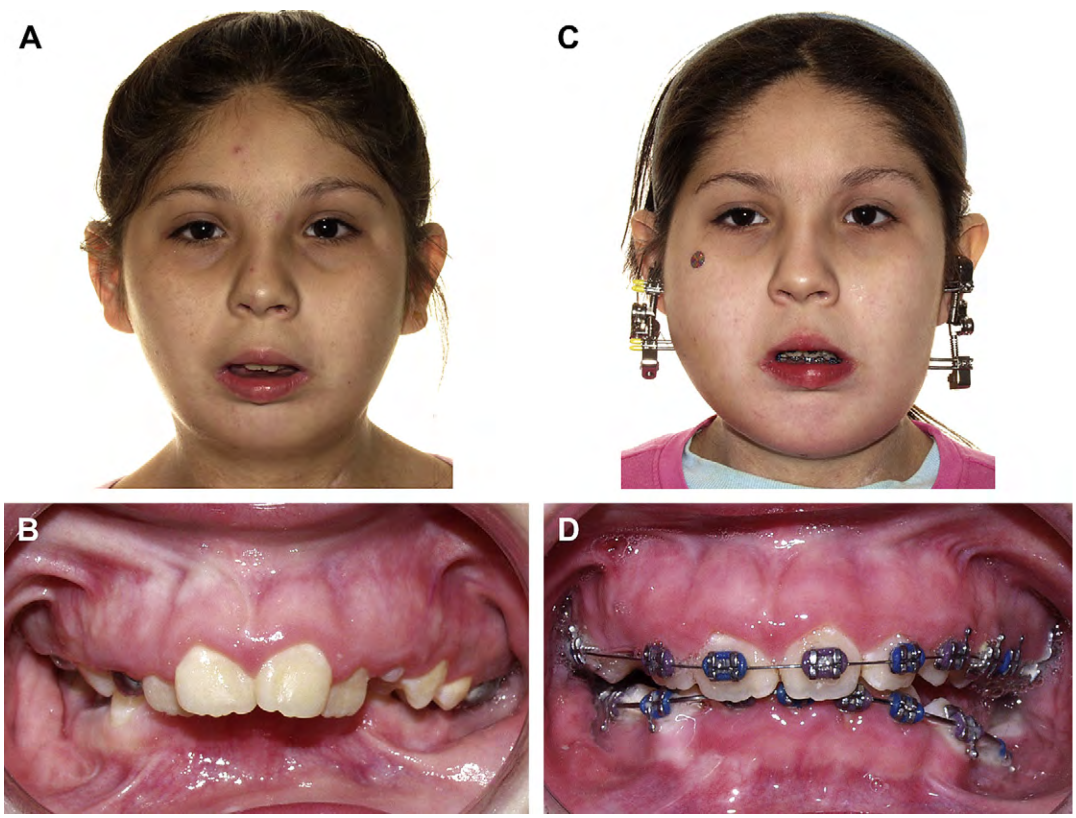

Fig. 11. In the pretreatment (*A*,) facial and (*B*) intraoral views, note that the maxillary and mandible midlines are coincident. Facial (*C*) and intraoral (*D*) views during distraction show premature consolidation of the left side with the chin point moving left, the right mandible lengthening and bowing, and the left mandible not lengthening. The pins on the left side are converging in the area of consolidation because device activation outpaces lengthening osteogenesis, which has stopped. The mandibular dental midline has shifted left significantly.

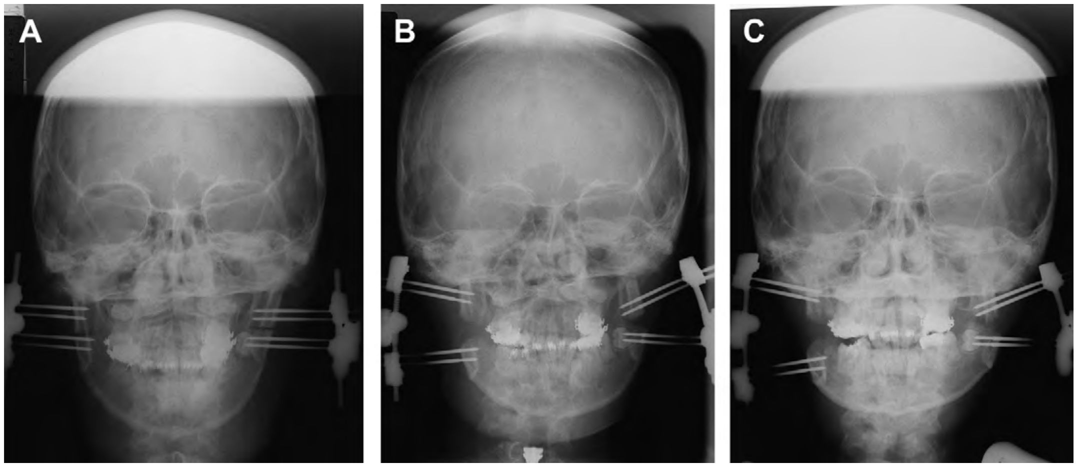

Fig. 12. Frontal radiographs of the patient shown in Fig. 11. (*A*) Radiograph taken immediately after device placement shows parallel pins and right-to-left symmetry. (*B*) After 4 weeks of distraction, the pins are beginning to converge toward the bone, activation becomes more difficult and painful, and facial, skeletal, and occlusal asymmetry is developing. (*C*) After 6 weeks of distraction, all findings shown in B have worsened, and the medial surface of ramus demonstrates boney consolidation on the left side.

osteotomy position and device orientation, careful surgical execution, and having orthodontic/orthopedic appliances in place before surgery will help mitigate unfavorable distal segment movement when it occurs. As mentioned, manipulating the distal segment by applying orthopedic force via dental appliances often is the most effective and precise means of correcting misdirection. Force may be applied to the advancing skeleton in any direction that change is indicated. A common example is the use of class III elastics placed unilaterally during a class II distraction to control a developing asymmetry (Fig. 4). In this scenario, additional linear lengthening may be needed to compensate for the period of class III elastic wear (Fig. 5). In addition to elastics, other orthopedic modalities (ie, high-pull headgear, protraction headgear) may be used 24 hours per day with elastics changed frequently throughout the day to maintain peak force. Close monitoring of orthopedic forces by the surgeon and/or orthodontist is necessary to assure that distal segment correction is adequate. It is common to alter the configuration of elastics at every appointment, twice per week, to achieve the desired result

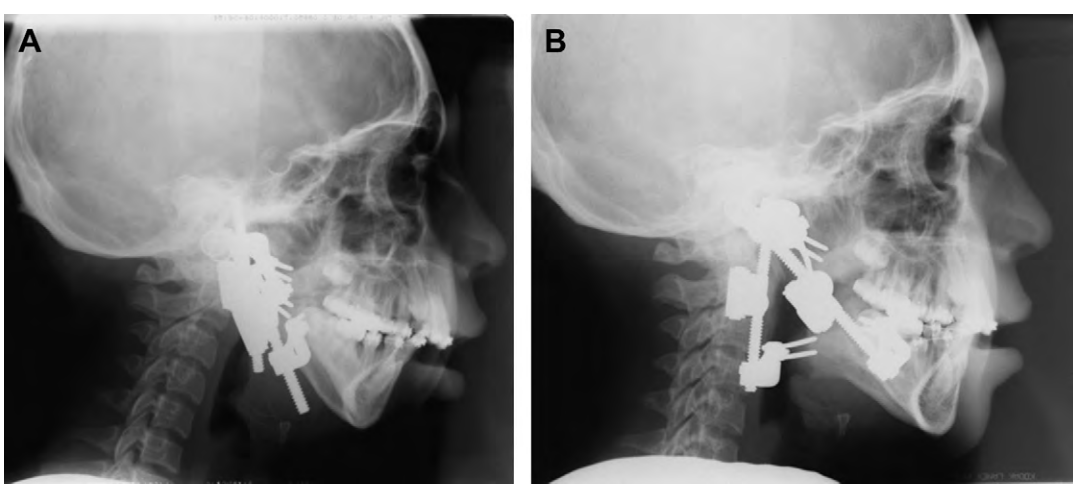

Fig. 13. Lateral radiographs of the patient in Fig. 11. (*A*) The predistraction radiograph shows the devices are approximately parallel. (*B*) During distraction premature consolidation occurs on the left. The distraction devices lose parallelism as osteogenesis ceases on the left side.

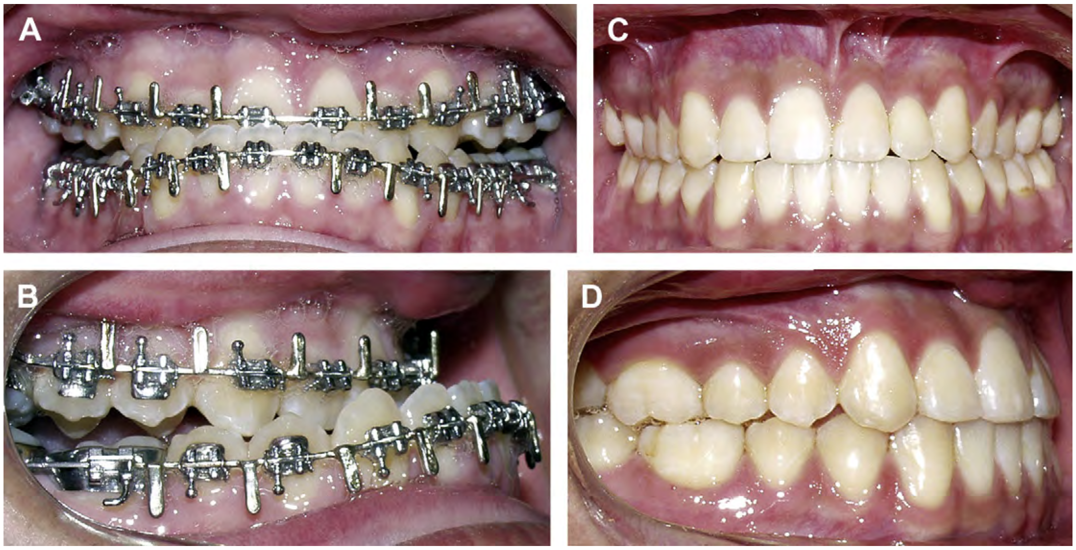

Fig. 14. (*A*, *B*) Before distraction, the arches are leveled, aligned, and coordinated, as they would be before orthognathic surgery. (*C*, *D*) After distraction and debonding.

