# CONTENTS

## FORTHCOMING ISSUES

September 2008

**Distraction**

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

March 2009

**Mandibular Trauma**

Vincent Ziccardi, DDS, MD, *Guest Editor*

## PREVIOUS ISSUES

September 2007

**Snoring and Sleep Apnea: An Illustrated Guide for Diagnosis and Management**

Mansoor Madani, DMD, MD, *Guest Editor*

March 2007

**Maxillary Reconstruction**

Tirbod Fattahi, DDS, MD, and
Rui Fernandes, DMD, MD, *Guest Editors*

September 2006

**Mandibular Reconstruction**

Tirbod Fattahi, DDS, MD, and
Rui Fernandes, DMD, MD, *Guest Editors*

Atlas of the
Oral and
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Surgery Clinics

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Atlas Oral Maxillofacial Surg Clin N Am 16 (2008) vii–viii

# Preface

George K.B. Sándor, MD, DDS, PhD,
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Robert P. Carmichael, DMD, MSc,
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*Guest Editors*

This issue is offered as a series of articles to help review the use of dental implants in this unique patient group. It is intended to be a useful guide for general practitioners in dentistry, all dental specialists, and those in disciplines of medicine and other areas of health care who are involved in the habilitation and rehabilitation of young patients who have congenital or acquired deformities involving the oral and maxillofacial complex.

The first article deals with the principles concerning dental implants in young patients, the growth of the jaws, and determination of skeletal maturity. The subsequent articles review the management of certain conditions within the envelope of experience of the authors, following a logical sequence of topics. These include articles on management of non-syndromal oligodontia and syndromal oligodontia, followed by articles concerning the use of dental implants in the management of dental malformations and cleft lip and palate. This is followed by articles on rehabilitation of trauma and reconstruction of ablative defects using dental implants. Finally, other articles review the use of dental implants together with other treatment modalities including articles entitled "Facilitation of Orthodontics and Orthognathic Surgery Using Dental Implants," and "Distraction Osteogenesis Using Dental Implants."

This atlas is not meant to be a definitive treatise on pathology or injury. It is intended mainly as a pictorial reference illustrating a series of principles that the authors have found to be useful in treating young patients who have dental implants. It is hoped that this will help practitioners to organize their thoughts when dealing with congenital and acquired deformities superimposed on the dynamic framework and timing of ongoing growth and development.

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Atlas Oral Maxillofacial Surg Clin N Am 16 (2008) ix

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# Dedication

This issue is dedicated to our own children, Kinga, Enikő, Hunor, Hayley, Nicholas, and Brittany, and to all those other children and parents who have enabled us to write this issue.

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Atlas Oral Maxillofacial Surg Clin N Am 16 (2008) xi–xii

Atlas of the
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Surgery Clinics

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This Atlas has tried to convey the guiding principles governing the use of dental implants in young patients and to catalogue the treatment of a wide variety of conditions in children, adolescents, and young adults. Such work is multidisciplinary by its very nature, bringing many clinicians together into close cooperation. The authors wish to acknowledge significant contributions to treatment documented in this issue of the *Atlas of the Oral and Maxillofacial Surgery Clinics of North America* by the following practitioners:

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Atlas Oral Maxillofacial Surg Clin N Am 16 (2008) 1–9

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# Dental Implants, Growth of the Jaws, and Determination of Skeletal Maturity

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The most appropriate earliest age for placement of dental implants is generally held to be the age at which skeletal growth is thought to cease. The end of adolescence and the beginning of young adulthood coincide with the exhaustion of growth potential, but adaptive changes of the jaws continue throughout life. Until recently it was thought that adaptation has little clinical effect on implants.

Growth of the maxilla is characterized by remodeling in a posterosuperior direction while simultaneously being displaced in the opposite anteroinferior direction (Fig. 1). In contrast, growth of the mandible is characterized by displacement away from its articulation in the glenoid fossae as the condyles and rami relocate in a posterosuperior direction (Fig. 2). Natural tooth movement occurs as a result of eruption and of being carried along passively with the maxilla and mandible, both of which undergo displacement anteroinferiorly during craniofacial morphogenesis (Fig. 3). Tooth movement facilitates adaptation to changing anatomic relationships as the entire craniofacial assembly changes during this period of great flux.

Experiments designed to study the effect of dental implants on dentoalveolar growth and development in pigs demonstrated that implants, owing to an absence of a periodontal ligament, behave like ankylosed teeth; that is, they remain stationary and do not erupt together with adjacent teeth (Fig. 4). In failing to move together with erupting teeth, implants were found to inhibit local growth and development of the alveolar process. A 3-year prospective clinical study in adolescents with congenitally missing teeth verified that implants do not move during growth of the jaws, and undergo relative submergence of a magnitude proportional to the amount of residual jaw growth (Fig. 5).

Submergence of an implant is disadvantageous for a number of reasons. First, an infraocclusion occurs, which disrupts carefully constructed occlusal relationships and leads to compensatory eruption of opposing teeth and tipping of adjacent teeth. Second, a vertical discrepancy develops between the mucosal margin of the implant and the gingival margins of adjacent teeth (Fig. 6).

Submergence of an implant or an ankylosed tooth appears not to be a passive phenomenon; rather, it exerts an inhibitory effect on eruption of neighboring teeth, the force of which diminishes with distance. The distance over which this field effect is seen is usually restricted to one or two teeth on either side of a submerged implant, and depending on the degree of residual

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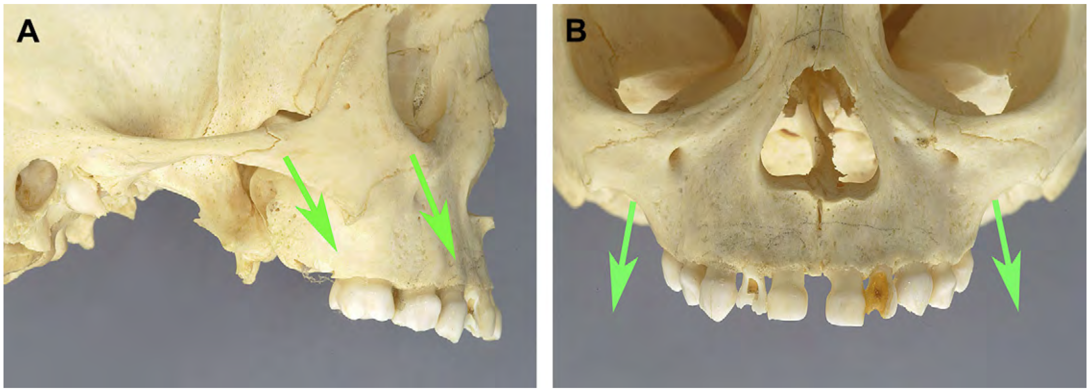

Fig. 1. Growth of the maxilla occurs by remodeling posterosuperiorly and simultaneous displacement anteroinferiorly. (*A*) Lateral view. (*B*) Anterior view.

alveolar growth remaining at the time of implant placement, disruption of the occlusal plane can be severe (see Fig. 4; Fig. 7).

In general, the damage caused by implant submergence is not correctable. Although it may be possible to revise or replace the restoration to correct an occlusal discrepancy, the crown/root ratio of the replacement restoration may become unfavorable. In addition, the esthetics of a replacement crown generally will be worse than the original because a soft tissue margin discrepancy cannot be corrected. Moreover, because the field effect disrupts normal local alveolar growth, the submergence and tipping of adjacent teeth cannot be corrected orthodontically without accentuating the implant submergence, aggravating the accompanying esthetic and occlusal defects, and compounding attachment loss of the orthodontically extruded implant-adjacent teeth (Fig. 8). This situation underscores the importance of ensuring that residual growth has been exhausted before implant placement is attempted, except in some situations where dentoalveolar growth is expected to be minimal or where the value afforded by an anchored prosthesis outweighs the disadvantage of local growth inhibition.

Development of the vertical dimension of occlusion is characterized by balance of vertical growth of the middle cranial fossa and the ramus, with an equivalent vertical development of the nasomaxillary complex and the dentoalveolar processes of the maxilla and mandible (Fig. 9). In patients who have oligodontia, it is common to see a deficiency in vertical development (Fig. 10A), presumably as a result of reduced dentoalveolar development (Fig. 10B–D). Therefore, less potential for vertical development in patients who have greater numbers of congenitally missing teeth would mean that early implant placement in these patients might be expected to have less inhibition on alveolar growth, and hence cause less submergence, than in patients who have only one or two missing teeth. Predictions of infraocclusion in an adult from a dental implant placed in adolescence or early adulthood based on data describing tooth eruption in normal populations may, therefore, be less accurate the greater the severity of oligodontia.

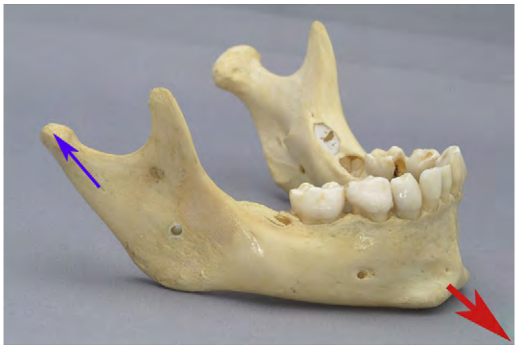

Fig. 2. Growth of the mandible occurs by relocation of the condyles and rami posterosuperiorly and displacement anteroinferiorly.

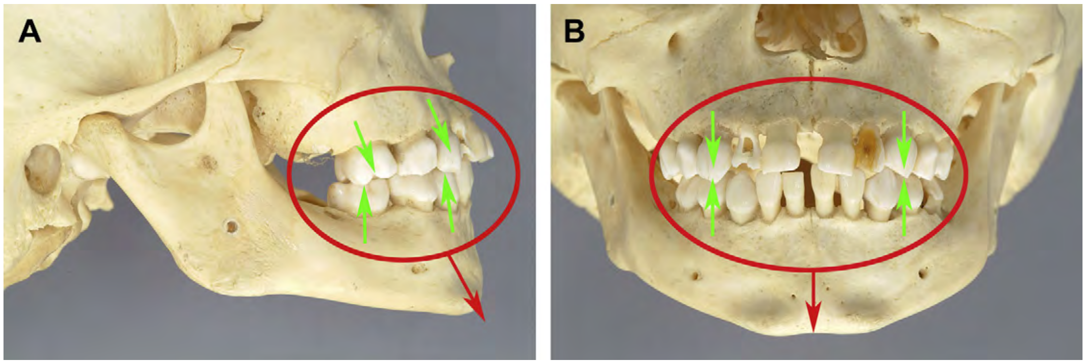

Fig. 3. Natural tooth movement is a net result of eruption (*green arrows*) and passive displacement anteroinferiorly (*red arrow*). (*A*) Lateral view. (*B*) Anterior view.

Transverse development of the maxilla occurs primarily as a result of growth at the midpalatal suture, and is greater posteriorly than anteriorly (Fig. 11A). Sutural growth ceases at about 17 years of age in boys (ie, about 2 years earlier than the condylar growth and growth in body height). In order not to constrain transverse development of the maxilla, implants on either side of the midline should not be united with either fixed or removable restorations either anteriorly or posteriorly until the cessation of skeletal growth. In addition to growth at the midpalatal suture, the maxilla grows by remodeling (Fig. 11B). As the maxilla and mandible enlarge, the dentition drifts vertically and horizontally to keep pace. Consequently, implants, like ankylosed teeth, undergo relative palatal/lingual displacement in addition to submergence in areas of dentoalveolar growth.

Most studies of mandibular growth suggest that transverse growth of the mandible between the canine regions is minimal, and that which does occur ceases early. Consequently, implants in the anterior mandible and united by a restoration spanning the symphysis may not constrain transverse growth (Fig. 12A). In contrast, mandibular growth may be accompanied by an

Fig. 4. Ankylosed primary mandibular molars in a 13-year-old boy undergo submergence relative to the adjacent teeth. (*A*) Right lateral view. (*B*) Left lateral view. (*C*) Frontal view.

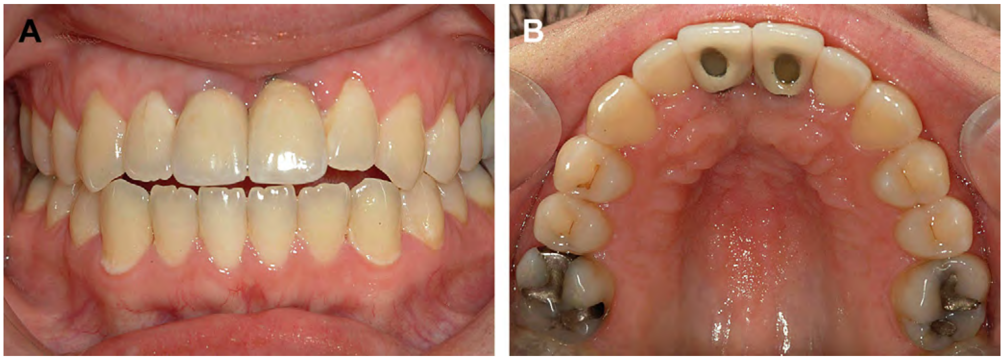

Fig. 5. Implant-supported crowns at sites 1.1 and 2.1 in a 23-year-old female demonstrate submergence secondary to residual dentoalveolar growth. The implants were placed at age 16 following avulsion of the natural teeth. (*A*) Frontal view. (*B*) Maxillary occlusal view.

opening hinge movement of its halves around a vertical axis located in or near the symphysis, in a pattern that would obviously be constrained by a cross arch restoration retained by implants placed bilaterally in the posterior mandible (Fig. 12B).

It is sometimes necessary to place implants into the jaws of prepubertal children. The most common indication for the placement of implants in young children is to anchor a lower bridge or overdenture using two or more implants between the lower canine regions of a child with hypohidrotic ectodermal dysplasia or other condition involving severe oligodontia or total anodontia (Fig. 13). In these situations, implants can be splinted or united by means of a fixed or removable restoration with impunity, at least as regards transverse growth. The prosthesis may have to be revised from time to time to keep pace with the growth of the jaws in their other dimensions, but, because growth of the dentoalveolar processes is limited in these patients anyway, the number and extent of revisions will be less than that required in a young nonsyndromic individual with an acquired dental anomaly whose jaws grow more normally. For example, a common sequela following ablation of a jaw tumor in a child is overeruption of the unopposed teeth into direct contact with the mucosa covering the edentulous region of the reconstructed jaw, which makes future replacement of lost teeth impossible. Often, a removable denture is inadequate to provide function and to prevent overeruption of the opposing dentition, so the only way to prevent distortion of the opposing occlusion is to anchor a fixed prosthesis in the reconstructed jawbone, using dental implants. Although growth may be limited in the region of the reconstructed mandible (with the exception of the anterior mandible, where transverse growth appears not to occur at all, either in the native situation or in a reconstructed one), growth continues unabated in all other regions of the jaws, so the restoration must be revised regularly to prevent inappropriate dental compensations that may permanently distort the occlusion (Fig. 14).

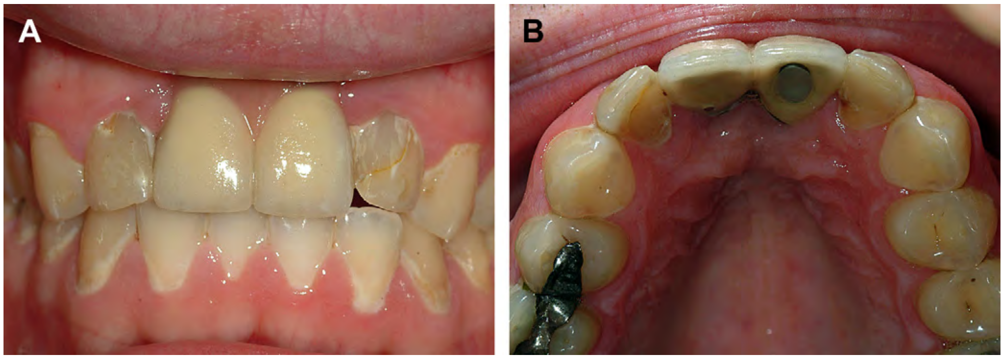

Fig. 6. Implant-supported crowns at sites 1.1 and 2.1 in a 22-year-old male demonstrate submergence, an upwardly curved distortion of the intercuspid occlusal plane, discrepancies of the marginal gingivae, compensatory eruption of the mandibular incisors, and mesial tipping of the maxillary lateral incisors and canines. (*A*) Frontal view. (*B*) Maxillary occlusal view.