(Fig. 6). Angular activation of the multidirectional distraction device may be used carefully in concert with orthopedic forces to achieve optimal distal segment control (Fig. 7).

When vertical and anteroposterior distraction lengthening is planned to correct mandibular asymmetry (most commonly for the correction of craniofacial microsomia), caution must be exercised to prevent the development of laterognathism (Fig. 8). For craniofacial microsomia, the desired distraction outcome is to create a unilateral open bite as the mandible is lengthened vertically on the affected side. The distraction-corrected mandible moves vertically away from the uncorrected maxilla on the treated side, resulting in the desired unilateral open bite (that subsequently is closed either surgically or orthodontically). As this open bite develops, caution must be exercised to assure that maxillary, mandibular, and facial midlines are maintained or improved. Doing so requires a truly vertical distraction vector that is accomplished by appropriate osteotomy and device orientation and careful orthopedic control. Vertically the device must be placed perpendicular to the occlusal plane; visually, this vector appears to have a slightly ‘‘backward’’ orientation (Fig. 9). This placement allows the vertical lengthening of the mandible with very limited or no sagittal advancement or rotation, which could lead to laterognathism. Some have described vertical device placement as being parallel with the long axis of the ramus. Parallelism with the ramus, however, adds a slight anterior horizontal vector that advances the distraction side anteriorly in addition to vertically, resulting in a lateral shift of the mandible. This lateral shift fails to achieve the desired vertical correction and open bite and also creates a contralateral midline shift, cross bite on the treatment side, and buccal cross bite on the unaffected side as the mandible advances rather than lengthens vertically during activation (Fig. 10). Predistraction placement of a distraction stabilization appliance (see Fig. 3) that also incorporates an expander allows maxillary transverse correction and can provide multiple attachments for orthopedic force delivery (see Fig. 3). In the example of craniofacial microsomia management, the stabilization device is used in conjunction with class III elastics on the affected/distraction side, class II elastics on the unaffected side, a cross-palatal elastic from the buccal of the maxillary first molar on the affected side to the buccal of the mandibular first molar on the unaffected side, and a cross-bite elastic on the unaffected side from the buccal of the maxillary first molar to the lingual of the mandibular first molar (see Fig. 10). This arrangement helps maintain the midline position of the distal segment, allows the unilateral open bite to develop, and prevents unwanted laterognathism. The elastic force required is determined by placing the elastics in position and increasing the weight and number of elastics until the mandibular dental midline reaches the desired position. If the midline position of the symphysis is

Fig. 15. An 18-year-old male who had severe maxillary hypoplasia secondary to unilateral complete cleft lip and palate and mandibular prognathism underwent midface advancement by distraction osteogenesis. Pretreatment (*A*) frontal and (*C*) lateral views. (*B*) Frontal and (*D*) lateral views after distraction and after orthodontics.

maintained, the desired unilateral open bite occurs, and the facial/occlusal cant is corrected in the mandible. The patient wears the elastics 24 hours per day, and they are changed throughout the day in association with eating and brushing.

Premature consolidation of the distraction regenerate also is a source of asymmetry, insufficient lengthening, and failure to maintain control of movement of the distal segment. Premature consolidation is the formation of a solid osseous union between the distal and proximal segments at the distraction gap during the activation phase of distraction. Premature consolidation may be the result of an incomplete corticotomy/osteotomy, a latency period that was too long and allowed osseous healing to occur, a rate of distraction that is too slow, angular adjustment with insufficient production of a linear distraction gap, an unusual healing response, or a combination of any of these factors. Premature consolidation may be identified by discomfort at the distraction site during activation, the convergence toward the corticotomy/osteotomy of pins that initially were parallel, the development of asymmetry, and increased resistance in the device during activation (Fig. 11). On frontal radiography, pin convergence can

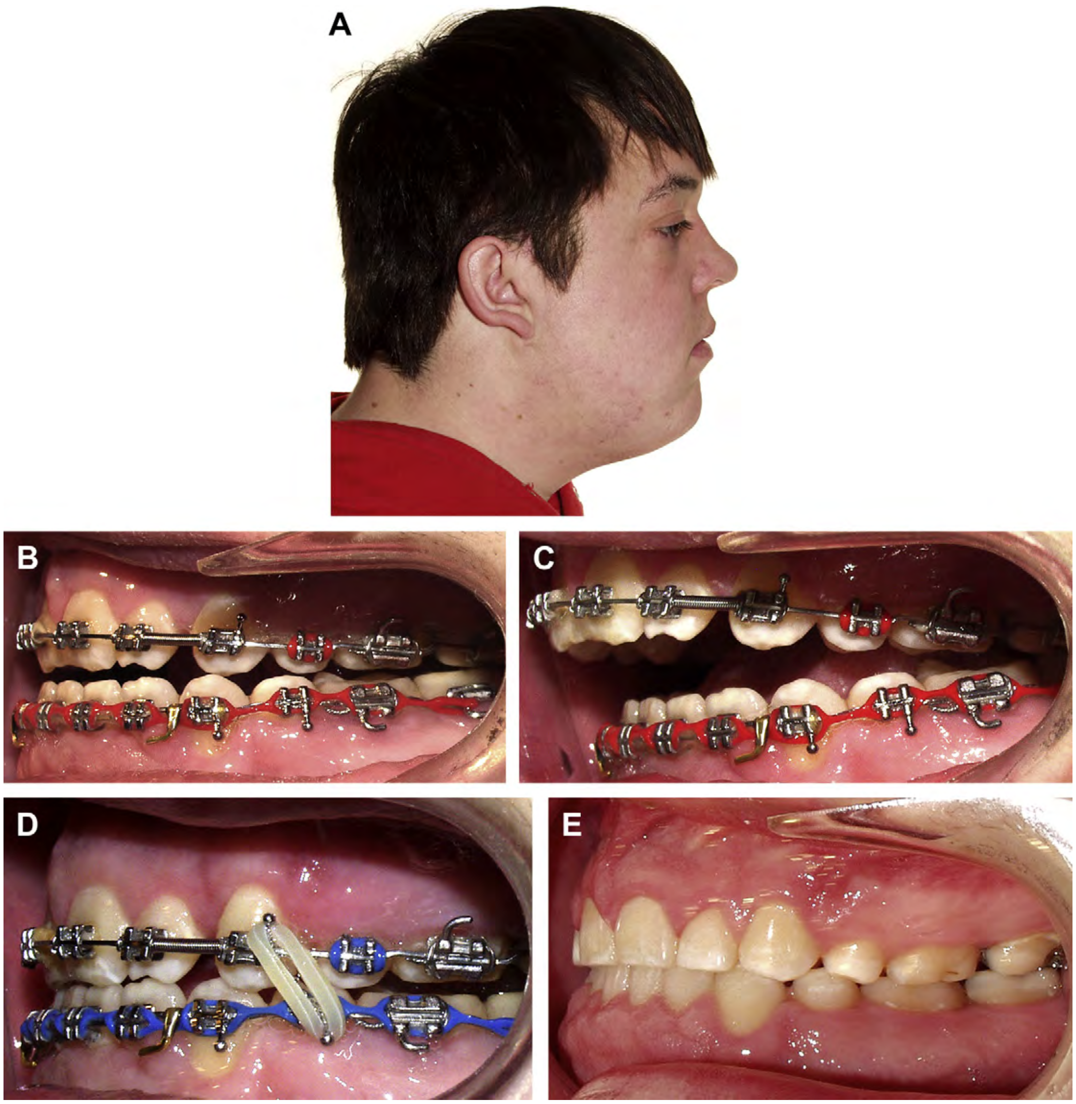

Fig. 16. A 17-year-old male who has Aperts syndrome undergoing midface advancement by distraction. (*A*) Midface advancing. (*B*, *C*) Midface advancement overcorrects occlusion to achieve desired esthetic midface result. Note the posterior dental interference and resultant open bite. (*D*) Class III elastics (opposite the distraction vector) are used to settle the occlusion. (*E*) Final occlusion. Distraction osteogenesis and orthodontics only.

be confirmed, and bony union at the distraction gap, often on the medial surface of the ramus, also can be detected (Figs. 12 and 13). Premature consolidation is less frequent in the maxilla and midface. In some instances, continued activation of the device may generate enough pressure to create spontaneous fracture at the area of consolidation, with resumption of distraction. Acute linear advancement occurs, often with significant discomfort, followed by a reported ''relief'' of the pressure that the patient was feeling with prior activation. In many instances, however, the surgeon must go back to surgery to reosteotomize the segments so that the distraction may resume. Orthopedic forces applied to the dentition are not effective in managing this complication. The best management is early recognition of the phenomenon, which allows quick surgical correction before significant asymmetry can develop.