Fig. 7. Distorted occlusion in an 18-year-old male secondary to retention of ankylosed right maxillary and mandibular primary first and second molars until 15 years of age. Teeth on either side of the bony alveolar defect demonstrate an element of submergence and tip toward the defect. The magnitudes of the two opposing defects were too great to permit orthodontic correction.

Fig. 8. Mutilation of maxillary occlusion in a 21-year-old female caused by residual dentoalveolar growth subsequent to placement of a dental implant to replace a congenitally missing maxillary left second premolar at age 15. The implant had been placed to provide orthodontic anchorage. Apparent fenestration of buccal bone and exposure of metal collar are related to surgical placement.

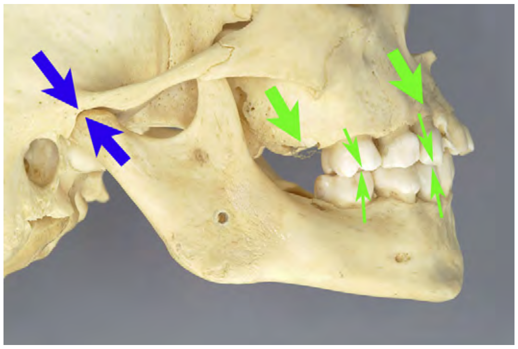

Fig. 9. Vertical dimension of occlusion is characterized by balance of vertical growth of the middle cranial fossa and rami (*blue arrows*) with an equivalent vertical development of the nasomaxillary complex (*large green arrows*) and dentoalveolar processes of the jaws (*small green arrows*).

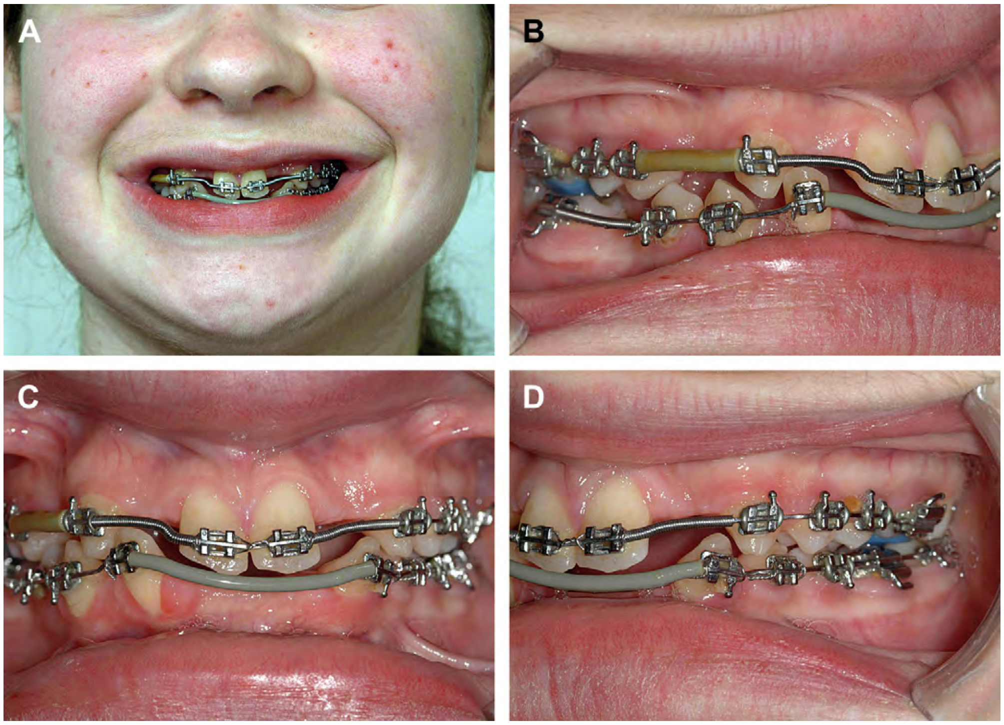

Fig. 10. A 17-year-old girl with oligodontia undergoing preprosthetic orthodontic treatment with fixed appliances. (*A*) Frontal facial view demonstrates that vertical development is deficient. Right lateral (*B*), frontal (*C*), and left lateral (*D*) views of the teeth reveal deficient dentoalveolar development, with resultant deficiencies in the vertical dimension of occlusion and intermaxillary space.

Mandibular growth pattern will have implications for implant placement. In growth patterns involving excessive rotation requiring dental compensation to maintain occlusion, implants placed in a growing individual could become deficient in height or improperly inclined at the cessation of growth, and, as a result, could be subjected to inappropriate loading, leading perhaps to loss of integration. For example, in an individual with a posterior rotational growth pattern, a central incisor implant may become submerged as the bite opens anteriorly and neighboring teeth erupt compensatorily. Conversely, in a patient who has an anterior rotational growth pattern, teeth neighboring an implant at the site of a maxillary central incisor might become displaced labially while the implant causes lingual displacement of the lower incisor or incisors it occludes with. In the same individual, posterior vertical growth is greater than in an individual with a posterior rotational growth pattern, and submergence of an implant placed in the posterior part of the mouth can be marked.

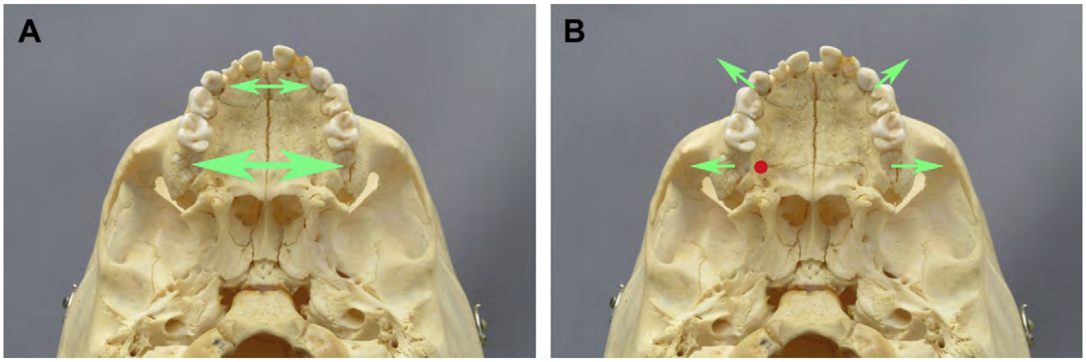

Fig. 11. Transverse development of the maxilla. (*A*) Growth at the midpalatal suture is greater posteriorly than anteriorly. (*B*) Remodeling allows the dentition to drift horizontally. A dental implant (red circle) will become displaced palatally (in addition to becoming submerged) in remodeling regions of the alveolar process.

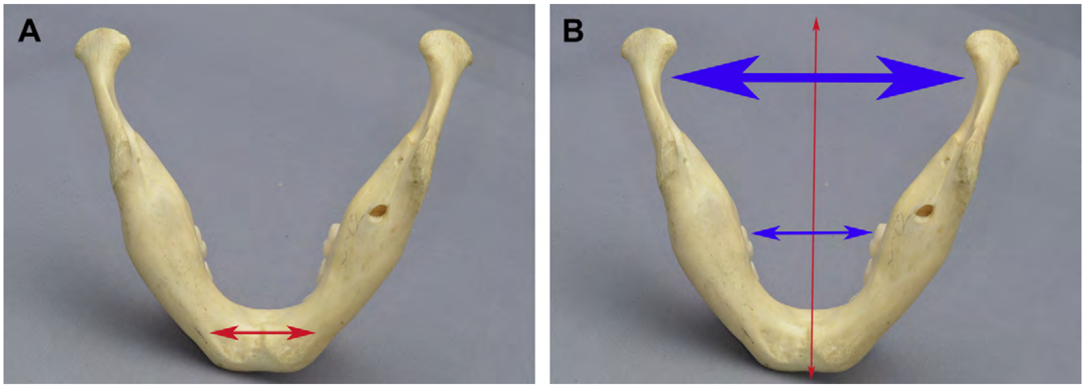

Fig. 12. Transverse development of the mandible. (*A*) Intercanine growth is minimal and ceases early. (*B*) Mandibular growth is characterized by an opening hinge movement of its two halves around an axis passing anteroposteriorly through the symphysis.

Mandibular growth will also have implications for patients who have undergone full or posterior arch reconstruction on implants. As the condyles and rami relocate in a posterosuperior direction, displacing the mandible away from its articulation in the glenoid fossae, a posterior open bite develops in the absence of any dental compensation and the mandible rotates anteriorly into a more prognathic position (Fig. 15), sometimes into an anterior edge-to-edge relationship of the upper and lower incisors or beyond into an negative overjet (see Fig. 13B). If mandibular growth is asymmetric, a crossbite may develop on the contralateral side. Whether mandibular growth is symmetric or asymmetric, posterior function is diminished, restorative materials in the anterior region wear excessively or fracture, and load distribution can become so disadvantageous as to cause loss of osseointegration.

Craniofacial growth may continue through adulthood, which may have implications for implant placement. One case report documents submergence of an implant occurring over a decade in an adult, putatively caused by continuing growth of the facial skeleton. Bernard and

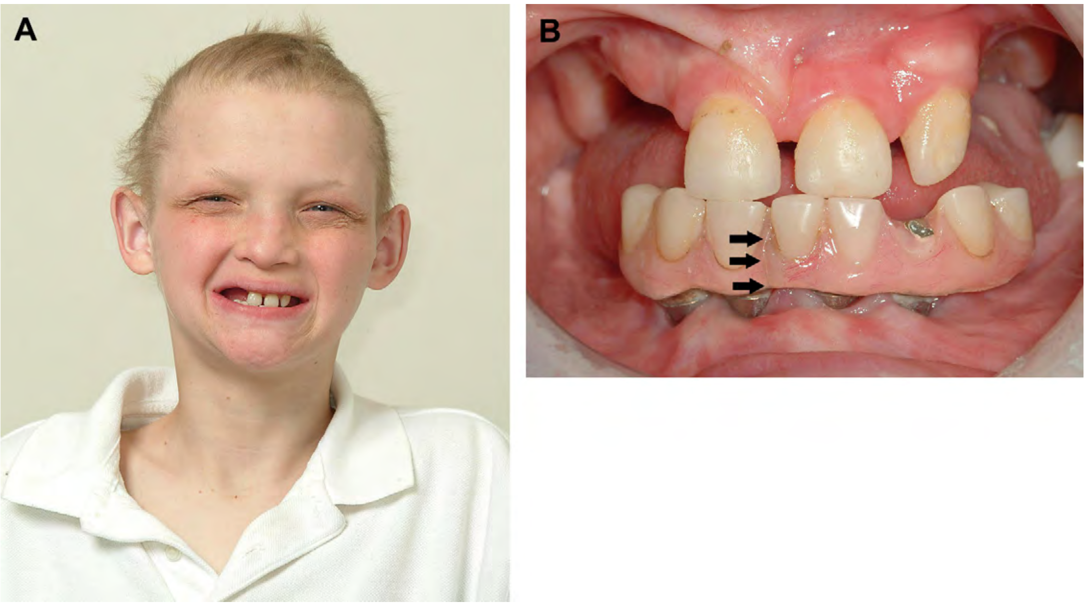

Fig. 13. An 11-year-old boy with hypohidrotic ectodermal dysplasia in whom a two-piece bridge, split at the mandibular midline, on four anterior mandibular implants, had been constructed at age 8. Mandibular growth has led to a separation of the jaws posteriorly and has advanced the mandible into an edge-to-edge incisal relationship. However, no separation of the proximal surfaces of the right and left sides of the bridge (*arrows*) is visible, suggesting no transverse growth across the symphysis has occurred. (*A*) Facial view. (*B*) Frontal view of teeth.

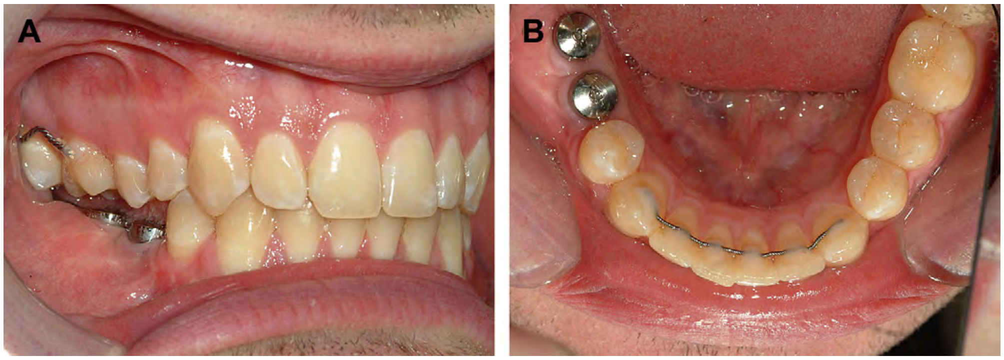

Fig. 14. A 19-year-old male undergoing implant reconstruction of an ablative defect secondary to resection of an ameloblastoma of the right side of the mandible. Despite a combination of the wearing of a Hawley appliance in the maxilla, and a buccal resin-bonded retainer applied to the opposing maxillary first and second molars, he has significant over-eruption of maxillary posterior teeth, with the result that the intermaxillary space has nearly been obliterated. (*A*) Right lateral view. (*B*) Mandibular occlusal view.

colleagues demonstrated intrusion of anterior implants in a group of 14 patients ranging between 40 and 55 years of age, which occurred to the same extent as in a group of young adults with residual growth potential.

The foregoing illustrates the importance of postponing implant placement until skeletal maturity. A series of studies of the growth of Swedish children has provided an understanding of the dynamics of adolescent growth. Growth in height terminates at around age 17 in girls and age 19 in boys (ie, skeletal maturity occurs about 2 years sooner in females than in males). Late-maturing boys tend to grow taller than early-maturing boys. Individual growth cessation varies by up to 6 years within each gender; consequently, chronologic age cannot be used as a guide in

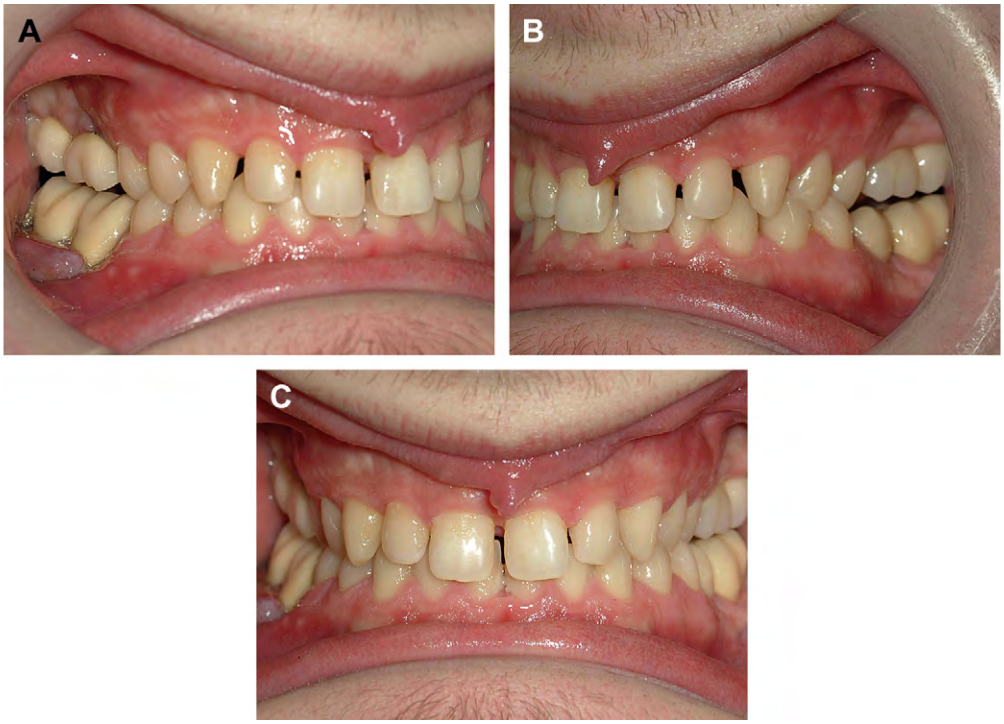

Fig. 15. A 21-year-old male who had been lost to follow-up since implants replacing all his molars had been placed at age 15. In the meantime, he had developed a bilateral posterior open bite following from mandibular growth in the absence of any posterior dental compensation. (*A*) Right side view. Note large exophytic, ovoid-shaped, firm, smooth-surfaced, maroon-colored lesion that was found to be a peripheral giant cell granuloma associated with the dental implant at site 4.6. (*B*) Left lateral view. (*C*) Frontal view. Note splaying of anterior teeth as a result of absent molar support.

planning implant placement in a young individual. Rather, analysis of skeletal development can be made from carpal radiographs or from superimposition of serial lateral cephalograms.

Despite best intentions, radiographic assessment of the cessation of skeletal growth may prove equivocal for technical reasons or because of erratic late growth. Moreover, the analysis may be of limited value in patients who have global growth disturbances or in situations where jaw growth will be restricted because of local factors. In the final analysis, psychosocial factors or the patient's own social imperatives may trump the clinicians' preference to wait out potential residual growth, and implant placement may proceed prior to the cessation of skeletal growth.

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# Dental Implants in the Management of Nonsyndromal Oligodontia

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No consensus concerning the nomenclature of agenesis of teeth exists in the literature. The most frequently used terms to describe tooth agenesis are *hypodontia* and *oligodontia*. Hypodontia is usually employed to describe a situation in which only a few teeth are missing, whereas oligodontia is used when a large number of teeth are missing. Nevertheless, *The Glossary of Prosthodontic Terms* makes no distinction between the two terms with respect to the number of teeth missing. In medicine, the Greek prefix *hypo*- denotes an abnormally low level of a substance in the body. The prefix *oligo*-, also Greek, denotes few. Because teeth are structures present in discreet numbers, the authors believe that oligodontia is the most appropriate term to describe the congenital absence of more than one tooth but not all teeth, and that the Tooth Agenesis Code may be used to assign a unique value to the pattern of agenesis. The term *anodontia* is reserved to describe the total absence of teeth, a use for which there seems to be no dispute.

## Etiology of oligodontia

Oligodontia is thought to have a significant genetic basis because it is associated with mutations in several genes, the protein products of which regulate odontogenesis. Oligodontia may also be associated with environmental influences.

## Prevalence of oligodontia

Oligodontia has been reported to be the most or one of the most common developmental dental anomalies, which probably explains why the prevalence of oligodontia is one of the few topics in the literature for which there is good evidence supported by meta-analyses. The prevalence of agenesis of permanent teeth in a meta-analysis of 28 studies covering Europe, Australia, and whites in North America was found to differ by continent and gender. Overall, oligodontia occurred 1.37 times more frequently in females than in males. Oligodontia was more prevalent in Australia (females: 7.6%; males: 5.5%) and Europe (females: 6.3%; males: 4.6%) than in North American whites (females: 4.6%; males 3.2%). Mandibular second premolars

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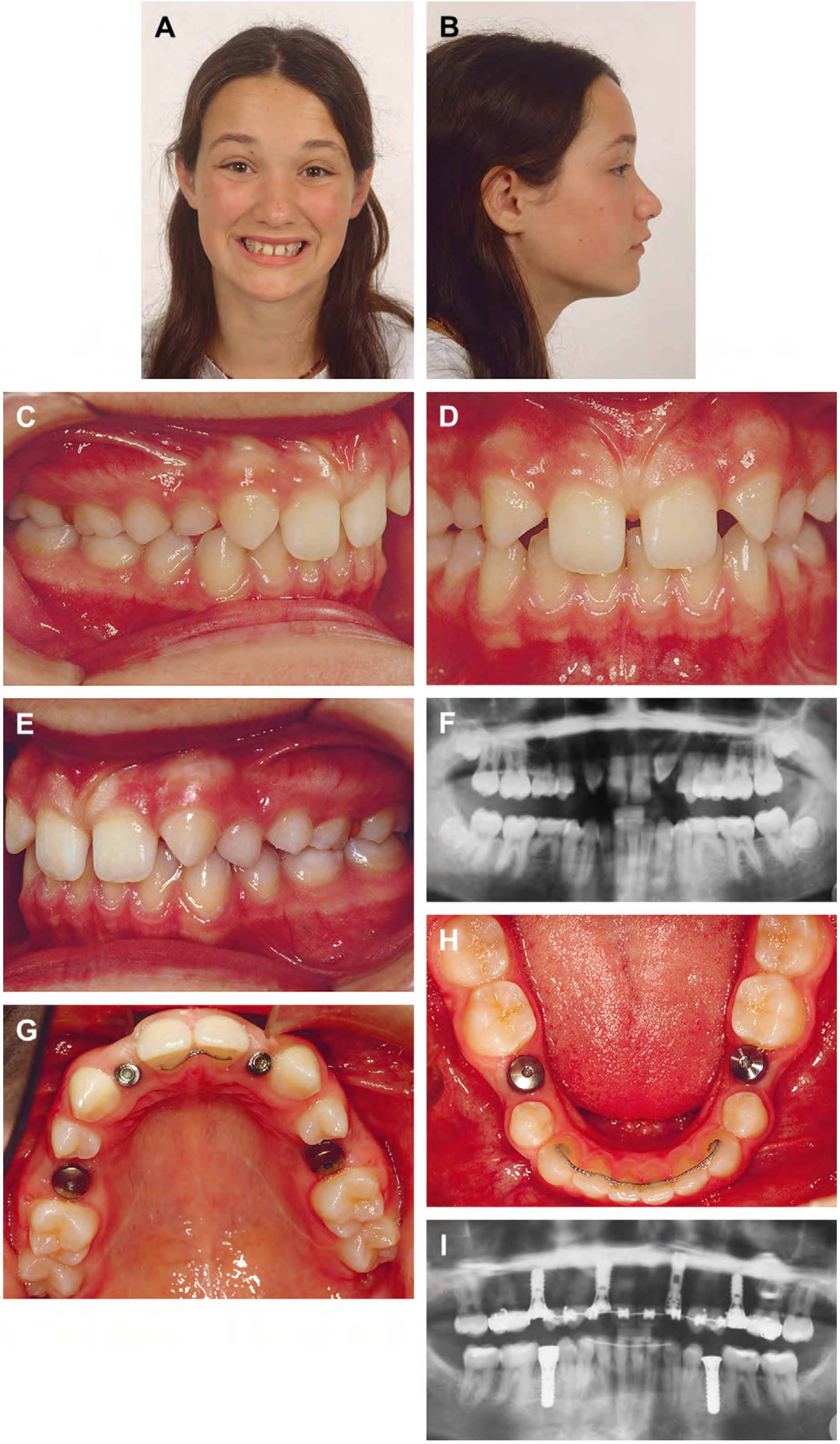
were found to be absent more frequently than maxillary lateral incisors or maxillary second premolars (Fig. 1A–T). Moreover, maxillary lateral incisors were found to be absent more frequently bilaterally than unilaterally, whereas the opposite was true for maxillary first and second premolars and mandibular second premolars.



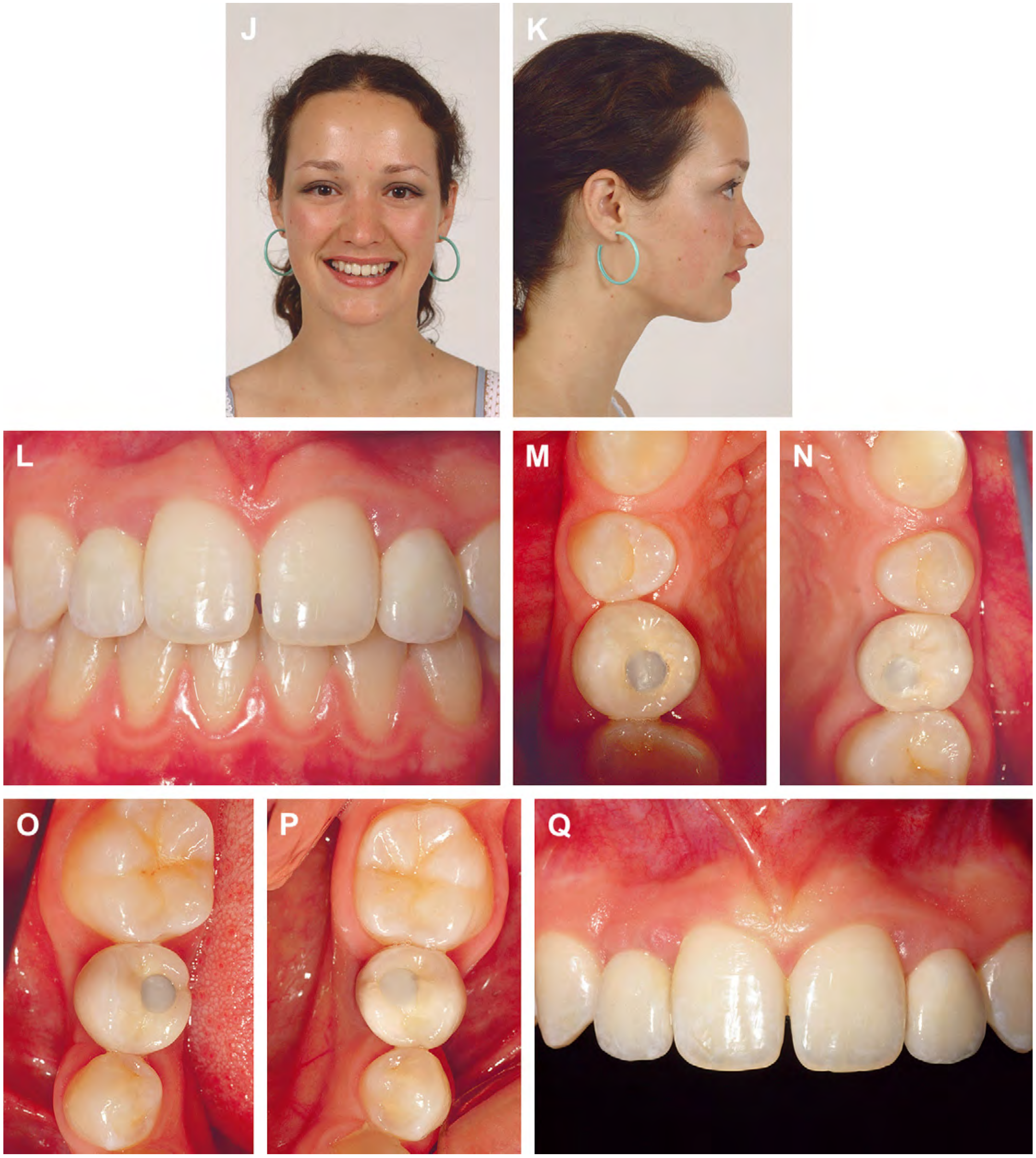


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Fig. 1. A 13-year-old female with congenital absence of the maxillary lateral incisors and second premolars, and mandibular second premolars. (*A*) Front facial view. (*B*) Profile view. Note orthognathic skeletal pattern. (*C*) Right lateral view of teeth. Note class I molar relationship. Note maxillary canines have erupted into the lateral incisor sites and second primary molars are retained. (*D*) Frontal view of teeth. Note maxillary canines have erupted mesially into lateral incisor sites. (*E*) Left lateral view. Note class I molars. Note maxillary canines have erupted into the lateral incisor sites and second primary molars are retained. (*F*) Panoramic tomography at age 13 years. Note maxillary and mandibular second molars are retained. (*G*) Maxillary occlusal view at 18 years of age. Note orthodontic alignment has opened space for maxillary lateral incisors and closed down the space for second premolars to approximately 8 mm. (*H*) Mandibular occlusal view at 18 years of age. Note orthodontic alignment has closed down space for second premolars down to approximately 8 mm. (*I*) Panoramic tomography at 18 years of age demonstrating implant alignment. (*J*) Post-treatment front facial view at 19 years of age. (*K*) Post-treatment profile view. (*L*) Post-treatment frontal view of teeth demonstrating implant supported maxillary lateral incisor crowns. (*M–P*) Maxillary right and left and mandibular right and left occlusal close-up views. Prosthetic second premolar crowns are larger than natural first premolars to avoid interdental spacing, a result of mild microdontia of anterior teeth. (*Q–S*) Maxillary anterior, right lateral, and left lateral close-up views. (*T*) View of smile.

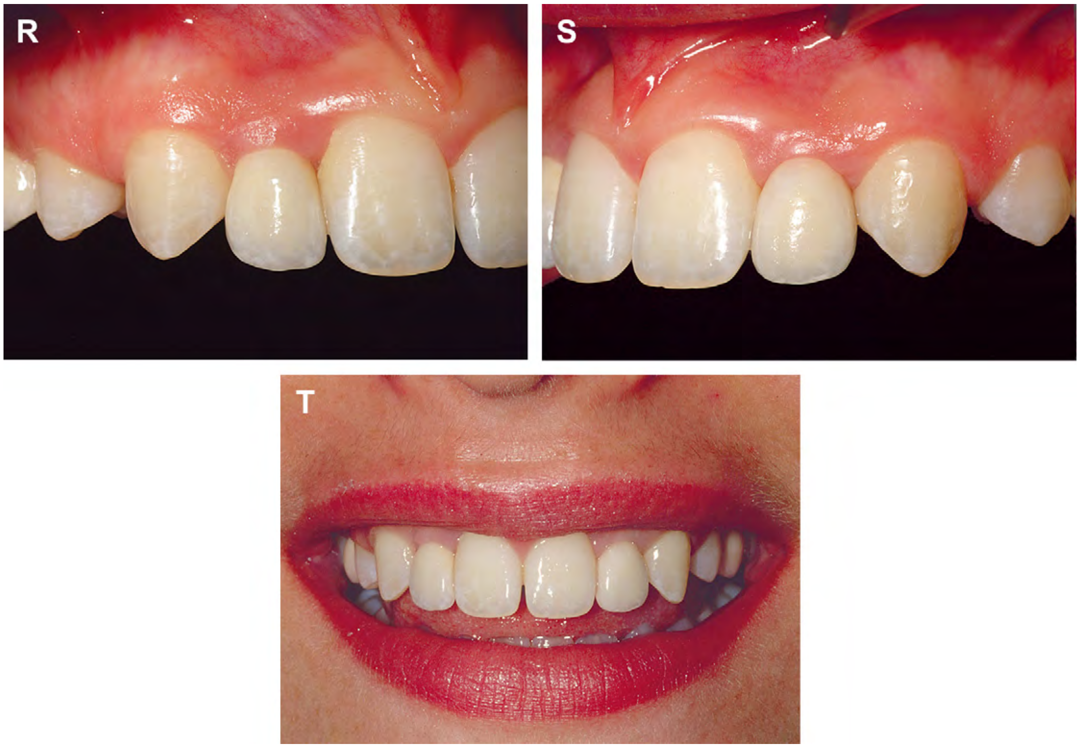

Fig. 1 (*continued*)

Most patients with oligodontia are missing only one or two teeth, fewer than 10% are missing four or more, and less than 1% are missing six or more. Estimates of the prevalence of oligodontia involving the absence of six or more teeth, third molars excluded, range from about 0.1% to 0.3%, whereas the prevalence of eight or more missing teeth has been reported to range from 0.01% to 0.03%.

## Consequences of oligodontia

Concomitant with oligodontia, there are often positional, morphologic, and size differences associated with the teeth that are present. Patients with ostensibly nonsyndromal oligodontia may also have signs or symptoms in other ectodermally derived tissues, such as low salivary secretion and impaired structure or function of the sweat glands, hair, or nails. The more severe the oligodontia, the more likely it is to be associated with a syndrome.

The subjective need for the replacement of missing teeth may be perceived by the patient as being undermined cosmetics, poor mastication, or malocclusion and spacing. In fact, 60% of patients with oligodontia present for treatment with these or other complaints. Other more objective findings in patients with oligodontia include the following: malocclusion involving a deep bite, crossbite, spacing, rotations, ectopic eruptions and transpositions; reduced orthodontic anchorage; cone-shaped incisors and canines; ankylosis and submergence of retained primary teeth; disruption of the growth of alveolar bone around ankylosed teeth; agenesis of edentulous regions of the alveolar process; resorption of the alveolar process following the exfoliation of primary teeth without succedaneous replacements; attrition and pulp exposure of retained primary teeth; attrition of permanent teeth, especially misaligned incisors; extrusion of unopposed teeth; and pneumatization of the maxillary sinuses. Oligodontia may also be accompanied by taurodontism and reduced length of teeth, left–right asymmetry of tooth dimensions, and delayed tooth eruption.