Distraction osteogenesis often is used as an interim correction measure in patients who have significant skeletal and soft tissue deficiencies that will require definitive surgical management at growth completion. Alternatively, distraction sometimes is used as the definitive procedure for correcting a skeletal facial deformity and associated malocclusion. Definitive correction with distraction is used when the magnitude of correction exceeds what might be stable with

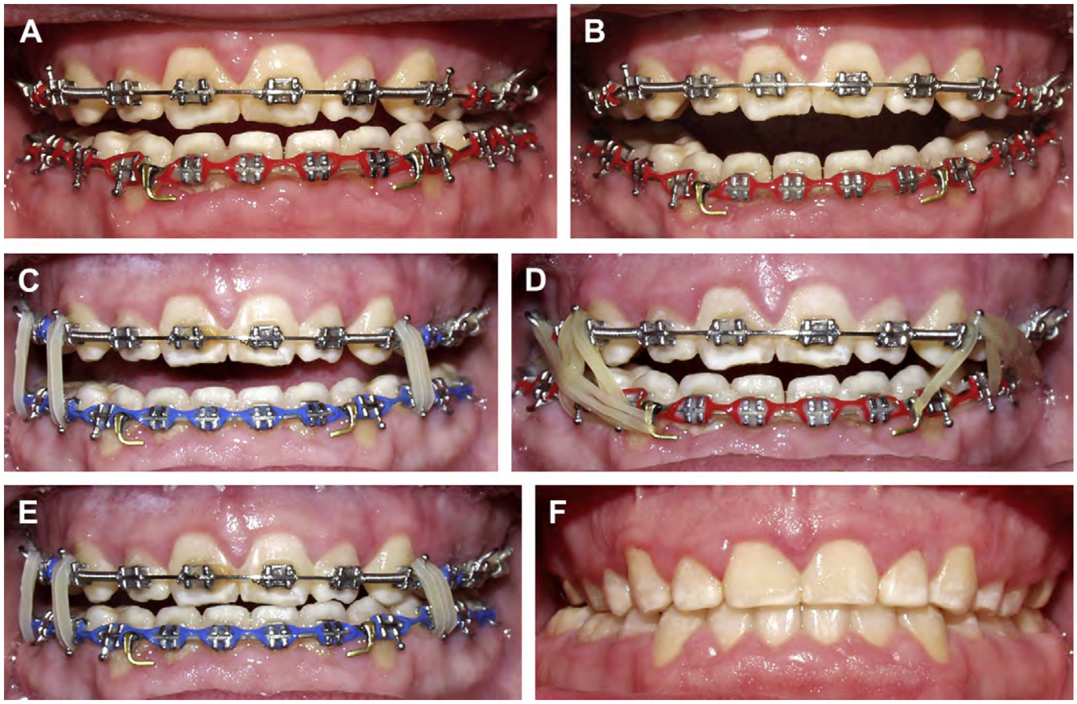

Fig. 17. A 17-year-old male who has Aperts syndrome with midface advancement. The successive images were taken less than 1 week apart. (*A*) Lateral shift of the midface with anteroposterior correction. Note midlines. (*B*) Bite opens with posterior dental interference as the midface is shifted left. (*C*) Improved midline, open bite is improving. (*D*) Midlines and open bite are improving. (*E*) Bite is closing, midlines are improving. (*F*) Finished occlusion.

conventional osteotomies (Figs. 14 and 15). For these patients, the presurgical preparation of the orthodontic arch, in terms of leveling, aligning, and coordinating the arches, may be similar to that done in preparation for orthognathic surgery. This preparation may require lengthier predistraction orthodontic treatment than needed in other distraction situations. At a minimum, the arches must be prepared so that during distraction the tripod contact can be achieved that

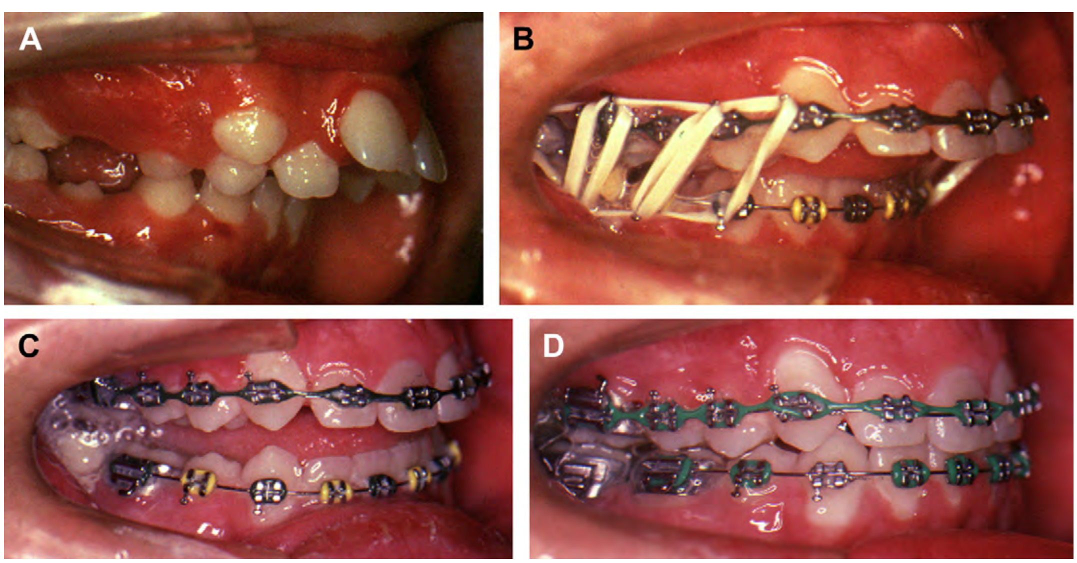

Fig. 18. A 17-year-old male undergoing bilateral mandibular distraction osteogenesis. (*A*) Before treatment. (*B*) The development of posterior dental interference during distraction osteogenesis creating an anterior open bite. Class II box elastics are used to advance and rotate the distal segment superiorly. (*C*) Progress photograph. (*D*) Final occlusion after distraction osteogenesis and elastic guidance of the distal segment.

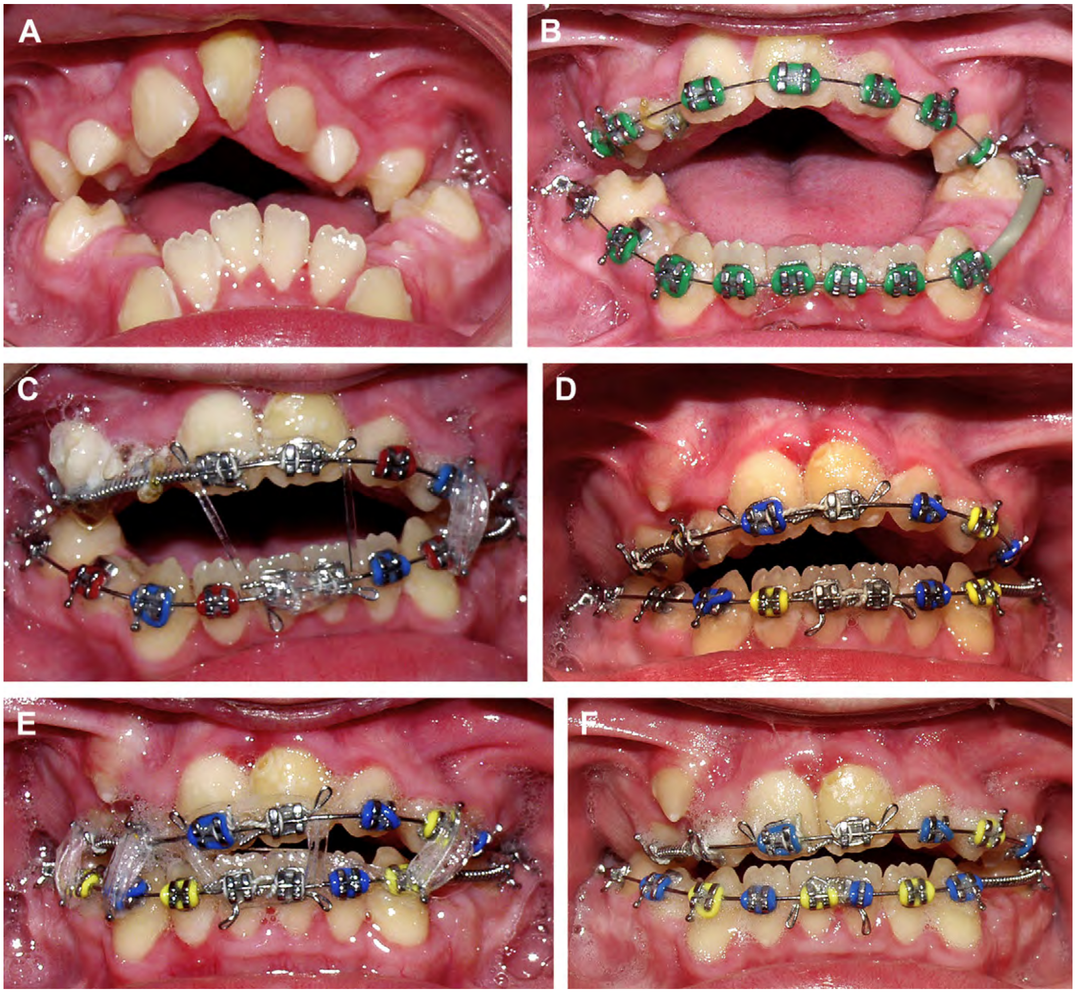

Fig. 19. Orthodontic/orthopedic management for a 12-year-old boy who has Aperts syndrome undergoing midfacial distraction advancement. (*A*) Before treatment. (*B*) Orthodontics preparation, level arches. (*C*) Open-bite closure via distal segment manipulation with interarch elastics. (*D*) The open bite is decreased. (*E*) Open bite decreased and midlines improved with elastics. (*F*) Occlusion 6 weeks after device placement.

allows further coordination and finishing after distraction. The occlusion can be detailed in the predistraction, interim, and postdistraction phases of treatment. During distraction, careful monitoring by both the surgeon and the orthodontist allows the final ''docking'' of the distal segment to be in a position that maximally corrects facial disharmony and provides an occlusion that can be finished functionally and esthetically (Figs. 16–21).