The severity and pattern of oligodontia has also been shown to affect craniofacial morphology, a situation with obvious implications for preprosthetic orthodontic treatment.

For example, patients with oligodontia may demonstrate shorter anterior and overall cranial base lengths, shorter maxillary and mandibular lengths, greater retroclination of maxillary incisors, greater retroclination and elongation of mandibular incisors, a larger interincisal angle, a more prognathic mandible, a more counterclockwise-rotated occlusal plane, and a shorter upper and lower anterior face height than normal.

It has been suggested that oligodontia may be an indicator of susceptibility to colorectal cancer. Moreover, calcification of the interclinoid ligament of the sella turcica may be associated with congenital absence of the mandibular second premolars. More recent evidence shows that at least some children with oligodontia may also have previously unassociated white matter diseases. The nature of the relationships between molecular mechanisms regulating the development of epithelial derivatives, such as teeth, skin, and hair, and of neural structures and those involved in the regulation of colorectal carcinogenesis are just now being elucidated. Given the associations between developmental pathways and tissue homeostasis, it is fascinating that oligodontia may be used as a marker for malignancy and hitherto unreported congenital malformations.

## Treatment of oligodontia

The authors subscribe to a holistic approach to the care of patients with oligodontia that integrates clinically relevant scientific evidence within the context of the patient's history, growth, development, needs, and psychosocial preferences. A multidisciplinary team approach to the treatment of oligodontia has been recommended because management requires the collaboration of at least a pediatric dentist, orthodontist, oral and maxillofacial surgeon, and prosthodontist. In most cases, patients should be referred to the team soon after the diagnosis of oligodontia is made. Clinical documentation should include at least a clinical assessment, preoperative intraoral and extraoral photographs, study casts of the teeth, panoramic tomographs, and intraoral radiographs and lateral cephalograms as required for orthodontic treatment planning and the determination of skeletal maturity. Follow-up to treatment should be ongoing and documented appropriately.

Patients should be evaluated for the appropriateness of providing no treatment or at least no prosthetic treatment if an alternative therapy such as orthodontic space closure can be considered. As a general guiding principle, dental implants are employed to safely replace missing teeth when removable prostheses are unacceptable to the patient, when fixed tooth-supported bridgework would involve an unconscionable sacrifice of virgin or minimally restored tooth structure, or when an edentulous span is judged to be too long to meet Ante's law for tooth-supported bridgework. Occasionally, healthy isolated permanent teeth are removed if they are judged to be likely to impede the establishment of a satisfactory prosthodontic outcome or to undergo intrusion following the restoration of adjacent implants.

Preprosthetic orthodontic treatment is usually necessary and is planned for and initiated at the age appropriate time. Generally, the goals of orthodontic treatment should include, if feasible, establishing a Class I canine and molar relationship, establishing correct midlines and alignment, optimizing the dimensions of the edentulous gaps, and achieving root parallelism adjacent to edentulous gaps.

Whenever possible, orthodontic treatment should employ a strategy to minimize or consolidate missing tooth spaces to reduce the number of dental implants required to restore the dentition to an acceptable level of function, as long as that strategy is unlikely to compromise the facial profile, dental esthetics, or function (Fig. 2A–D). For example, substitution of a canine for a missing maxillary lateral incisor would be considered if a reasonable esthetic outcome could be expected (Fig. 3A–C).

Alignment of the teeth is usually established with the same goals for implant-supported restorations, resin-bonded bridges, or removable partial dentures. Exceptions to this strategy include instances when orthodontic tooth movement is used to promote development of alveolar bone, when teeth are positioned remotely from their native sites to minimize orthodontic treatment time (Fig. 4A–D), or when an attempt is made to consolidate arch space in fewer edentulous gaps to minimize the numbers of implants required to restore the arch.

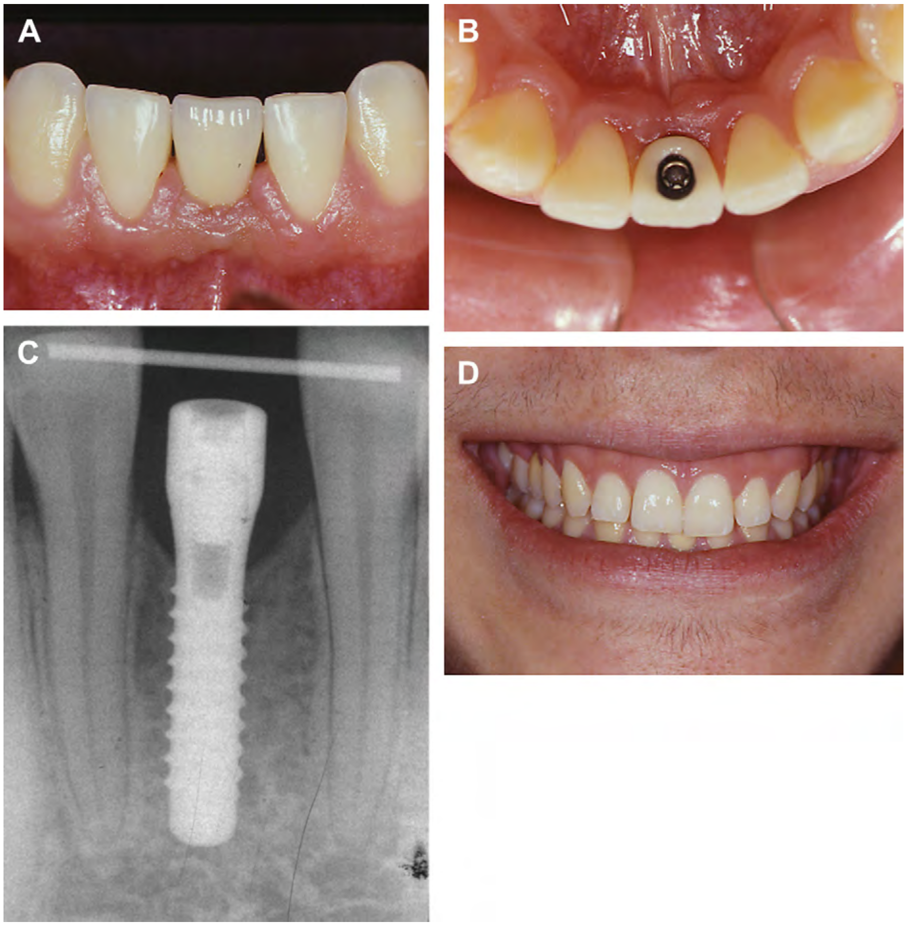

Fig. 2. An 18-year-old man with agenesis of the mandibular central incisors. (*A*) Space was closed orthodontically to accommodate a single implant-supported central incisor crown. (*B*) Occlusal view. (*C*) Periapical radiograph. (*D*) Space closure affected neither esthetics nor function adversely.

The facial profile may govern decisions to close or fill space. If space closure would adversely affect the facial profile, missing teeth should be replaced. For example, if a patient presents with maxillary retrusion, retraction of anterior teeth to close spaces would exaggerate the poor upper lip support and must be avoided (Fig. 5A–C; Fig. 6A–C; Fig. 7A–C). Similarly, tooth size discrepancies may dictate whether to close or fill spaces. Microdontia is commonly associated with oligodontia and may necessitate extra replacement teeth over and above the missing teeth when space closure would be inappropriate or unfeasible, especially when the facial profile stands to be adversely affected (Fig. 8A–D). Moreover, following space closure, the potential for relapse with reopening of space is high; therefore, prolonged retention is necessary.

### *Missing anterior teeth*

The treatment of young patients with a unilateral or bilateral congenital absence of the lateral incisors is often a contentious issue in the literature and clinically among treating specialists. The question invariably arises whether to close the space orthodontically or to open it and replace the tooth, usually with a dental implant. In the absence of a lateral incisor, the canine usually erupts into the site of the missing lateral incisor (see Fig. 7B). Distalization of a canine into its native site can be a difficult and lengthy procedure (Fig. 7C) and is usually easier to accomplish if initiated early on. Once accomplished, the tooth alignment must be maintained until the cessation of skeletal growth, when a dental implant may be placed. During this time, temporization can be a problem, the relapse potential is high if fixed appliances are removed, and the residual alveolar ridge may atrophy to the point beyond which the site will have to be

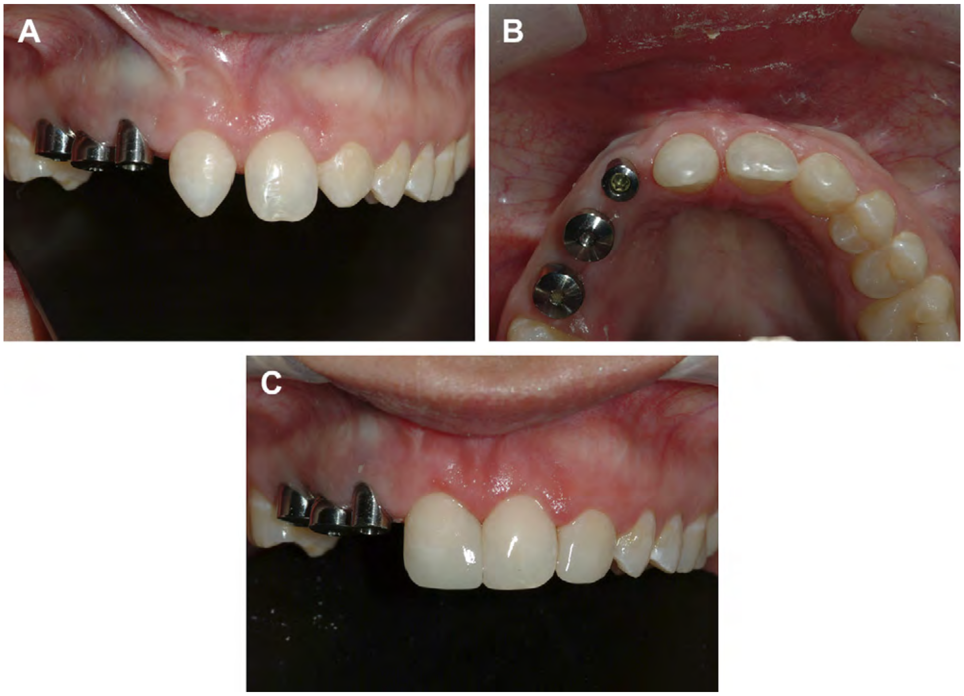

Fig. 3. A 21-year-old female carrier of hypohydrotic ectodermal dysplasia following orthodontic consolidation of spaces in the maxillary arch. (*A*) The maxillary right central incisor is conically shaped. The left maxillary canine has been mesialized to the site of the ipsilateral lateral incisor—a so-called "canine-lateral" substitution. (*B*) Occlusal view. (*C*) A good esthetic outcome is achieved by direct bonding of composite resin on the three maxillary anterior teeth. The size, shape, and color of the left canine are conducive to substitution for a lateral incisor.

Fig. 4. An 18-year-old woman with congenital absence of all premolars. The maxillary canines have erupted distally into the sites of the first premolars. (*A*) Frontal view of post-orthodontic alignment. The maxillary canines were left to substitute for first premolars. (*B*) Frontal view of completed implant-supported restorations. (*C*) Occlusal view of implant restorations. Note bilateral canine-premolar substitutions. (*D*) View of smile demonstrates that bilateral maxillary canine-premolar substitutions result in an acceptable esthetic outcome.

Fig. 5. A 22-year-old man with maxillary retrusion and congenital absence of the maxillary first premolars. The decision was made to replace the missing teeth rather than close spaces orthodontically to not worsen the facial profile and dental relationship. (*A*) Profile view demonstrates poor support of upper lip. (*B*) Occlusal view of the teeth demonstrates replacement of maxillary premolars with implant-supported crowns. (*C*) Lateral view of teeth illustrates how replacement of maxillary first premolars instead of orthodontic space closure maintains anterior dental edge-to-edge relationship.

Fig. 6. A 20-year-old man with maxillary retrusion and congenital absence of the maxillary lateral incisors. The decision was made to replace the missing teeth rather than close spaces orthodontically to not worsen the facial profile and negative overjet. (*A*) Profile view demonstrates poor support of upper lip. (*B*) Occlusal view of the teeth demonstrates replacement of maxillary lateral incisors with implant-supported crowns. (*C*) Lateral view of teeth illustrates how replacement of maxillary lateral incisors instead of orthodontic space closure and canine substitution prevents worsening of negative overjet.

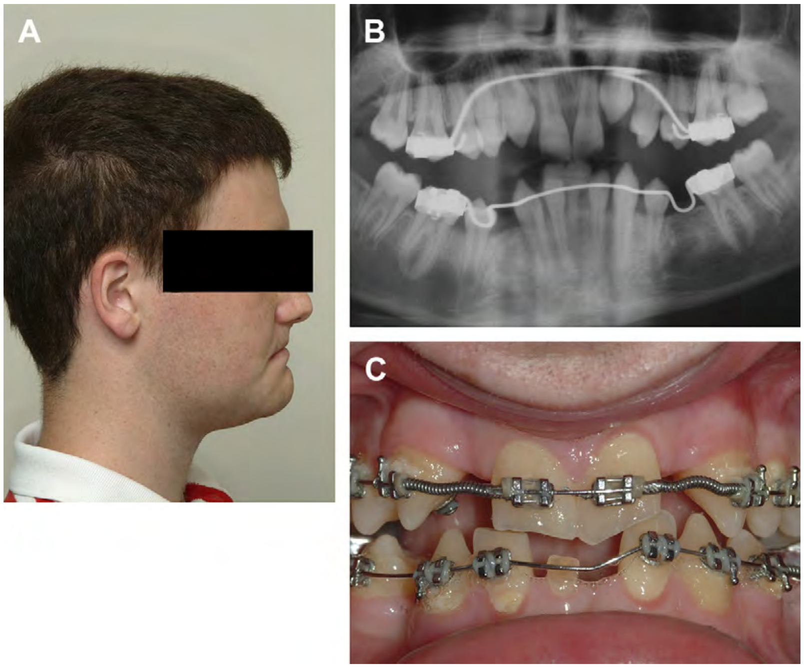
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Fig. 7. A 16-year-old adolescent boy with congenital absence of the maxillary lateral incisors, mandibular central incisors, and first premolars. Decision was made to replace maxillary lateral incisors because large, yellow canines were thought unlikely to permit acceptable esthetic outcome if substituted for laterals, and because of borderline maxillary retrusion. (*A*) Profile view shows straight profile with poor lip support. (*B*) Panoramic tomograph at age 13 years demonstrates space maintainers and eruption of maxillary canines mesially into lateral incisor sites. (*C*) Frontal view of teeth demonstrates orthodontic hardware used to distalize maxillary canines and open lateral incisor spaces. Progress was slow, and the procedure was aborted in favor of canine substitution.

augmented before or together with implant placement. Increased cost and prolongation of treatment may be potent disincentives for parents and their affected child to consent to implant treatment for a congenitally missing lateral incisor. In order for a canine substitution to provide an acceptable result, several factors should be favorable, such as the skeletal pattern, occlusal relationships, tooth size and arch length coordination, and the size, shape, and color of the canine relative to the central incisor (canines are usually darker and less translucent than lateral incisors) (Fig. 9A–C).

Orthodontic space closure in the anterior maxilla can be considered for patients with maxillary crowding, or in some cases with Class II malocclusions where retraction of the maxillary anterior teeth to close the lateral incisor space would also improve the malocclusion by reducing overjet. It is generally contraindicated in patients with a Class III malocclusion (see Fig. 6A–C). If the crown of the canine is too large or too dark in color to masquerade as a lateral incisor without invasive modification, or if the shape of the gingival margin is too highly scalloped or receded, substitution with space closure should be reconsidered carefully (Fig. 10A–C; Fig. 11A–D).