In addition to orthodontic management of the dental arch and guidance of the distal segment by elastic traction, a satisfactory occlusal outcome is achieved by taking advantage of the enhanced movement of the tooth and bone segment that is observed following jaw osteotomy, that is, the rapid acceleratory phenomenon (RAP) response. In 1983, Frost described the RAP as ''a complex reaction of mammalian tissues to diverse noxious stimuli [that] … occurs regionally[,] … involves soft and hard tissues, and is characterized by an acceleration and domination of most ongoing normal vital tissue processes. It may represent an 'SOS' mechanism which evolved to potentate tissue healing and local tissue defensive reactions'' following surgery. Frost defines the noxious stimuli as bone operations of any kind, among other insults.

> Once evoked, many ongoing regional soft and hard tissue vital processes accelerate above normal values. Collectively, those accelerated processes represent the RAP, and they include: profusion; growth of skin, bone, cartilage and hair, turnover of bone, cartilage, synovial fluid, connective and fibrous tissue; chondral and bone modeling including correction of malunions in children; skin epitheliazation; cicatrisation; soft tissue and bone healing; and cellular metabolism.

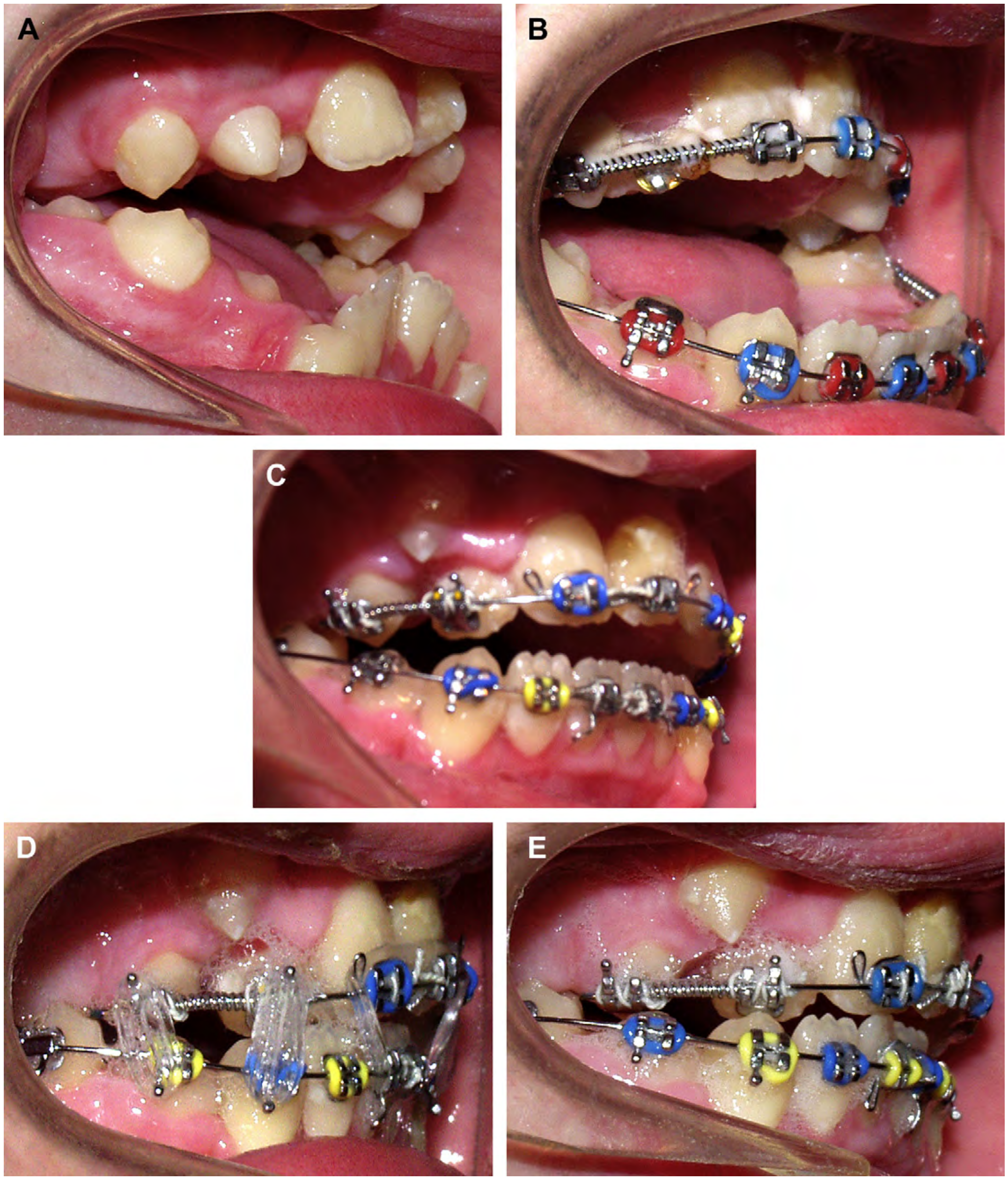

Fig. 20. Orthodontic/orthopedic management of a 12-year-old boy who has Aperts syndrome undergoing midfacial distraction advancement. (*A*) Before treatment. (*B*) Dentition aligned, posterior dental interference and open-bite formation. (*C*) Bite closing secondary to elastic traction. (*D*) Elastics and bite closure. (*E*) Bite closure.

Clinically, an acceleration of dental movement and an apparent plasticity of the alveolar process allow quicker resolution of substantial occlusal disharmonies than would be seen in the nonsurgical patient. Exploitation of the RAP response allows postsurgical manipulation and large-scale alteration of the position of dental and skeletal segments to optimize occlusion. Orthopedic forces obtained with the use of elastic traction and headgear can create these RAP-enhanced movements when incorporated with distraction osteogenesis. Caution must be exercised to assure that teeth are not being extruded or otherwise moved to the limit of the alveolus under the applied orthopedic forces.

An additional response to the application of orthopedic force that allows distal segment repositioning involves reshaping and reorienting the bone created by distraction (the regenerate). The regenerate responds to forces generated on it by the angular activation of the distraction device and by applied orthopedic forces so that the shape and orientation of

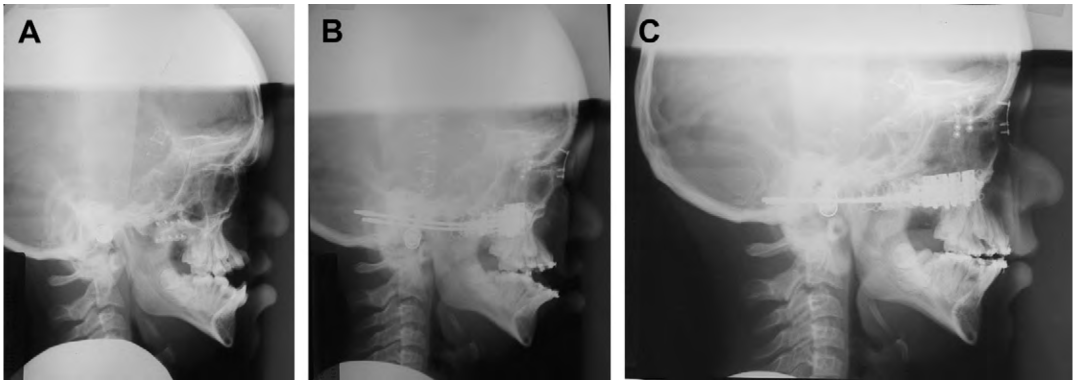

Fig. 21. Orthodontic/orthopedic management of a 12-year-old boy who has Aperts syndrome undergoing midfacial distraction advancement. (*A*) Before midface distraction. (*B*) Distraction osteogenesis devices and orthodontic appliances are placed. (*C*) Six weeks after device placement, distraction osteogenesis advancement of the midface, orthopedic (elastic traction) rotation of the midface which removes posterior dental interferences and vertically positions the anterior maxilla, autorotation of the mandible, and open-bite closure. Note the anterior open bite closed primarily by clockwise rotation of the distal segment (midface), with slight mandibular incisor eruption and uprighting.

this bone is altered permanently. By directing the distal segment, the conformation and orientation of the new bone that is generated is altered in a permanent and stable fashion to maintain the position of the distal segment over the long term.

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Mandible Reconstruction with Transport Distraction Osteogenesis

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The mandible is a unique intramembranous bone that crosses the facial midline terminating in fibrocartilage-covered joints articulating against the cranial base. The basal portion of the mandible—the condylar neck, ramus, body, and symphysis—functions to support facial, oral, and pharyngeal soft tissues. The basal portions serve as attachments for muscles of facial expression and the muscles of mastication and the muscles of the tongue. The alveolar process is uniquely adapted to support the development and function of the dentition and periodontium. The mandible is in near constant motion as a result of the normal functions of swallowing, breathing, speaking, chewing, and expression. During these functional activities, the mandible is stressed or loaded by tensile and compressive forces, which vary with protrusive and right and left lateral excursive movements. A loss of continuity of the mandible and a breach of its ability to support the face and perform these important functions can occur as a result of trauma, infection, and benign and malignant neoplasms. Selection of the appropriate reconstruction technique for a mandibular continuity defects is based on many issues, including the host characteristics. Host characteristics that can influence successful reconstruction include patient age, metabolic status, tissue vascularity, and availability of stem cells. Ideally there is an absence of infection, minimal scar tissue, and minimal tissue damage as a result of radiation. Considerations when reconstructing the mandible include appropriate stability, isolation from the oral cavity, and a source of inducible stem cells. The result of the reconstruction should provide patients with a mandible of appropriate size, shape, and maxillary mandibular relationship.

Continuity defects of the mandible

Traditional approaches to achieve mandible reconstruction have been the use of autogenous bone from the iliac crest together with a reconstruction plate, a metal or alloplastic tray, or allograft bone to achieve the appropriate shape of the mandible. These approaches, although successful, require large amounts of autogenous bone and often require time-consuming intraoperative procedures, such as rolling a patient over to access posterior iliac crest. An alternative choice is the use of viable fibula osteomyocutaneous grafts, which requires a significant donor site and substantial operating time and expertise associated with graft procurement and vascular anastomosis. Current trends in mandibular reconstruction aim to achieve reestablishment of a viable mandible of proper form and maxillary mandibular relationship while decreasing the need for invasive autogenous graft procurement. To date the need for autogenous bone has not been completely eliminated in mandible reconstructions, but the amount needed has been substantially decreased and, thus, the morbidity and time

The author discloses that he participated in the development of the threadlock transport distractor, but he does not have a financial interest associated with its sale or its manufacturer KLS Martin.

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associated with graft procurement improved. In addition, when grafts are used they are combined with recombinant human bone morphogenetic protein-2 (rhBMP2)/absorbable collagen sponge (ACS) (1.5 mg/mL) (Infuse, Medtronic, Minneapolis, Minnesota) or transport distraction osteogenesis. This article's *Further Readings* lists articles on mandible reconstruction using rhBMP-2/ACS and transport distraction osteogenesis.

Transport distraction

The purpose of this atlas article is to provide relevant principles and technique information regarding approaches to mandible reconstruction by transport distraction osteogenesis. The use of transport distraction osteogenesis for reconstruction of the temporomandibular joint was published in a previous issue of *Atlas of the Oral and Maxillofacial Surgery Clinics of North America*; thus, the focus of this article is on reconstruction of defects of the mandibular body with transport distraction. I discuss these concepts by reviewing four cases. The complexity of these cases does not vary greatly with the complexity of the defect or surgery but more with regard to the important host (patient) factors. Transport distraction for reconstruction of continuity defects is most efficient for defects of the mandibular body. When used to reconstruct a defect of the body of the mandible, the transported segment not only achieves bone continuity but also, through histiogenesis, the associated attached tissue is reconstructed achieving a natural ridge with a vestibule. Transport distraction is limited to reconstruction of a relatively straight line defects as seen with defects of the mandibular body. This is because the connective tissue stroma within regenerate dictates the shape of the reconstructed tissue. If attempts are made to move a transport disc around a curve, the regenerate forms a straight segment between the point of transport origin and completion. Thus, if it is necessary to reconstruct a defect of the symphysis, the best plan is to create transport discs from the right and left posterior stumps of the mandible and move them toward the symphysis. The residual defect in the symphysis requires a bone graft. An alternative plan is to transport right and left transport discs forward from the body with a vector that lets them consolidate in the midline and then follow that procedure with a second midline osteotomy and application of a midline distracter to widen the symphysis.

Figs. 1–4 provide information regarding the basic features of a transport distracter, (Threadlock design, KLS Martin, Jacksonville, Florida) and the concepts of transport distraction. The design of this transporter is universal in nature. It can be used to transport segments of the right or left body of the mandible from anterior to posterior or from posterior to anterior. The transport shaft is available in a variety of lengths, including 30, 40, 50, and 60 mm, and can be attached above the bone plate, below the bone plate for continuity defects, or to native mandible in cases of marginal resection with remaining basal bone. In Fig. 1, the components of the device are labeled. Component 1 is a fixed titanium mesh that extends above and below the transport shaft 5. It can be attached to residual bone to provide additional stability or removed if not needed. Component 2 is the transport segment attachment mesh that moves along the variable length transport shaft 5 at 0.5 mm per complete turn of the activation arm 4. The activation arm is attached to the transport shaft and includes multiple ball joints to permit unstressed alignment of the activation arm during turning of the device. The activation arm can

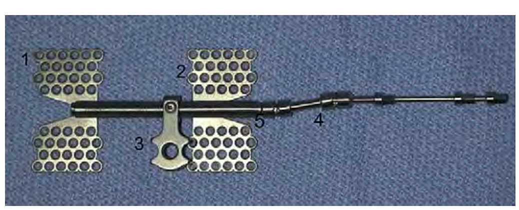

Fig. 1. Threadlock transport distractor with components labeled: static mesh designed for attachment to native bone adjacent to the defect (1); transport mesh designed for attachment to the transport segment (2); attachment arm that holds the transport shaft and permits anterior posterior adjustment of its position relative to the defect—it can be attached to a threadlock plate or directly to bone in a marginal resection (3); activation arm (4); and transport shaft (5).

Fig. 2. Shows the transporter attached (3) to a threadlock plate (6) stabilizing a continuity defect. The transport mesh (2) is attached to a transport segment.

remain intraoral and emerge through mucosa or it can emerge through the skin for percutaneous activation. Component 3 is the attachment arm that provides an attachment for the transport shaft 5 to a reconstruction plate or basal mandible. The attachment location of the attachment arm to the transport shaft relative to the defect or its attachment to a plate or mandible can be adjusted anterior or posterior by loosening the set screw and sliding it along the groove in the transport shaft and then tightening the set screw to fix it in the desired location. It is best to attach the arm (see Fig. 3) to the plate or mandible at the point of greatest curvature if a curve exists, to avoid binding of the transport segment as it moves along the transport arm. The attachment arm accepts a screw designed to attach it to a locking plate or a locking screw for attachment to the mandible. The attachment arm can be removed from its slot in the transport shaft and flipped for cases where it is best to have the transport arm located below the reconstruction plate. Fig. 2 shows the transporter configured for anterior to posterior transport with attachments to the reconstruction plate proximal mandible and the transport segment. The transport bone segment should be 1.5 cm wide $\pm$ 0.5 cm and equal to the full thickness of the mandible. Care should be taken during preparation of the transport segment to maintain its vascular supply by not detaching periosteum or soft tissue attached to its coronal or lingual surfaces. Transport usually is initiated after a latency of 5 to 7 days at a rate of 1 mm per day $\pm$ 0.5 mm. In Fig. 3, there is a partially transported segment showing the clearance between the transport segment and the curvature of the bone plate. In Fig. 4, the linear relationship of the transport shaft between the points of initiation and completion of distraction is shown. The principles of distraction can be applied by using a system such as the one described previously. These principles include linear transport of a segment with appropriate dimensions and vascular supply with a mechanically smooth but rigid system that permits adaptation to the defect and minimizes micromotion.

Fig. 3. Shows a partially transported segment.

Fig. 4. Shows the linear path of the transport segment (1) from its origin to its destination; (2) is the proximal segment attachment.

Case presentations

Case 1

A 27-year-old man was referred to the author's practice with an infected bone graft of his right mandible and a nonunion of the left mandibular angle (Fig. 5). His initial injury was a job-related mandible fracture that was treated by a closed reduction. His second surgery before presenting to the office was an autogenous bone graft from the iliac crest to the right mandibular body stabilized with a locking reconstruction plate and he was placed into maxillomandibular fixation. He had a significant social history that included a 10-pack-year history of cigarette smoking, which continued during the first two surgeries. His findings at the author's institution were that his bone graft was infected and he had a draining oral cutaneous fistula.

His treatment was divided into two phases. In phase one, an open reduction with rigid internal fixation on the left angle fracture was planned with débridement of the right side and his jaw was stabilized with external pin fixation. He was treated with oral chlorhexidine rinses and antibiotics until there was complete resolution of the infection. Phase two treatment included reconstruction with transport distraction osteogenesis and an autogenous cancellous bone graft from the tibial plateau that was done at the completion of the distraction. A stereolithographic model was obtained and model surgery was completed to establish the appropriate occlusion and alignment of the segments. A reconstruction plate was adapted to the form of the mandible, and the transporter was configured for posterior to anterior distraction of a 1.5-cm segment (Fig. 6). The continuity defect was 2.5 cm (Figs. 7 and 8) and distraction of 1 mm and 1.5 mm on alternating days was started after a 7-day latency period. The transport segment

Fig. 5. Case 1 baseline panorex of patient who had infected bone graft and oral facial fistula at nonunion of right mandible (1) and nonunion of left angle (2).

Fig. 6. Shows transport distractor preconfigured for surgery on a model. The distractor is attached to proximal bone (1) and the transport segment (2). The transport shaft (3) is attached to the adjustable attachment arm (4) and stabilized with the set screw. A screw will be used to attach the attachment arm (4) to the threadlock plate (5). The activation arm (6) is configured for emergence in the facial vestibule.