Several studies have documented that canine substitution has produced results that were deemed satisfactory by the patient, at least in the context of the times 40 to 50 years ago when the patients in these studies received treatment. Dental implant treatment offers many advantages over conventional prosthodontic treatments that have been available in the past to replace missing lateral incisors, and patients' expectations of esthetics have heightened, both of which justify additional clinical research comparing space closure with replacement with dental implants in the treatment of congenitally missing lateral incisors (Fig. 12A–C; Fig. 13A–C).

A strategy to avoid the need for ridge augmentation at the site of the missing lateral incisor is to postpone distalization of the canine until near the end of skeletal growth. As the tooth is moved distally, it can lay down bone, leaving in its wake an alveolar ridge of sufficient thickness to accommodate a dental implant. A similar strategy can be applied to other teeth in other parts of the mouth. For example, where an alveolar defect has developed at the site of a congenitally

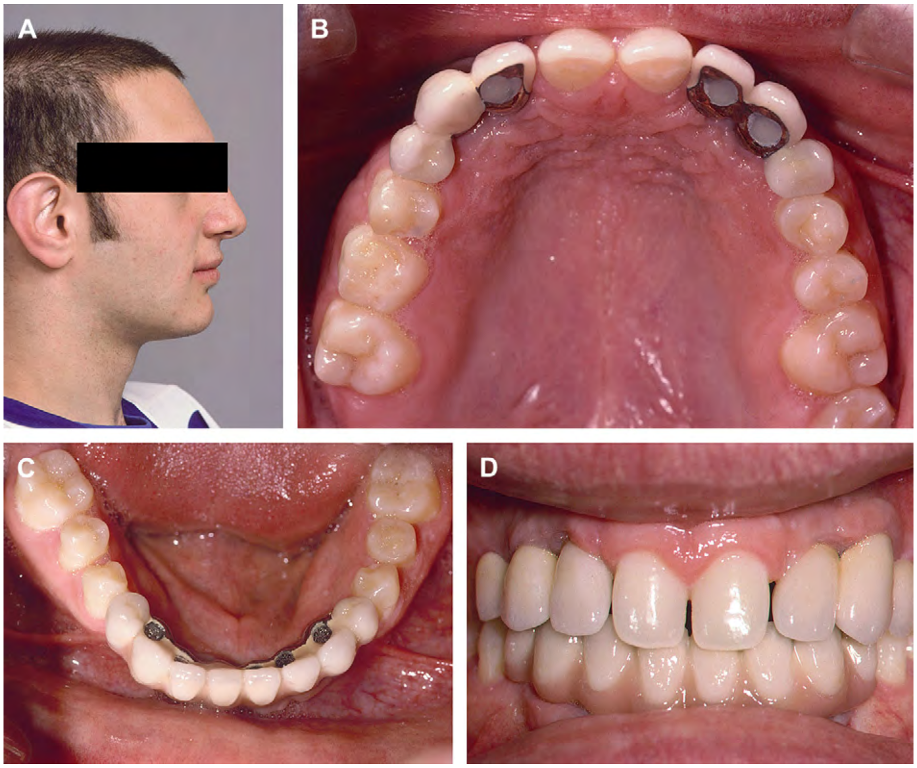

Fig. 8. A 21-year-old man with oligodontia missing the maxillary laterals and canines and mandibular incisors and canines. A tooth size/arch length discrepancy caused by the associated microdontia and the skeletal pattern necessitated extra replacement teeth over and above the missing teeth to avoid disturbing the facial profile. (*A*) Profile view. (*B*) Maxillary occlusal view. (*C*) Mandibular occlusal view. (*D*) Frontal view.

Fig. 9. A 19-year-old man with congenital absence of the maxillary right central incisor and both lateral incisors. The skeletal pattern, occlusal relationships, tooth size/arch length coordination, and size, shape, and color of the canine relative to the left central incisor were all favorable; therefore, bilateral canine substitution was employed, and implants were placed at the sites left vacant by the mesially erupted canines. (*A*) Frontal view following implant placement. (*B*) Frontal view following restoration of implants and modification of canines using direct bonding of composite resin. (*C*) View of smile demonstrates satisfactory esthetic outcome.

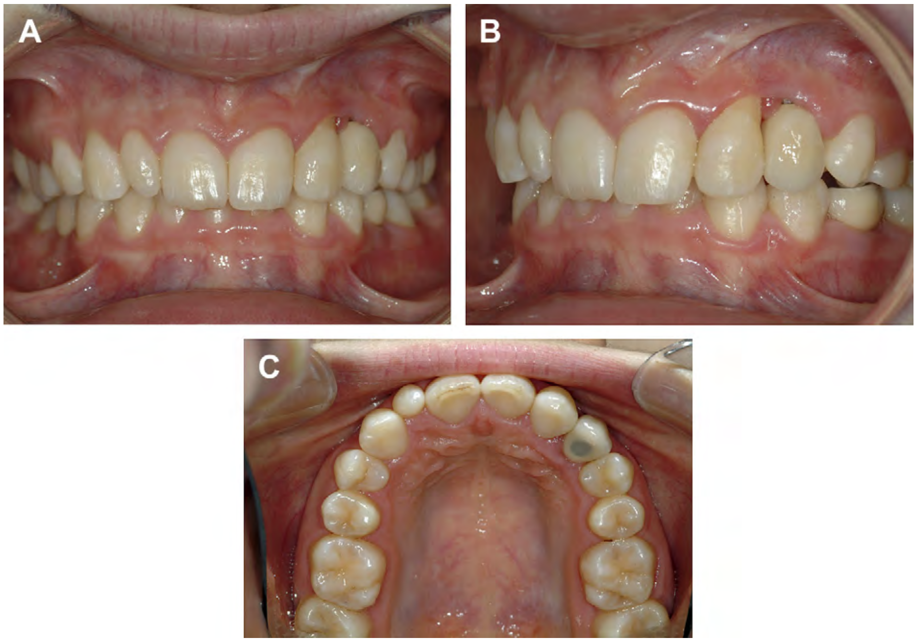

Fig. 10. An 18-year-old woman with congenital absence of the maxillary left lateral incisor, lateralization of the left canine, and restoration of an implant placed in the space opened up behind the canine. (*A*) Frontal view. (*B*) Left lateral view. Note the absence of attached gingiva and gingival recession at the distobuccal margin of the canine and exposure of the implant shoulder. (*C*) Occlusal view.

missing first premolar, the second premolar can be mesialized into the first premolar site, leaving behind an alveolar ridge with adequate dimensions to permit the placement of a dental implant safely out of the way of the mental foramen (Fig. 14).

Dental substitutions other than canines for lateral incisors can often facilitate treatment of patients with oligodontia. An infrequent substitution is the use of a lateral or a canine for

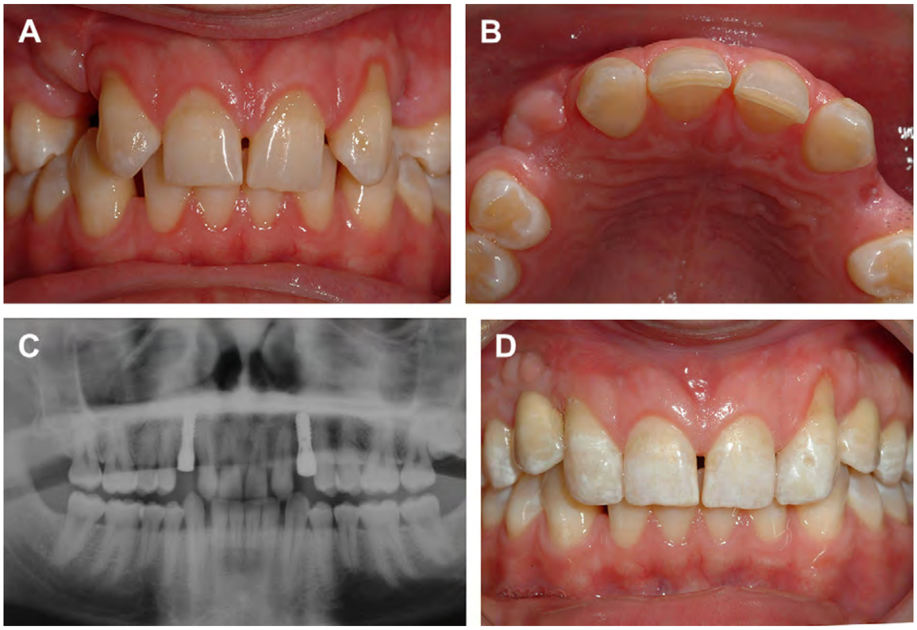

Fig. 11. A 20-year-old man with congenital absence of the maxillary lateral incisors and eruption of the canines into the lateral incisor sites. (*A*) Frontal view. The shape, size, and gingival contours of the canines did not favor canine substitution for lateral incisors. Nevertheless, the patient refused orthodontic treatment. (*B*) Occlusal view. (*C*) Panoramic tomography demonstrates placement of implants at canine sites. (*D*) Despite satisfactory lateralization of the canines with direct application of bonded composite resin, the overall esthetic outcome improved but remained poor.

Fig. 12. A 21-year-old man with congenital absence of the maxillary left lateral incisor. (*A*) Placement of an implant at the site of the missing lateral incisor. (*B*) Restoration of implant. (*C*) View of smile reveals a satisfactory esthetic outcome.

a missing central incisor. Either approach can be an elegant solution if clinical conditions are favorable. In most instances, the narrower lateral incisor will have to be positioned in the center of the central incisor gap made wide enough to accommodate a porcelain restoration with dimensions mirroring the contralateral central incisor. Care must be exercised to intrude the lateral incisor sufficiently so that its gingival margin is level with the gingival margin of the central incisor.

Fig. 13. An 18-year-old woman with implant-supported crowns at sites of congenitally missing maxillary lateral incisors. (*A*) Frontal view of teeth. (*B*) Occlusal view of teeth. (*C*) View of smile.

Fig. 14. Mesialization of the second premolar into the hypoplastic site of a congenitally missing first premolar leaves behind an alveolar ridge with adequate dimensions to permit the placement of a dental implant safely out of the way of the mental foramen.

Canines that erupt distally into the site of a congenitally missing first premolar can be left to substitute for the premolar while the vacancy left at its native site can be filled with an implant-supported crown. The size, shape, and color of the two teeth are usually sufficiently close to achieve an adequate esthetic result (see Fig. 4A–D; Fig. 15A, B). Conversely, a premolar can be used occasionally with impunity to substitute for a missing canine unless it is too short or its lingual cusp would interfere with the opposing dentition and could not be reduced without aggressive enameloplasty.

### *Missing premolars*

As is true for decisions to employ dental substitutions in the anterior part of the mouth, decisions to close or fill spaces left by missing premolars are also governed by factors such as the skeletal pattern, occlusal relationships, tooth size, arch length, and facial esthetics. In oligodontia characterized by patterns of agenesis of both anterior and posterior teeth, canine substitution or other variations of anterior tooth substitutions are avoided to establish a Class I canine relationship when possible (Fig. 16A–E). This approach has the twofold result of enabling the establishment of canine guidance, which reduces potentially damaging lateral forces on posterior implants, and enhancing the probability of obtaining acceptable esthetics.

Usually, situations in which one premolar is missing in the upper or lower arch or both can be corrected orthodontically without adversely affecting the facial profile. An elegant way to close space created by the absence of a mandibular premolar in a patient with a dental Class I relationship and an orthognathic profile is to treat that side of the jaw to achieve a Class I canine and a Class III molar. Conversely, a situation involving a missing maxillary premolar can be treated to achieve a Class I canine and a Class II molar. When one premolar is missing from the

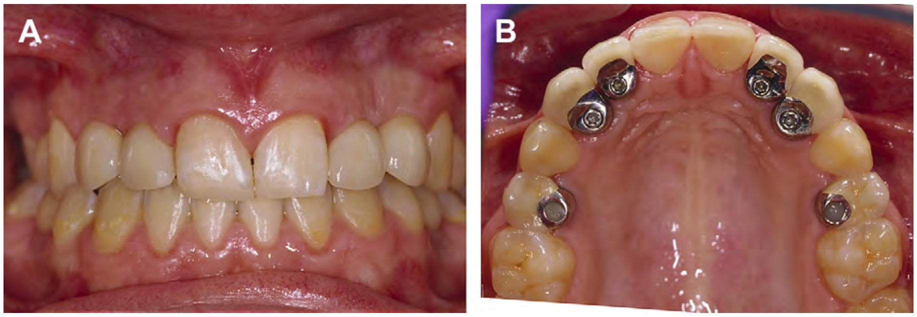

Fig. 15. A 19-year-old woman with congenital absence of the maxillary lateral incisors and first and second premolars. The canines have erupted distally into the first premolar sites and have been left to substitute for them. (*A*) Frontal view. The color, size, and shape of the canines are sufficiently close to that of the missing premolars to permit substitution with preservation of a natural appearance. (*B*) Occlusal view.

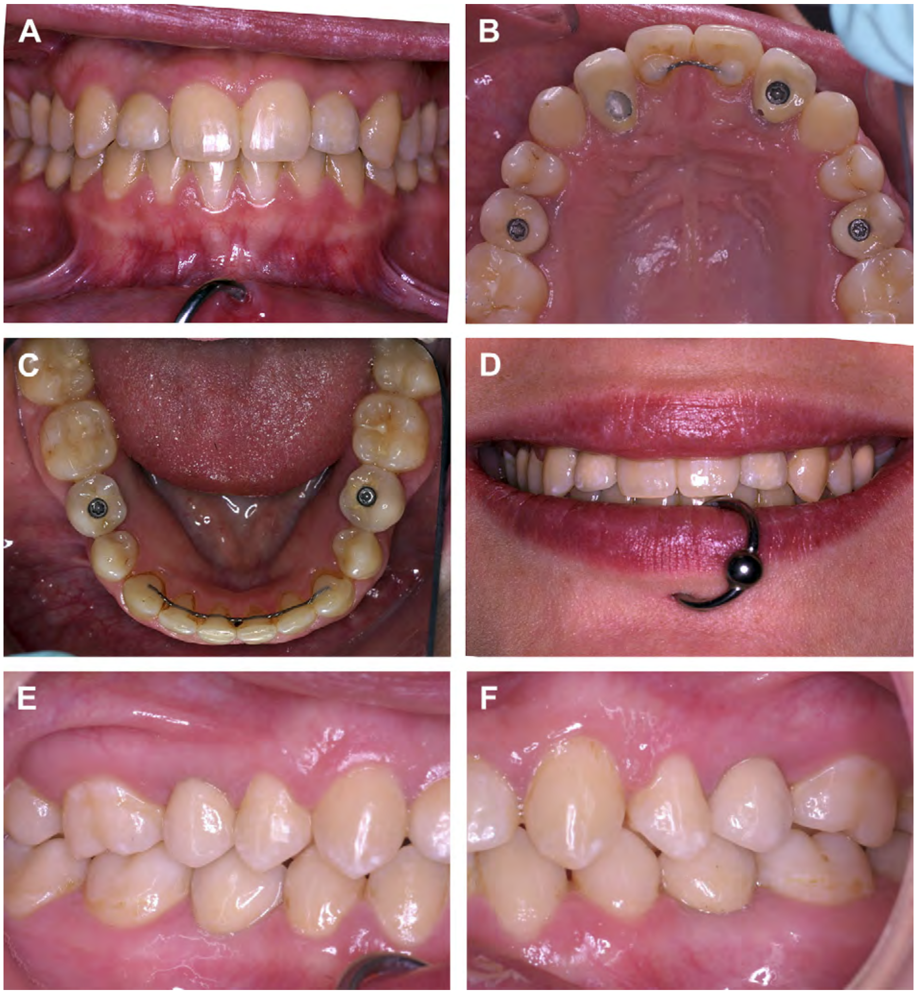

Fig. 16. An 18-year-old woman with congenital absence of the maxillary lateral incisors, second premolars, and mandibular second premolars. Arches were aligned with canines and molars in a Class I relationship. Missing teeth were habilitated with their respective prosthetic counterparts. (*A*) Frontal view. (*B*) Maxillary occlusal view. (*C*) Mandibular occlusal view. (*D*) View of smile. (*E*) Right lateral view. (*F*) Left lateral view.

same side of each arch, it should be possible to close both spaces and maintain the Class I canine and Class I molar. Because it is harder to close space resulting from the absence of both premolars on one side, it may not be possible to eliminate the need for prosthetic intervention in a situation involving two missing premolars on one side of one or each arch; however, closing gaps down from two premolar spaces to one halves the number of spaces to fill. In a patient with a Class I canine and Class I molar with a straight profile missing one maxillary premolar and both mandibular premolars on the same side, it should be possible to close the maxillary premolar space and one of the two missing mandibular premolar spaces while preserving the Class I canine and slipping the molars into a Class III. Instead of needing three implants to replace the missing three premolars, the patient needs only one implant to replace the single missing mandibular premolar. The corollary is also possible. In a patient with a Class I dental relationship and a straight profile missing both maxillary premolars and one mandibular premolar on the same side, it should be possible to close one of the maxillary premolar spaces and the mandibular premolar space while preserving the Class I canine and creating a Class II molar. Again, instead of needing three implants to replace the missing three premolars, the patient needs only one implant to replace the single missing maxillary premolar. These approaches are helpful strategies to use in the treatment of patients with oligodontia and normal skeletal and dental relations; obviously, many more combinations and permutations exist (Fig. 17A–D; Fig. 18A–D). In cases in which complex underlying jaw relationships exist,

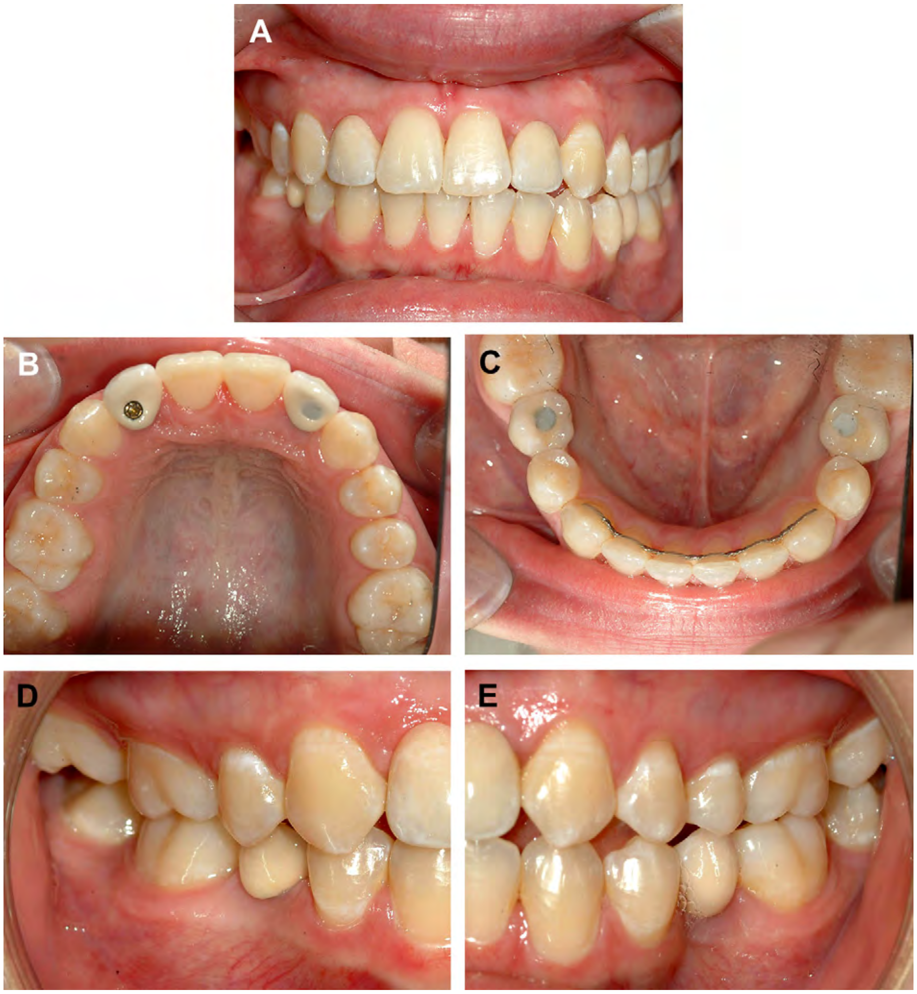

Fig. 17. The 18-year-old woman shown in Fig. 13. In addition to missing maxillary lateral incisors, she is also missing the right maxillary second premolar, the space of which has been closed, and the right mandibular second premolar, which has been replaced by an implant-supported crown. In addition, she is missing the left mandibular second premolar, which has been replaced. (*A*) Frontal view. (*B*) Maxillary occlusal view. (*C*) Mandibular occlusal view. (*D*) Left lateral view. (*E*) Right lateral view.

variations of the same strategies can be employed to advantageously manipulate the canine and molar relationships in an effort to minimize the need for prosthetic intervention.

### *Missing molars*

The need to replace missing molars is debatable. The World Health Organization has recommended the lifelong retention of a natural dentition of not less than 20 teeth, the implication being that adequate oral function can be maintained in the absence of molars. Nevertheless, clinical experience suggests that functional and esthetic demands vary from patient to patient; therefore, the minimum number of teeth required by any one individual cannot be prescribed. When planning the treatment of a patient with oligodontia, it may be appropriate to aim for habilitation of all molars in some instances, but it is more than likely that such a goal may be neither practicable nor necessary. The extent to which the prescription of a full complement of first and second molars is executed is governed by a synthesis of elements specific to each individual patient, including finances, occlusion, anatomy, and medical status.

Although many studies support the functionality of a shortened dental arch, that is, one comprising anterior and premolar teeth only, in the authors' experience, it is a concept that few parents of children with oligodontia embrace. Young patients and their parents often perceive

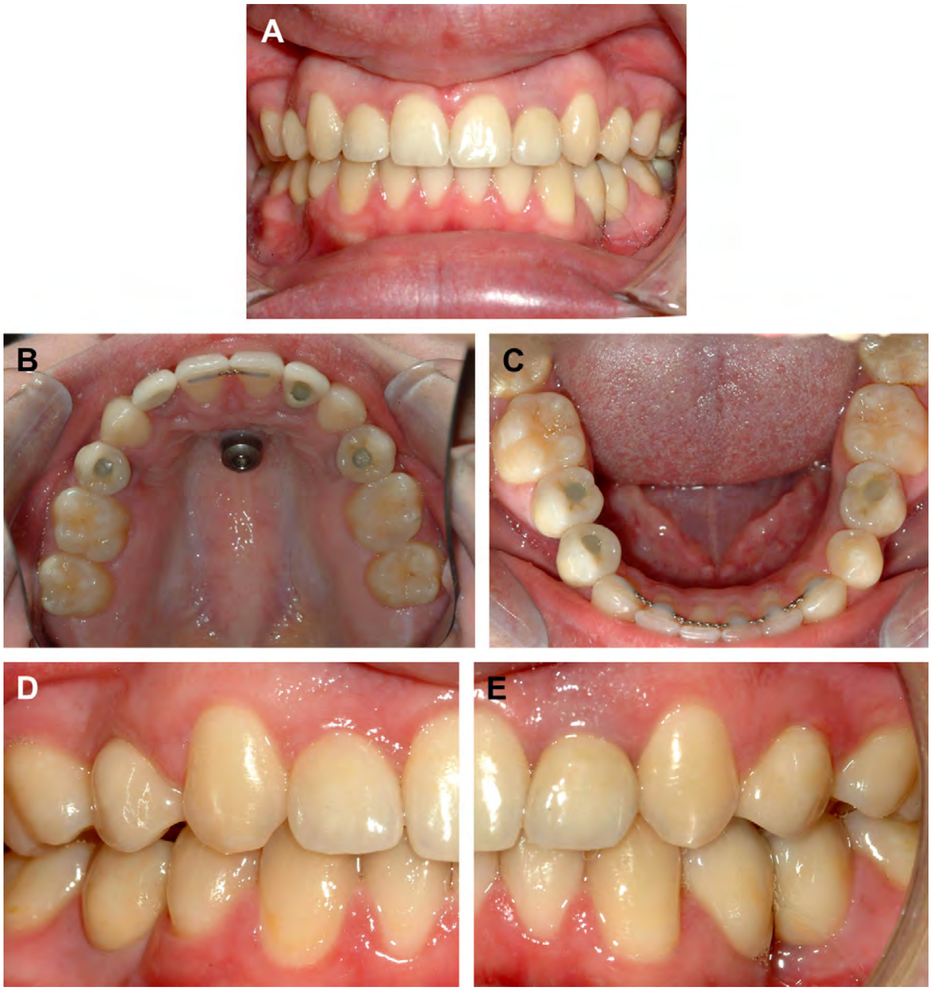

Fig. 18. An 18-year-old woman with congenital absence of the maxillary lateral incisors and premolars, right mandibular first premolar, and both mandibular second premolars. (*A*) Frontal view. (*B*) Maxillary occlusal view. Note retained palatal implant. (*C*) Mandibular occlusal view. (*D*) Right lateral view demonstrates class I canine relationship and class II molar relationship. (*E*) Left lateral view demonstrates Class I canine and molar relationships.

and complain about the adverse effects of missing molars on esthetics and function; therefore, when priorities are set, restorative treatment planning should take into account the patient's perceptions. In addition, objective parameters specific to the clinical management of oligodontia may support a decision to replace missing molars. Such parameters include clinicians' opinions about the deleterious consequences of missing molars on individual esthetics and function (Fig. 19A–D), the need to inhibit potential overeruption of opposing teeth (Fig. 20A, B), the need for skeletal orthodontic anchorage, the need for intermaxillary fixation during orthognathic surgery beyond what can be obtained from the natural teeth alone, and the need to effect an increase in the vertical dimension of occlusion. Temporary implant-supported molars are also useful for increasing the bite and for disengaging the bite to retract a bimaxillary protrusion or an anteriorly splayed and spaced anterior/premolar dentition. Contrary to some opinions, placement of molar implants in a patient with oligodontia should not necessarily be considered overtreatment.

Just as there are valid reasons to habilitate missing molars, there are valid reasons not to. Agenesis of alveolar bone associated with tooth agenesis heightens the risk of implant failure and the risk of implant placement causing injury to vital structures such as the trigeminal nerve. Agenesis of alveolar bone may also necessitate sinus floor elevation and augmentation, a procedure the patient may wish to avoid.

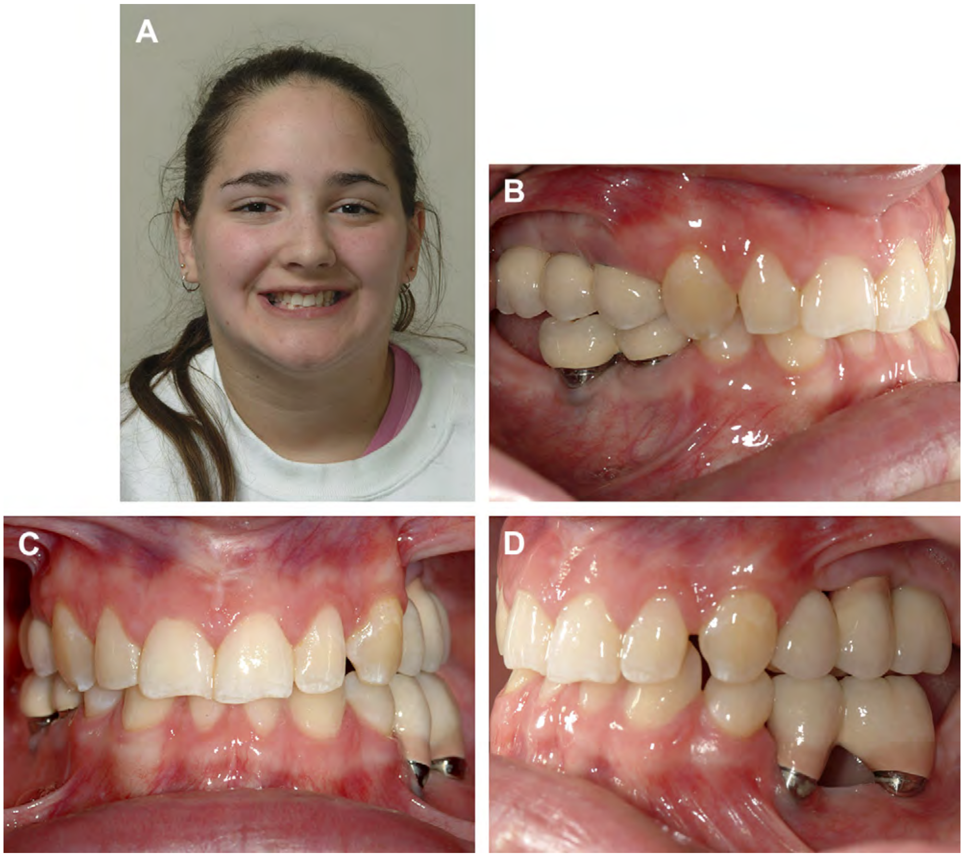

Fig. 19. An 18-year-old woman with congenital absence of all maxillary posterior teeth, mandibular second lateral incisors, second premolars, and first and second molars. Mandibular incisor spaces were closed, and missing premolars and first molars were habilitated. (*A*) Facial view. (*B*) Right lateral view. (*C*) Frontal view of teeth. (*D*) Left lateral view.

### *Temporary anchorage devices*

In general, orthodontic treatment is more difficult the greater the number of missing teeth, primarily owing to the relative lack of anchorage. Consequently, treatment times for patients with oligodontia usually exceed the average, and outcomes are sometimes non-ideal. Several methods can be employed to obtain skeletal anchorage that can facilitate the treatment of severe oligodontia. These methods include the use of temporary anchorage devices such as osseointegrated palatal implants (see Fig. 18B), immediately loaded mini-implants, and temporary crowns and bridges placed on conventional dental implants located within the dental arch (Fig. 21), which are converted to definitive prostheses following the completion of orthodontic therapy.

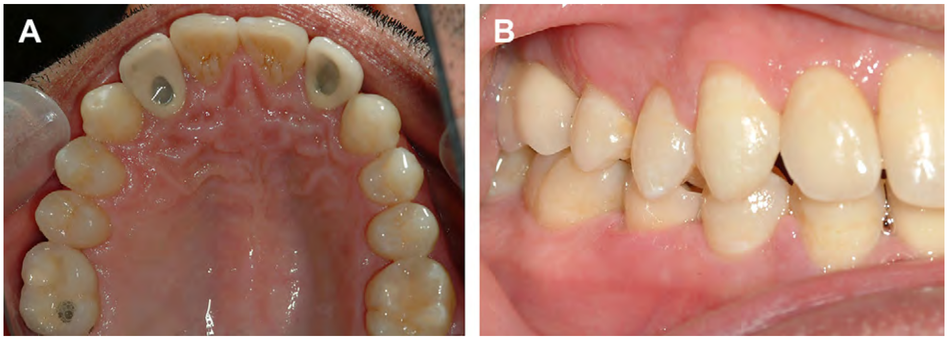

Fig. 20. A 23-year old man with congenital absence of the maxillary lateral incisors and right maxillary molars. (*A*) Maxillary occlusal view. (*B*) Right lateral view demonstrates prevention of overeruption of the mandibular first and second molars by an implant-supported maxillary first molar crown.

Fig. 21. Implant-supported temporary crowns at the sites of a congenitally missing mandibular right second premolar and left first premolar are used as temporary anchorage devices to obtain skeletal anchorage and facilitate orthodontic treatment of oligodontia.

Temporary anchorage devices facilitate treatment by means of increasing orthodontic anchorage, reducing the need for patient compliance vis-à-vis the wearing of appliances, reducing treatment time, and enabling some orthodontic maneuvers that would otherwise require surgery.

### *Orthognathic surgery*

Occasionally, orthognathic surgery must be used in combination with orthodontic treatment to correct severe skeletal discrepancies in all three planes of space and to correct significant asymmetries.