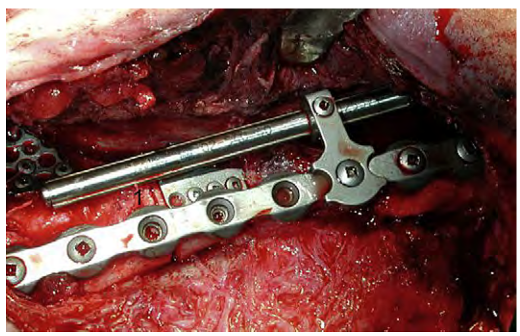

Fig. 7. The preconfigured transport distractor is placed at the reconstruction site. The transport segment osteotomy is shown (1).

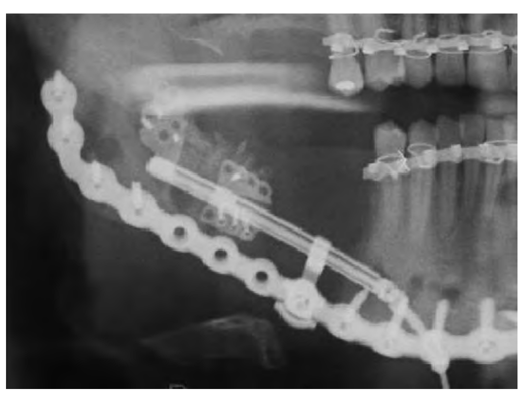

Fig. 8. Baseline postsurgical panorex representing latency phase.

was docked after 20 days of distraction with development of a ridge form, attached mucosa, and vestibule (Fig. 9) but without significant radiographic evidence of maturation of the regenerate (Fig. 10). Consolidation (maturation phase) was continued for 35 days after completion of distraction during which time significant radiographic evidence of regenerate maturation developed (Fig. 11). A second surgery was performed to remove the transporter and place a small amount of autogenous bone graft to achieve a final union of the reconstructed segment. Exposure of the treated area revealed a vascular palpable firm regenerate (Fig. 12). Removal of the transporter (Fig. 13) exposed regenerate bone firmly attached to the transport segment and a small gap with fibrous tissue between the transport segment and native bone at the dock site. Ten cm of cancellous bone was procured from the tibial plateau and packed in the dock site gap and adjacent to the regenerate (Fig. 14). The reconstruction plate was left to resist regenerate contraction during maturation of the bone graft (Fig. 15). The patient's mandible occlusion symmetry and facial form were re-established (Fig. 16).

Case 2

A 23-year-old woman was referred with a recurrent infected ameloblastoma involving the body and ramus of the mandible (Figs. 17 and 18). She had no negative systemic health factors, but pertinent local host factors including the infection and a post-resection continuity defect of 60 mm. Again, her therapy was divided into the two phases. In the first phase, she had an incision and drainage of the infection, antibiotics, and extraction of teeth 28, 29, and 30. Phase two surgery included a vestibular incision with intraoral resection of the tumor, and nerve preservation by pullout and reanastomosis. The surgical defect of 60 mm was stabilized with a reconstruction plate formed on the original model (see Fig. 18). An oscillating saw was used to prepare a 1-cm transport segment in area 28, and a transport distracter was attached to the transport segment, reconstruction plate, and proximal bone. A latency period of 7 days was selected to allow the mucosal incision to heal. Transport of the segment was begun advancing the segment 1 or 1.5 mm per day on alternating days (Fig. 19). The transport segment was docked by 45 days approximately 0.5 cm short of the ramus bone, with radiographic evidence of early regenerate maturation (Fig. 20). Clinically the patient had a well developed ridge, vestibule, and attached tissue (Fig. 21). After a 35-day maturation phase, the reconstruction site was examined (Fig. 22), and a firm vascular regenerate was observed. Similar to case 1, the transporter was removed and a cancellous bone graft was placed in the gap between the transport disc and proximal segment and along the surface of the regenerate. The reconstruction plate was left to stabilize the mandible during final maturation of the regenerate and bone graft (Fig. 23). Four months after placing the bone graft the reconstruction plate was removed, a wide viable mandible was observed, and implants were placed (Fig. 24). The patient's mandible,

Fig. 9. Intraoral view of the vestibule and attached gingiva present after the distraction phase is complete. Reconstructed vestibule ridge and attached tissue.

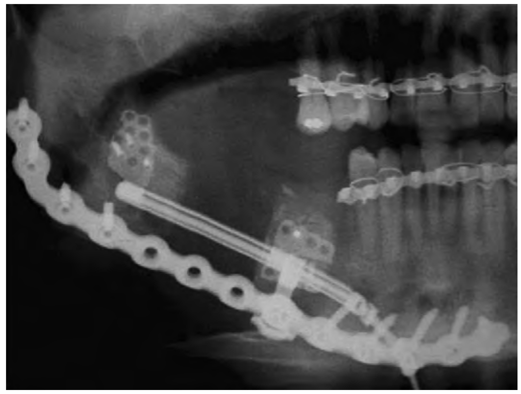

Fig. 10. Panorex of the docked transport segment at the completion of the distraction phase but before maturation.

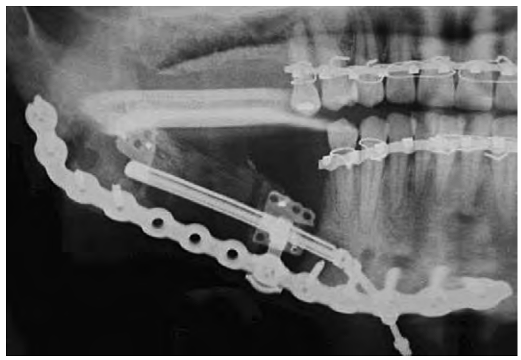

Fig. 11. Panorex after maturation phase showing radiopacity of the mature regenerate.

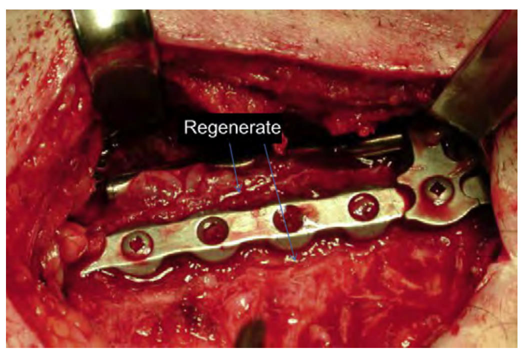

Fig. 12. Vascular regenerate shown filling the reconstructed defect.

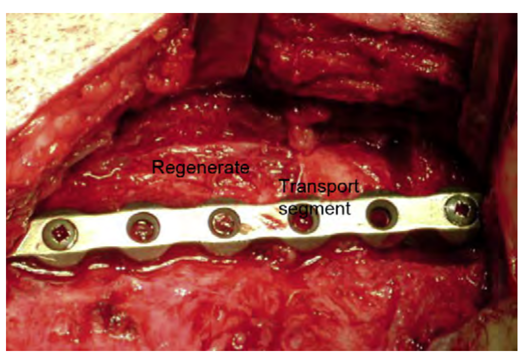

Fig. 13. The regenerate filling the reconstructed defect has the same dimensions as the transport segment. A small gap remains at the dock site between the transport segment and native bone.

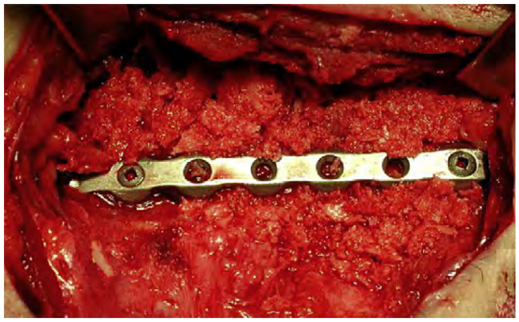

Fig. 14. Autogenous particulate bone from the tibial plateau placed in the transport dock gap and over the regenerate.

Fig. 15. Panorex after the bone graft shows mature regenerated mandible and union between the transport segment and native bone (1).

Fig. 16. The patient's post-treatment facial form is normal.

Fig. 17. Case 2 baseline panorex shows large recurrent infected ameloblastoma (1).

Fig. 18. Threadlock plate configured to mandible before resection. Model shows ameloblastoma and reconstruction plate.

Fig. 19. Partially transported segment (1). Transporter attached to native bone (2) and to threadlock plate (3).

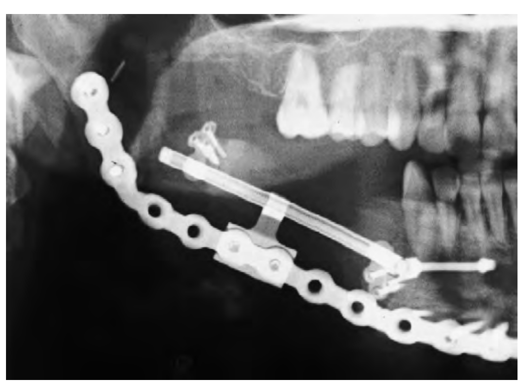

Fig. 20. Docked transport segment before maturation.

Fig. 21. Intraoral view after distraction phase showing regenerated vestibule and attached gingiva.