### *Dealing with retained primary molars*

When supervising the care of an adolescent with oligodontia, timing is everything. Retained primary teeth can be ideal space maintainers where the succedaneous tooth is absent. Unfortunately, primary molars can ankylose and, in a growing child, submerge below the occlusal plane and disrupt local alveolar development. If allowed to progress unchecked, this process can result in the creation of a bony defect that, in the future, may compromise implant placement at the site (Fig. 22). Ankylosis of a submerged primary molar can be confirmed clinically by percussing it with the handle of a metal mouth mirror, which elicits a sound like tapping on glass. Radiographically, a discrepancy in the height of the interproximal bone can be identified between an ankylosed primary molar that has started to submerge and the adjacent permanent teeth. Depending on the age and gender of the patient, one should consider extracting an ankylosed primary tooth to prevent creation of a bony defect. The decision to extract will rest on an assessment of the amount of residual skeletal growth. For example, there would be no urgent need to extract an ankylosed primary molar in a 15-year-old girl in whom little residual

Fig. 22. Ankylosis of a maxillary left second primary molar in a growing child has submerged below the occlusal plane and disrupted local alveolar development, resulting in the creation of a bony defect that, in the future, may compromise implant placement at the site.

jaw growth is anticipated. On the other hand, the same tooth in a 15-year-old boy who may continue growing until 19 or 20 years of age should be extracted to avoid creating a significant bony defect. Great care must be taken to remove an ankylosed primary molar atraumatically without unnecessarily removing alveolar bone. Some degree of residual alveolar ridge resorption is inevitable following extraction. In situations involving the absence of a single premolar, the authors expect about a 25% decrease in alveolar ridge width over the first 3 years or so, after which resorption tapers off. In situations involving the absence of the first and second premolars, greater resorption can be expected.

Timely extraction of ankylosed primary molars may have the additional benefit of permitting mesial drift of molars with orthodontic space closure, perhaps obviating the need for a dental implant and associated augmentation procedures.

### *Bone grafting*

Bone grafting may be used to augment alveolar bone before placing dental implants. Autogenous bone can be harvested from several donor sites. The most common extraoral site is the os ilium, the use of which requires general anesthesia in a hospital or private practice setting. Intraoral bone harvesting may take the form of collecting bone chips from the implant osteotomy with a suction trap. Procedures used to augment the alveolar ridges before, or together with, implant placement include sinus floor elevation, onlay grafting, and guided bone regeneration. Coral granules have been used in some instances to preserve alveolar ridge dimensions in alveolar defects resulting from traumatic tooth loss or from the extraction of ankylosed retained primary molars with no succedaneous teeth. Large continuity defects may be reconstructed using vascularized bone grafts from the fibula.

### *Temporization*

Temporary prosthetic treatment must be provided when necessary to minimize the impact of impaired cosmetics of missing teeth. Ironically, the cosmetics often worsen with the progress of orthodontic treatment when retained primary teeth, especially incisors, must be extracted to make room for the alignment of permanent teeth, or when alignment opens up edentulous gaps that hitherto had been somewhat camouflaged by the misalignment. During periods of no fixed orthodontic treatment, temporary restorations may take the form of acrylic removable partial dentures or Hawley-type orthodontic appliances furnished with prosthetic teeth and other components designed to effect minor tooth movements. During periods of active orthodontic tooth movement with fixed appliances, and later during retention of the orthodontic alignment, especially during the surgical phases of treatment when the surgical site cannot be loaded by a removable retainer, prosthetic teeth should be attached to the fixed arch wires in the esthetic zone whenever possible (Fig. 23). Transitional therapy may also include recontouring of hypoplastic teeth with composite resin where necessary (see Fig. 3A–C).

Fig. 23. Acrylic resin denture tooth suspended from an orthodontic arch wire at the site of a missing maxillary left central maintains an esthetic appearance during periods of active orthodontic tooth movement and later during retention of the orthodontic alignment.

### *Prosthodontic habilitation*

Depending on the location and number of implants to be restored, prosthodontic habilitation may involve the construction of single implant-supported crowns, multi–implant-supported fixed partial dentures, full-arch fixed bridges, and bar-retained complete overdentures. Screw-retained restorations are recommended over cement-retained appliances because they allow for retrievability, facilitate maintenance and revision, enhance retention in situations of restricted interocclusal space, and permit shaping and molding of the peri-implant soft tissues during provisionalization.

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Atlas of the
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# Use of Dental Implants in the Management of Syndromal Oligodontia

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Every instance of agenesis of a tooth represents an inborn error in dentogenesis. Just as current knowledge of metabolic and regulatory roles of essential molecules has been shaped partly by how inborn errors of their metabolism cause metabolic diseases, so too can accumulation and diffusion of knowledge of defects in dentogenesis facilitate a better understanding of craniofacial morphogenesis. On a practical level, clinicians should know the extent to which protocols for oral habilitation involving dental implants can be borrowed from our primary knowledge base and used to manage patients born with multiple malformations. This article reviews the literature relevant to the use of dental implants in patients with oligodontia secondary to chromosomal syndromes, such as it is, and illustrates the management of several of them.

In Sweden, it was estimated that 15% of children and adolescents missing eight or more permanent teeth were afflicted with a syndrome such as ectodermal dysplasia (ED). Of the 2800 syndromes listed in POSSUM, a computer-based resource that helps clinicians to diagnose syndromes in their patients, 126 syndromes are associated with anodontia or oligodontia (http://www.possum.net.au/). A synthesis of available literature estimated that the most frequent syndromes associated with agenesis of teeth are the EDs and Down syndrome.

ED is a syndrome characterized chiefly by abnormalities of the tissues that originate from ectoderm, namely skin, nails, hair, and teeth (Fig. 1). There are more than 150 variants of ED, with hypohidrotic ED (HED) exhibiting the most severe dental anomalies and a typical craniofacial dysmorphology, which makes it of greatest interest to dentists (Figs. 2 and 3). With an incidence of 1/100,000 births, HED is a relatively common syndrome. Depending on the type of treatment required, dental care for patients with ED has a significant financial impact on patients and their families.

Articles in the dental implant literature tend not to distinguish among the many variants of ED (Fig. 4), labeling them all simply as ED when it is likely that many—if not most—reported cases are HED. Numerous single case reports and small cohort studies in the literature describe the use of implants to support mandibular prostheses in children with ED. Since 1991, reports of single cases and small series of children with ED having been treated with implants have appeared in the literature; follow-up periods range from 0 months to 12 years and report few failure statistics. One retrospective study of 61 implants placed in 14 adolescents and young adults

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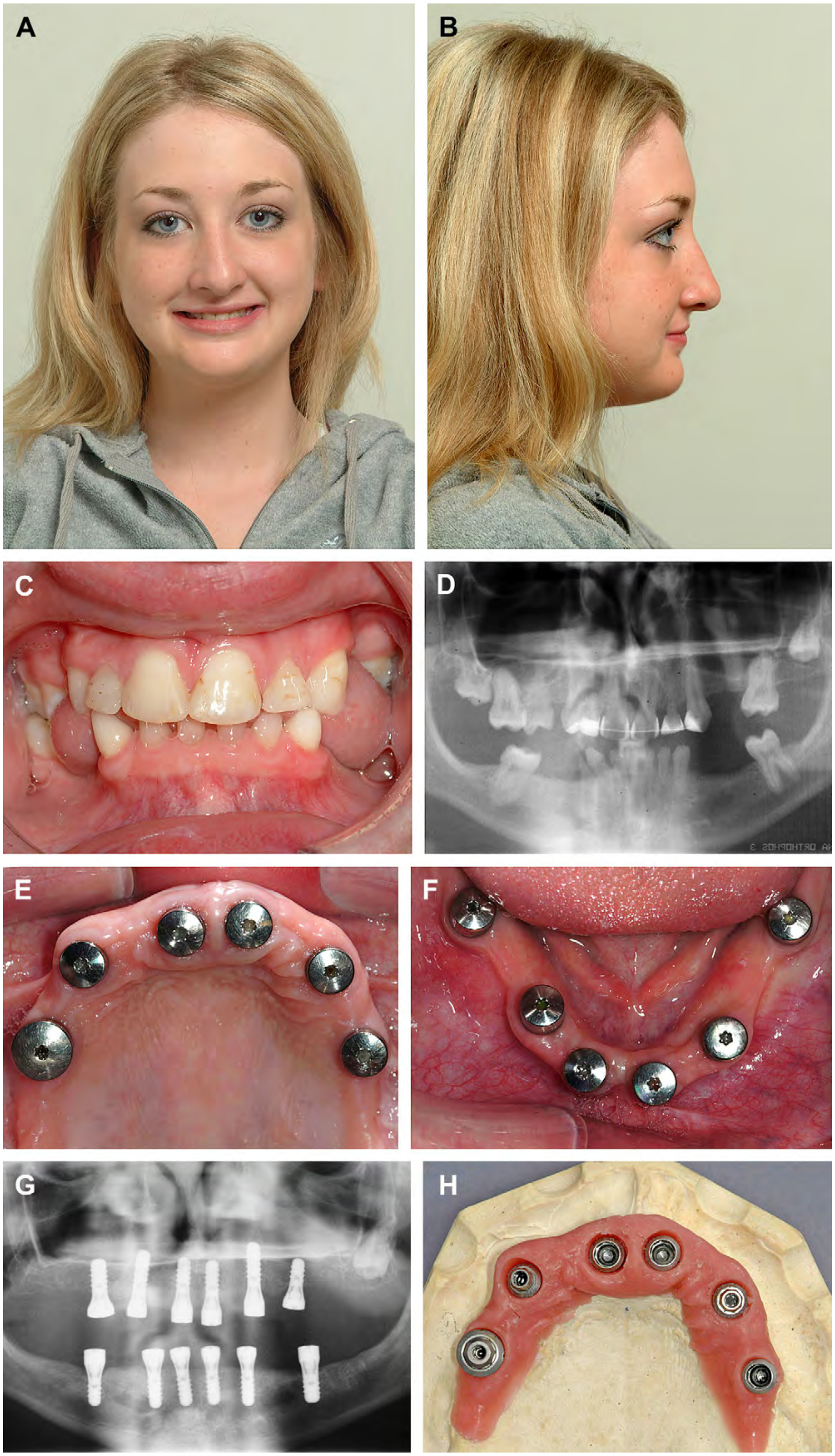

Fig. 1. A 17-year-old girl with mild expression of a hidrotic variant of ED. She expressed a pattern of anomalies, including thin hair and nails and severe oligodontia. (*A*) Facial view. (*B*) Right profile view. (*C*) Frontal view. (*D*) Preoperative panoramic tomography. (*E*) Maxillary occlusal view after edentulation and placement of dental implants. (*F*) Mandibular occlusal view after edentulation and placement of dental implants. (*G*) Postoperative panoramic tomography. (*H*) Maxillary master cast. (*I*) Mandibular master cast. (*J*) Frontal view of fixed bridges. (*K*) Occlusal view of maxillary fixed bridge. (*L*) Occlusal view of mandibular fixed bridge. (*M*) Postoperative facial view. (*N*) Postoperative right profile. (*O*) Postoperative view of smile.

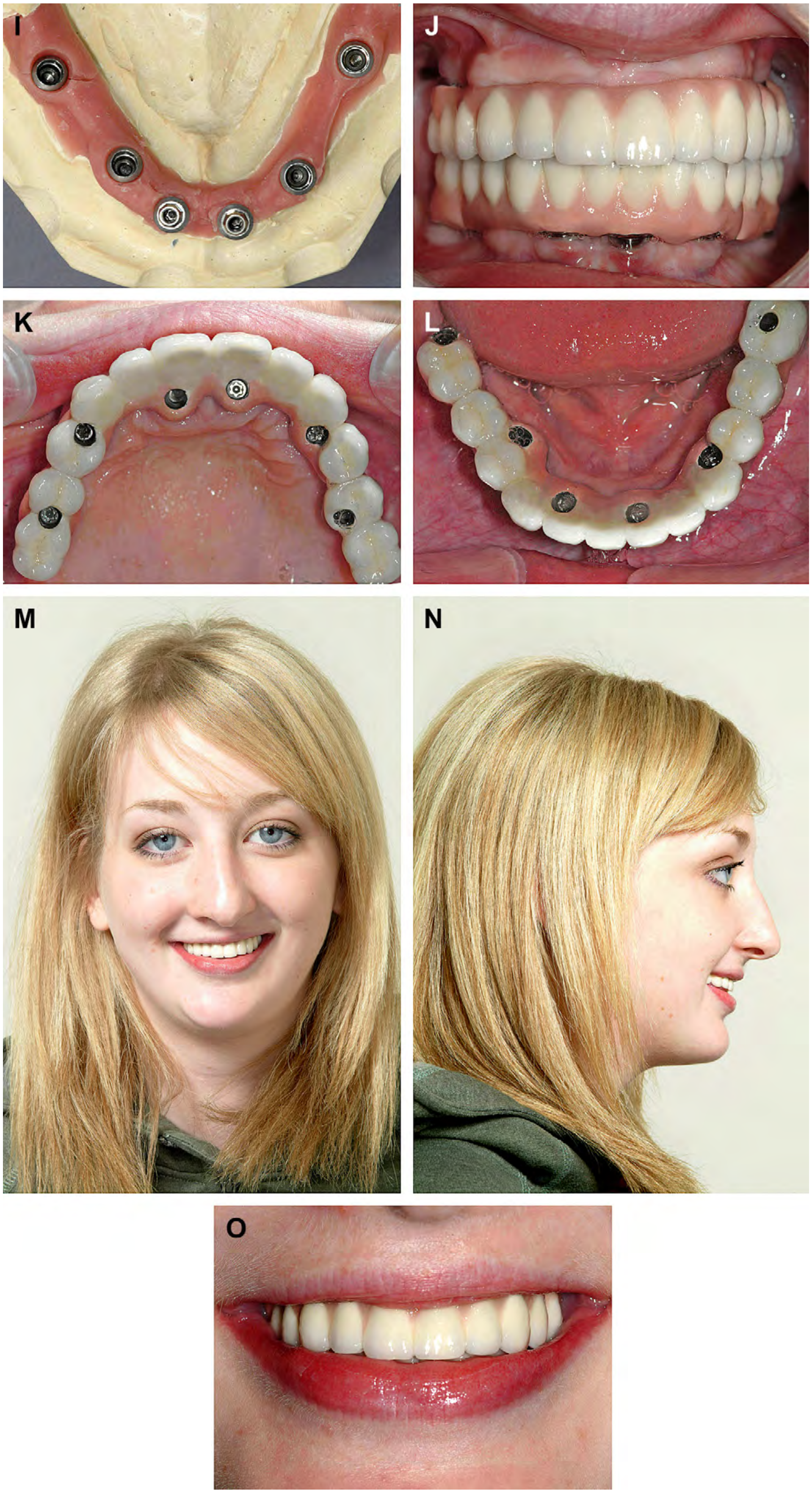

Fig. 1 (*continued*)

Fig. 2. A 21-year-old woman with hypohidrotic ED characterized by hypotrichosis (note hairpiece), hypohidrosis, and severe oligodontia. The entire permanent dentition comprised cone-shaped maxillary central incisors and canines and a small maxillary left first molar. (*A*) Facial view. (*B*) Right profile. (*C–F*) Initial definitive treatment included decoronation of all five teeth, construction of cast copings and a complete upper overdenture, and placement of an acrylic/gold fixed mandibular bridge. (*G–J*) Series of panoramic tomographs demonstrates initial presentation at age 21 years (*G*), maxillary cast overdenture copings and a first mandibular fixed bridge (*H*), and maxillary implants (*I*). (*J–N*) Current dental status at age 41. (*J*) Frontal view. (*K*) Maxillary occlusal view. (*L*) Mandibular occlusal view. (*M*) Facial view, age 41 years. (*N*) Right profile.