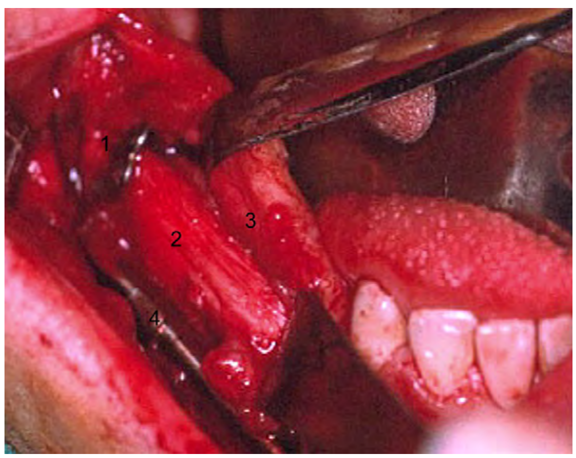

Fig. 22. Intraoral view at time of distractor removal. Transport segment (1), regenerate (2), reflected mucosa (3), and distractor shaft (4).

Fig. 23. Reconstructed mandible after maturation phase of regenerate and placement of a small amount of particulate autogenous bone graft.

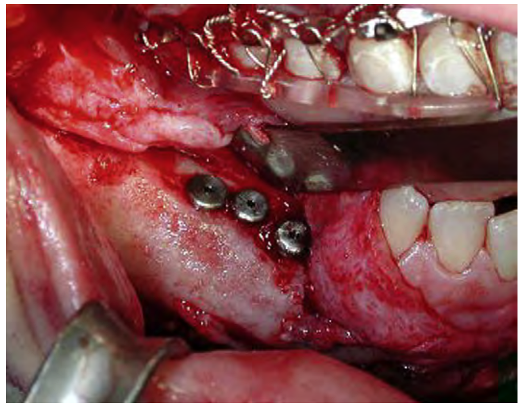

Fig. 24. The reconstructed mandible is shown at the removal of threadlock plate and placement of dental implants procedure.

occlusion, attached tissue, and vestibule all were reconstructed via a strictly intraoral approach (Figs. 25 and 26), and her natural facial form and symmetry were preserved without facial scars (Fig. 27).

Case 3

A 45-year-old woman required resection of the mandible as a result of osteomyelitis that had not responded to intravenous antibiotic therapy and débridement (Fig. 28). During phase one surgery, the nonvascular portion of the mandible was resected resulting in a 50-cm defect. The remaining mandible was stabilization with a preformed locking reconstruction plate (Fig. 29). Phase two surgery occurred 6 months after the resection with CAT scan evidence of no further osteomyelitis. The residual mandible and continuity defect were approached by an intraoral vestibular incision and dissection to expose the facial surface but not the coronal or lingual surfaces of the proposed transport segment in area 28. A sagittal saw used to osteotomize the mandible and prepare a 1-cm wide transport segment in the area of tooth number 28. The transport segment was attached to the transport distracter, and the distracter was attached to the mandible and reconstruction plate (Figs. 30 and 31). A 7-day latency period permitted healing of the vestibular incision, and then distraction was commenced at 1 or 1.5 mm per day on alternating days. Thirty-five days of distraction resulted in the development of a well-formed mandibular ridge attached tissue and vestibule (Fig. 32). Thirty days after completing the distraction phase radiographic evidence of regenerate consolidation was present (Fig. 33).

Fig. 25. Panorex of reconstructed mandible.

Fig. 26. Restored implants in relation to the reconstructed ridge and vestibule.

Fig. 27. The patient was reconstructed to normal symmetry without facial scars.

Fig. 28. Case 3 panorex of painful osteomylitis that did not respond to conservative medical or surgical care.

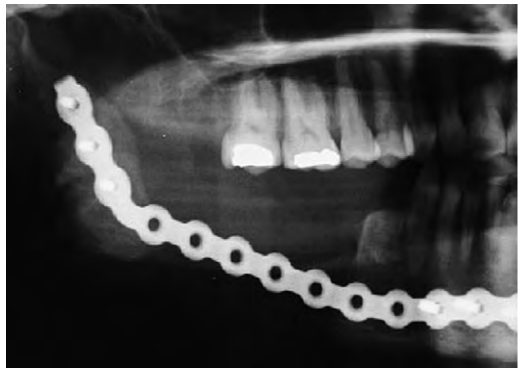

Fig. 29. Case 3 mandible after resection with large continuity defect.

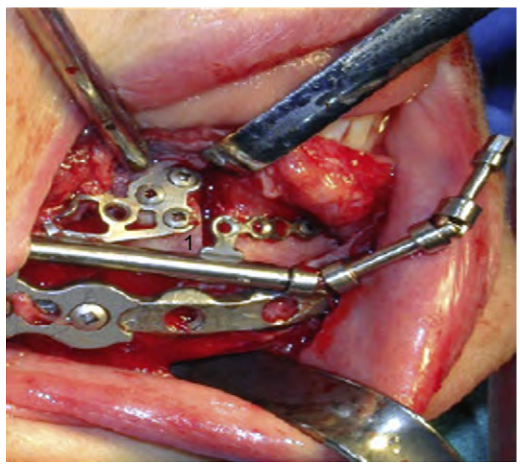

Fig. 30. Intraoral reconstruction with placement of the transport distractor and attachment to the transport segment (1).

Fig. 31. Baseline panorex showing the transport distractor attached to the transport segment, threadlock plate, and proximal bone during latency stage.

Fig. 32. Intraoral view of the reconstructed vestibule, mandibular ridge, and attached gingiva after the distraction phase.

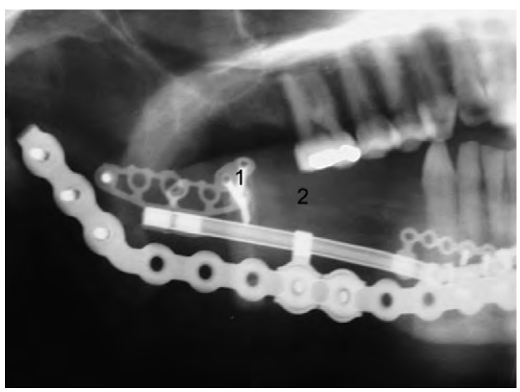

Fig. 33. Docked transport segment (1) and regenerate (2) during early maturation phase.

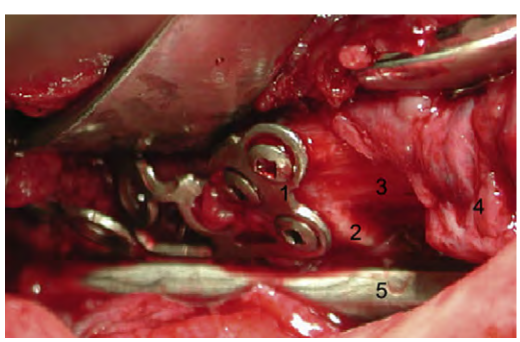

Fig. 34. Intraoral view at the time of distractor removal. Transport mesh (1), transport segment (2), regenerate (3), mucosa (4), and transport shaft (5).

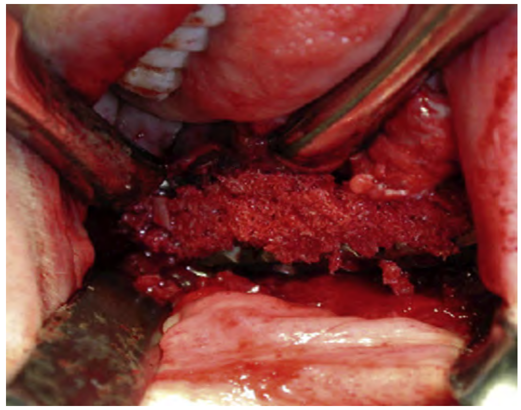

Fig. 35. Autogenous particulate bone graft at transport dock site and over surface of the regenerate.

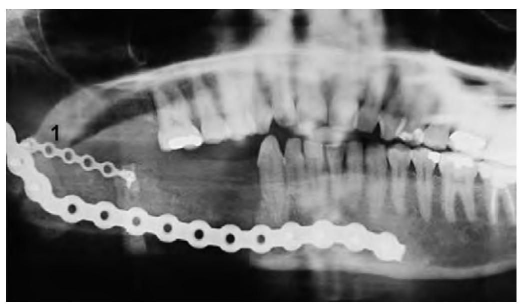

Fig. 36. The transport segment docked short of the proximal mandible; thus, it was stabilized to resist regenerate contraction with a small bone plate (1). The graft (shown in Fig. 35) was placed in the gap and over the regenerate.

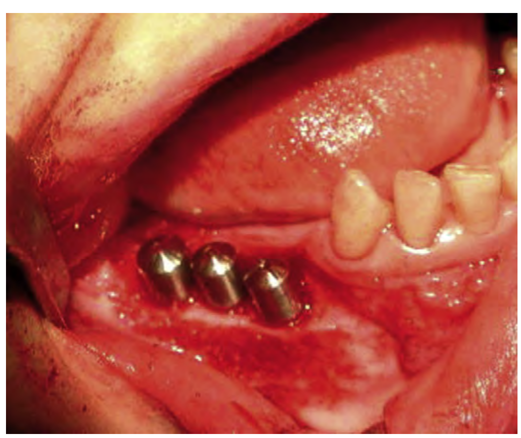

Fig. 37. The mandible and implants shown at the time of reconstruction plate removal.

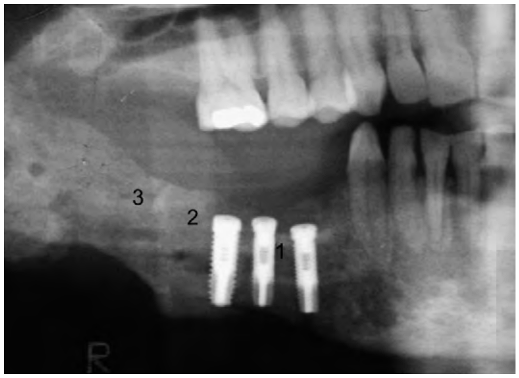

Fig. 38. The implants are shown in the regenerate portion of the reconstruction (1). The transport segment (2) and the grafted segment (3) are proximal.

Fig. 39. The implants are restored to the patient's crossbite. The restored implants are shown in relationship to the reconstructed ridge and vestibule.

Fig. 40. The patient was reconstructed to normal form without facial scars.

Fig. 41. Case 4 model before reconstruction. The continuity defect was the result of osteoradionecrosis, infection, pathologic fracture and débridement.

The reconstruction site was re-entered and findings similar to cases 1 and 2 were observed. The regenerate was vascular firm and connected to the transport segment (Fig. 34). In this case, a gap of 1 cm remained between the transport disc and the proximal mandible and, thus, a bone plate and autogenous cancellous bone graft were placed to complete the reconstruction (Figs. 35 and 36). Six months later, the reconstruction plate was removed, implants were placed, and a wide vascular stable mandible was present (Figs. 37 and 38). The implants were restored to her normal crossbite (Fig. 39), and her normal facial form was preserved without facial scars (Fig. 40).

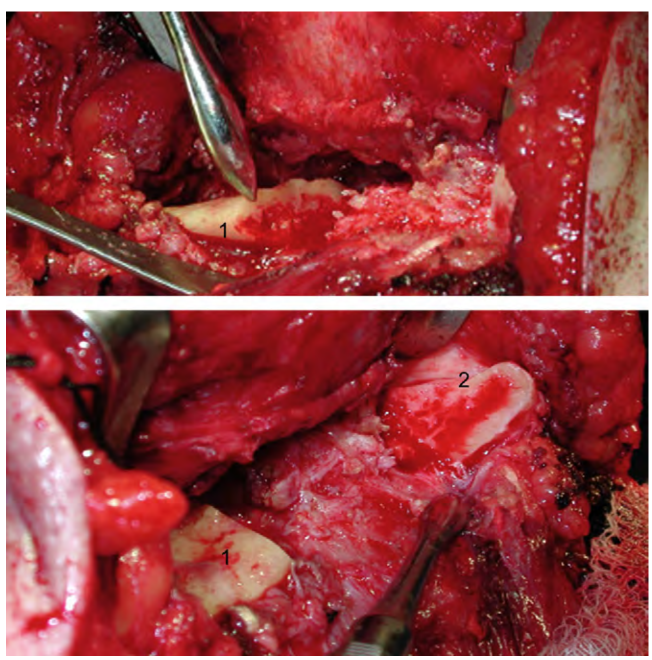

Fig. 42. The proximal transport segment (1) and the distal dock site are shown after hyperbaric oxygen therapy and further débridement. Both segments have a vascular marrow space.

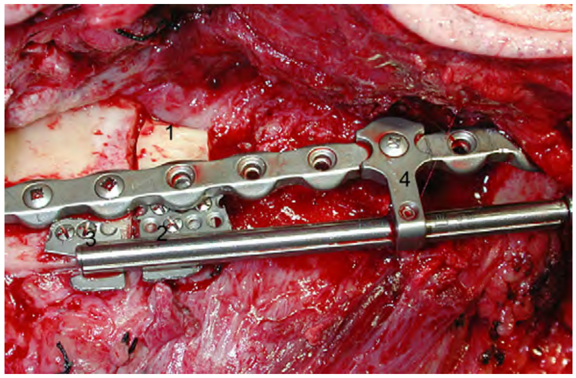

Fig. 43. The transport distractor is configured for attachment below the threadlock reconstruction plate. It is attached to the transport segment (1) by the transport mesh (2). It is attached to proximal bone by the static mesh (3) and to the threadlock plate by the attachment arm (4).

Fig. 44. In this case, the activation arm was configured for exit through the submental skin. This allows easy access for activation and simple site care including normal washing and the placement of antibiotic ointment where it emerges through the skin.

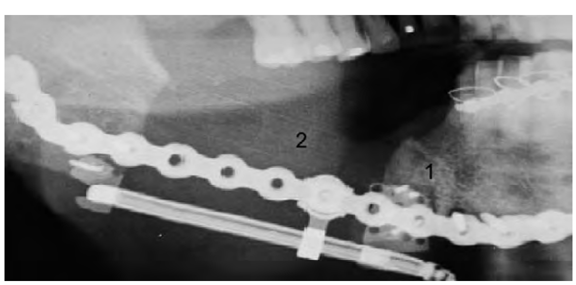

Fig. 45. Panorex of docked transport segment (1) and regenerate (2) during maturation phase.

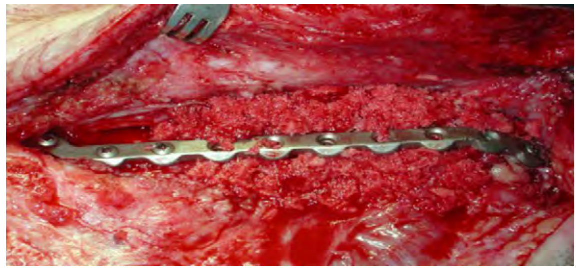

Fig. 46. Particulate autogenous bone graft placed at dock site and over regenerate.

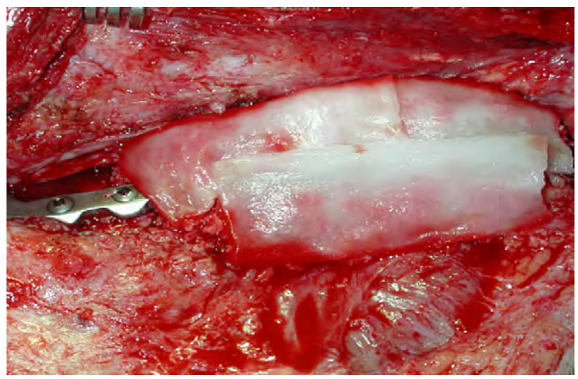

Fig. 47. rhBMP2/ACS (1.5 mg/mL) (Infuse, Medtronic, Minneapolis, Minnesota) placed over graft.

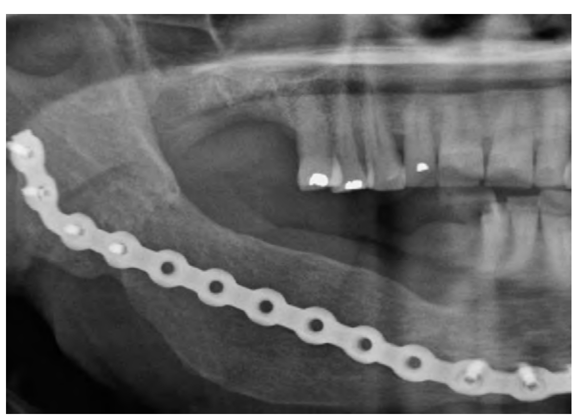

Fig. 48. Complete regeneration of the mandible.

Case 4

A 60-year-old man was referred with a pathologic fracture of the right mandible secondary to osteoradionecrosis. His social and medical histories were significant for a 40-pack-year history of cigarette use that was stopped 6 months before the fracture and type 1 diabetes mellitus. He had had resection of a floor of the mouth, carcinoma with marginal lingual mandibular resection, and radiation of the neck and mandible. Phase one surgery included débridement and stabilization of the mandible with external pin fixation (Fig. 41). Prior to reconstruction, the patient underwent 40 dives of hyperbaric oxygen. The reconstructive surgery included a transfascial approach to the mandible, followed by débridement of the mandible until bleeding bone was present on the proximal and distal segments (Fig. 42). This resulted in a 60-mm continuity defect. The segments of the remaining mandible were stabilization with a preformed reconstruction plate. A 1-cm transport segment was prepared for posterior to anterior transport and care was taken to avoid stripping of periosteum from the coronal and lingual surfaces of the segment (Fig. 43). The transport distractor was attached inferior to the reconstruction plate to avoid encroachment on the oral mucosa, and the transport segment was attached to the mesh (see Fig. 43). In this case, the activation arm was passed through the submental skin where it was easily accessible for turning with the activation tool (Fig. 44). The latency period was 10 days and distraction was completed at 1 mm per day over a 60-day period. Thirty days after completing transport distraction there was radiographic evidence of regenerate maturation (Fig. 45). The reconstruction site was re-entered and the transporter was removed. Evaluation of the regenerate revealed vascular tissue that was firm but not as rigid as the regenerate palpated in the other cases. Although this patient had hyperbaric oxygen to improve the vascularity of the tissue, it is likely that he had decreased stem cells available for bone regeneration as a result of the combined effects of age, tobacco use, diabetes, and radiation tissue damage. The reconstruction was completed by placing 10 cm^3 of autogenous cancellous bone procured from the iliac crest by a trephine technique (Fig. 46), and coverage of the graft with rhBMP2/ACS (1.5 mg/mL) (Infuse, Medtronic, Minneapolis, Minnesota) (Fig. 47). After the graft with bone and bone morphogenetic proteins, a complete union and stable reconstruction with a well-formed ridge were achieved (Fig. 48).

Summary

Transport distraction osteogenesis is a useful method that can be used in conjunction with minimal bone grafting or bone morphogenetic proteins to reconstruct continuity defects of the body of the mandible. In many cases it can be used as a strictly intraoral technique, but in situations where the oral mucosa is compromised by deficiency, disease, or radiation, it should be applied as an extraoral technique. It offers the advantage of osteogenesis combined with histiogenesis to aid in achieving a mandibular ridge supported by bone, covered with attached gingival, and related to an appropriate vestibule. Mandibles reconstructed with transport distraction and bone graft are consistently suitable for implant placement.

Further readings

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