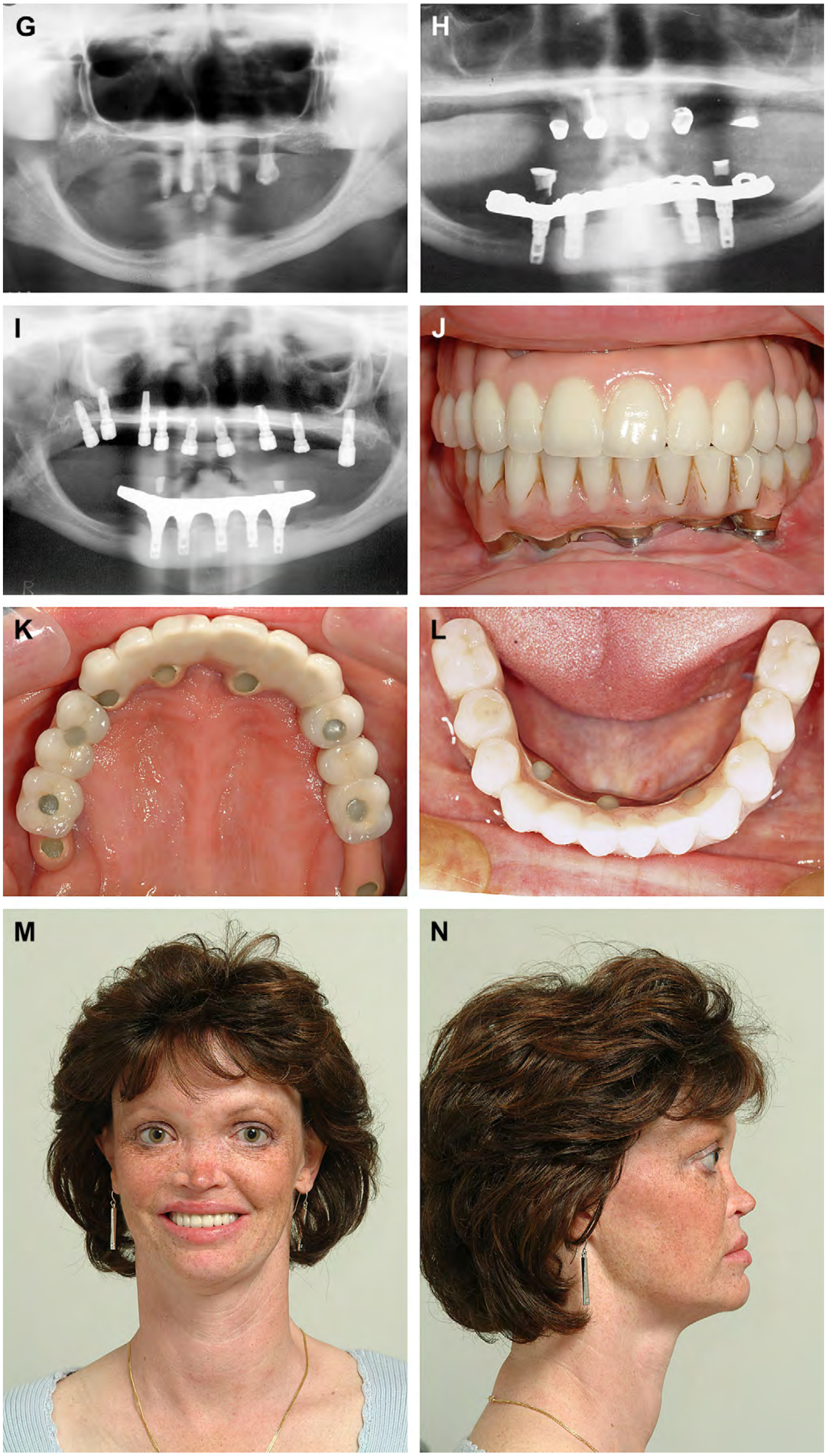

Fig. 2 (*continued*)

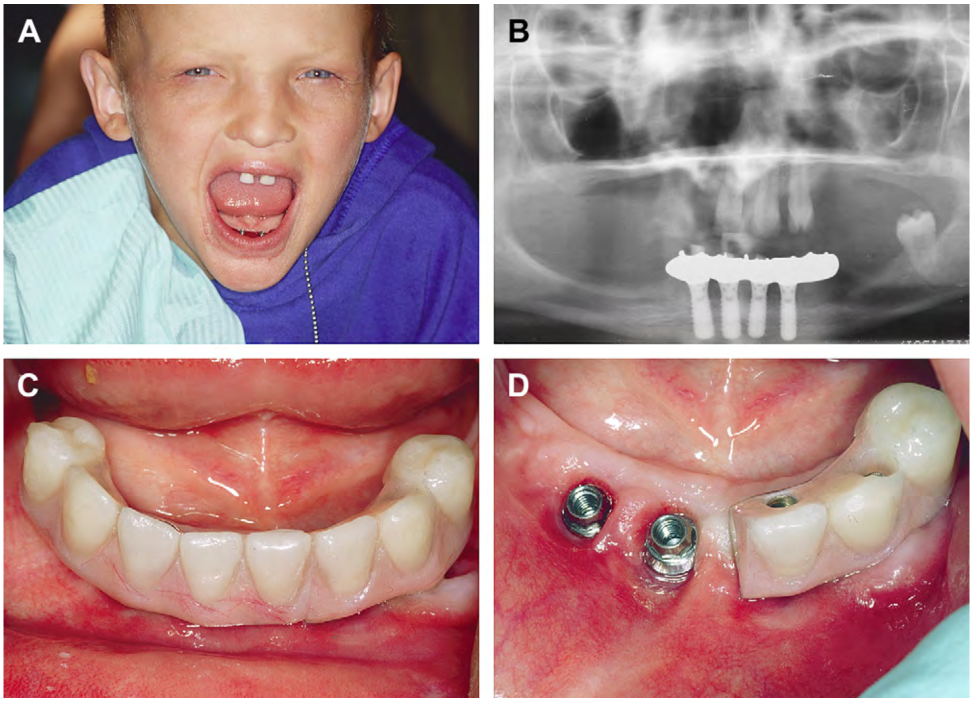

Fig. 3. (*A*) An 8-year-old boy with hypohidrotic ED in whom a two-piece bridge, split at the mandibular midline, on four anterior mandibular implants, was constructed. (*B*) Panoramic tomography. (*C*) Despite ongoing mandibular growth, no separation of the proximal surfaces of the right and left sides of the bridge is visible, which suggests that no parasymphyseal growth has occurred. (*D*) Right half of bridge removed.

who were followed from 1 to 5 years reported a 67% success rate. A prospective trial of 51 patients followed for up to 78 months reported survival rates of 91% in the mandible and 76% in the maxilla. The consensus from these reports seems to be that results support the continued use of implants in young children when appropriate precautions are taken not to interfere with growth of the jaws. Research has shown that treatment with implants in patients with HED does not rescue normal craniofacial growth and development.

Isolated case reports in the literature have documented the use of dental implants in patients with some other syndromes or conditions that may be associated with oligodontia: Down syndrome (Fig. 5), which occurs at an incidence of 1 in approximately 660 births and is the most common pattern of malformation in humans, and cleidocranial dysplasia (Fig. 6). In one retrospective study, implant survival was investigated retrospectively over 12 years in patients who exhibited various systemic diseases and congenital defects, including eight implants in three adult patients who had Down syndrome who were followed for 2, 9, and 11 years, respectively. The survival rate of the loaded implants was 100%. Oral hygiene that resulted in gingivitis and mucositis was noted as the only complication with these patients. In a preliminary report of a prospective study of patients with neurologic disabilities, one of the two adults who had Down syndrome lost one implant because of bone loss at 17 months after loading, and another experienced loss of half the bone support because of a sequestration after flap dehiscence attributed partly to the patient's macroglossia. The author speculated that the immune defects known to exist in patients who have Down syndrome may have played a role in implant bone loss and stressed the importance of informing the patient's caregiver about maintenance of good oral hygiene.

Patients with cleidocranial dysplasia commonly present with significant dental problems, such as aplasia, impaction or delayed eruption of permanent teeth, and the presence of supernumerary teeth. Several approaches have been described for the management of such patients. Although there has been a shift in the management paradigm for cleidocranial dysplasia from edentulation and prosthetic replacement to orthodontically assisted forced eruption and fixed appliance orthodontic treatment combined with orthognathic surgery, dental implant supported restorations have been used in both modes of treatment. Retrospective

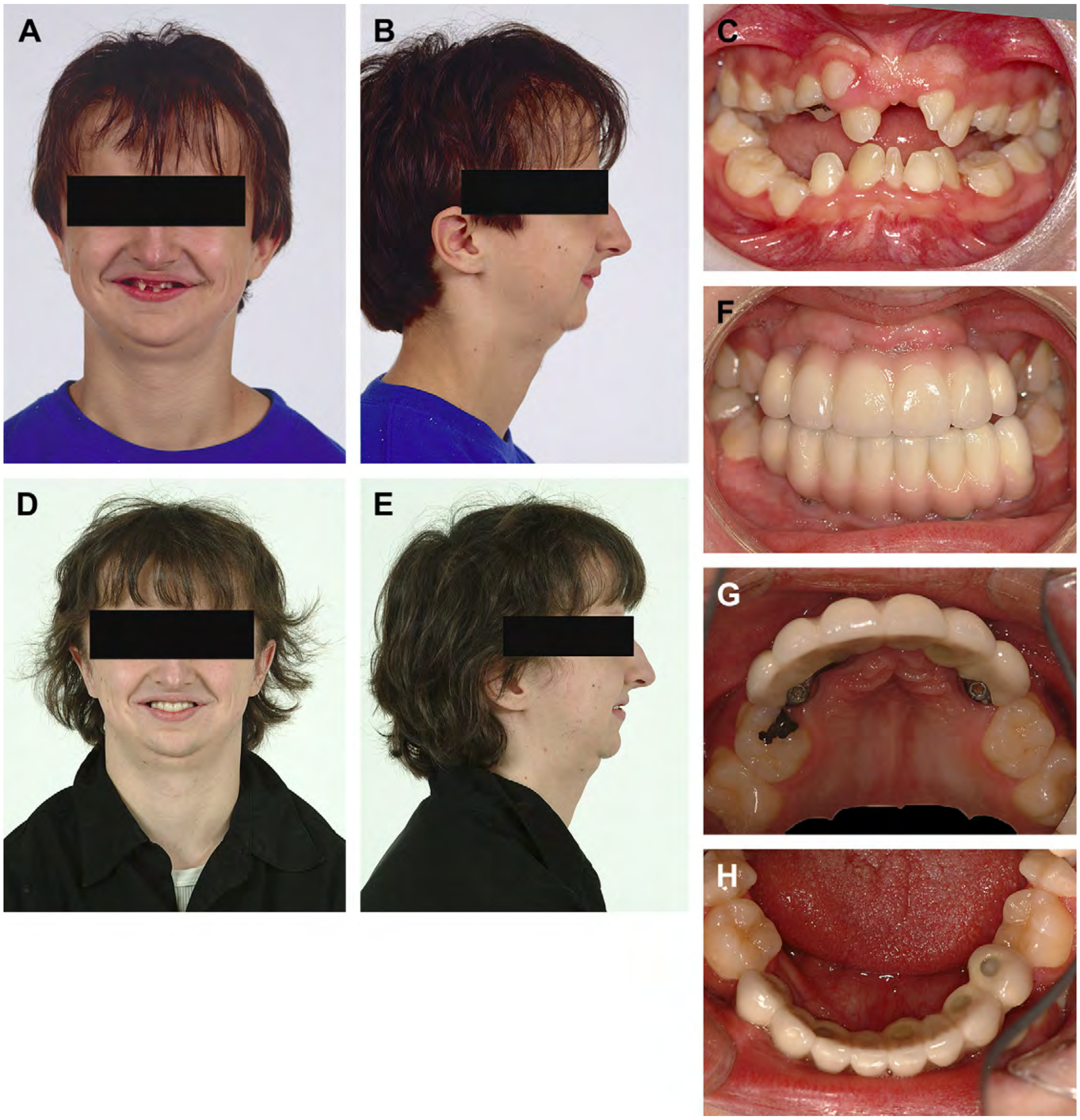

Fig. 4. An 18-year-old young man with Hallermann-Streiff syndrome (oculomandybulodyscephaly with hypotrichosis syndrome) characterized by small stature, microphthalmia, small pinched nose, hypotrichosis, and oligodontia. (*A*) Preoperative facial view. (*B*) Preoperative right profile. (*C*) Frontal view of teeth demonstrates severe oligodontia and retention of primary molars and skeletal anterior open bite. (*D*) Facial view after removal of retained primary and misaligned and misshapen permanent teeth and restoration with maxillary and mandibular porcelain/gold fixed bridges. (*E*) Right profile. (*F*) Frontal view of restored dentition. (*G*) Postoperative maxillary occlusal view. (*H*) Postoperative mandibular occlusal view.

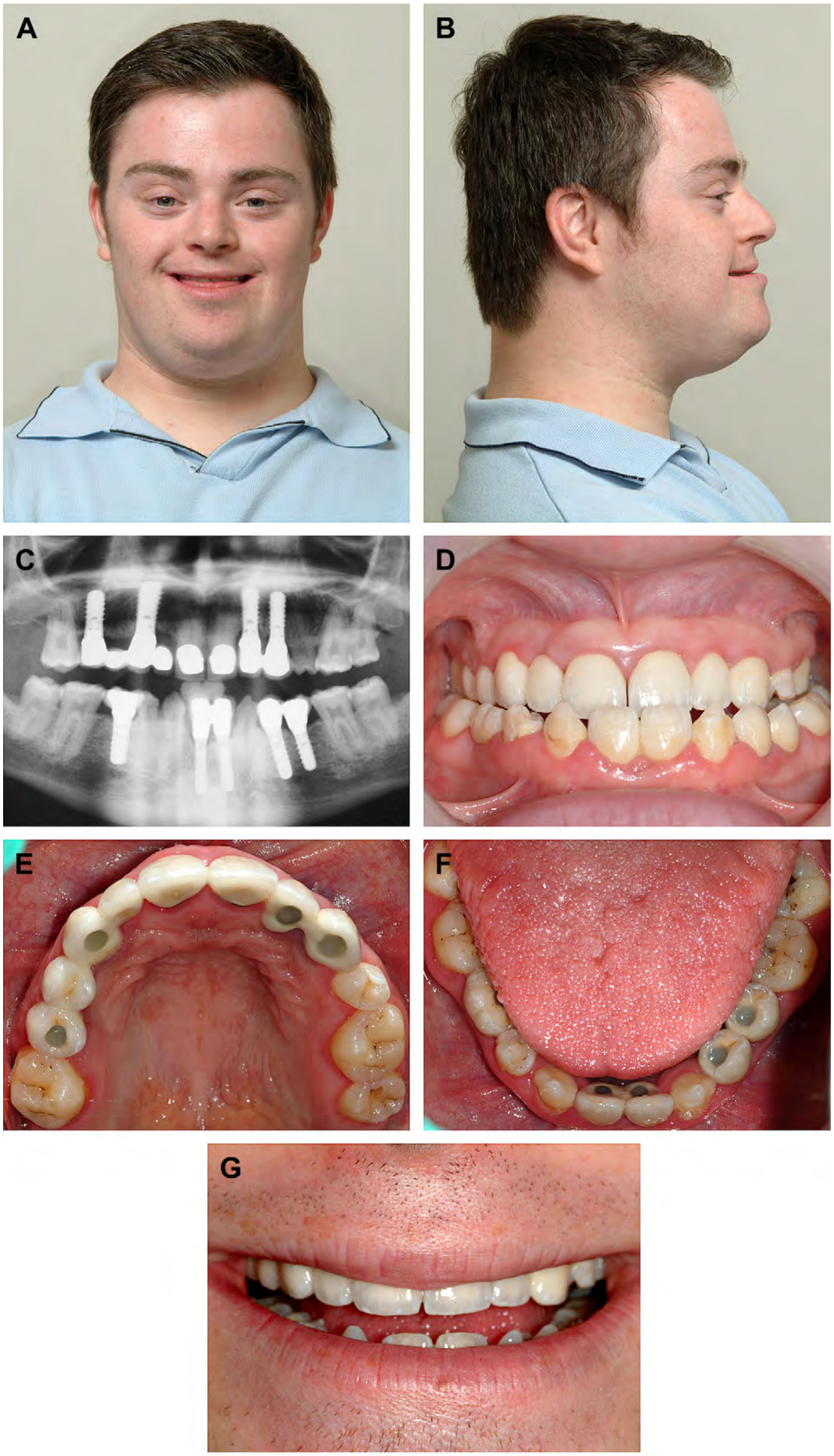

Fig. 5. A 22-year-old man with Down syndrome (trisomy 21) after orthodontic therapy and replacement of missing teeth with dental implants. (*A*) Facial view demonstrates hypotonia with tendency to keep mouth open and protrude the tongue. (*B*) Profile demonstrates prognathic mandible. (*C*) Panoramic radiograph demonstrates implant replacement of missing teeth. (*D*) Postoperative frontal view of teeth demonstrates class III occlusion with negative overjet. (*E*) Postoperative maxillary occlusal view. (*F*) Postoperative mandibular occlusal view demonstrates macroglossia. (*G*) View of smile.

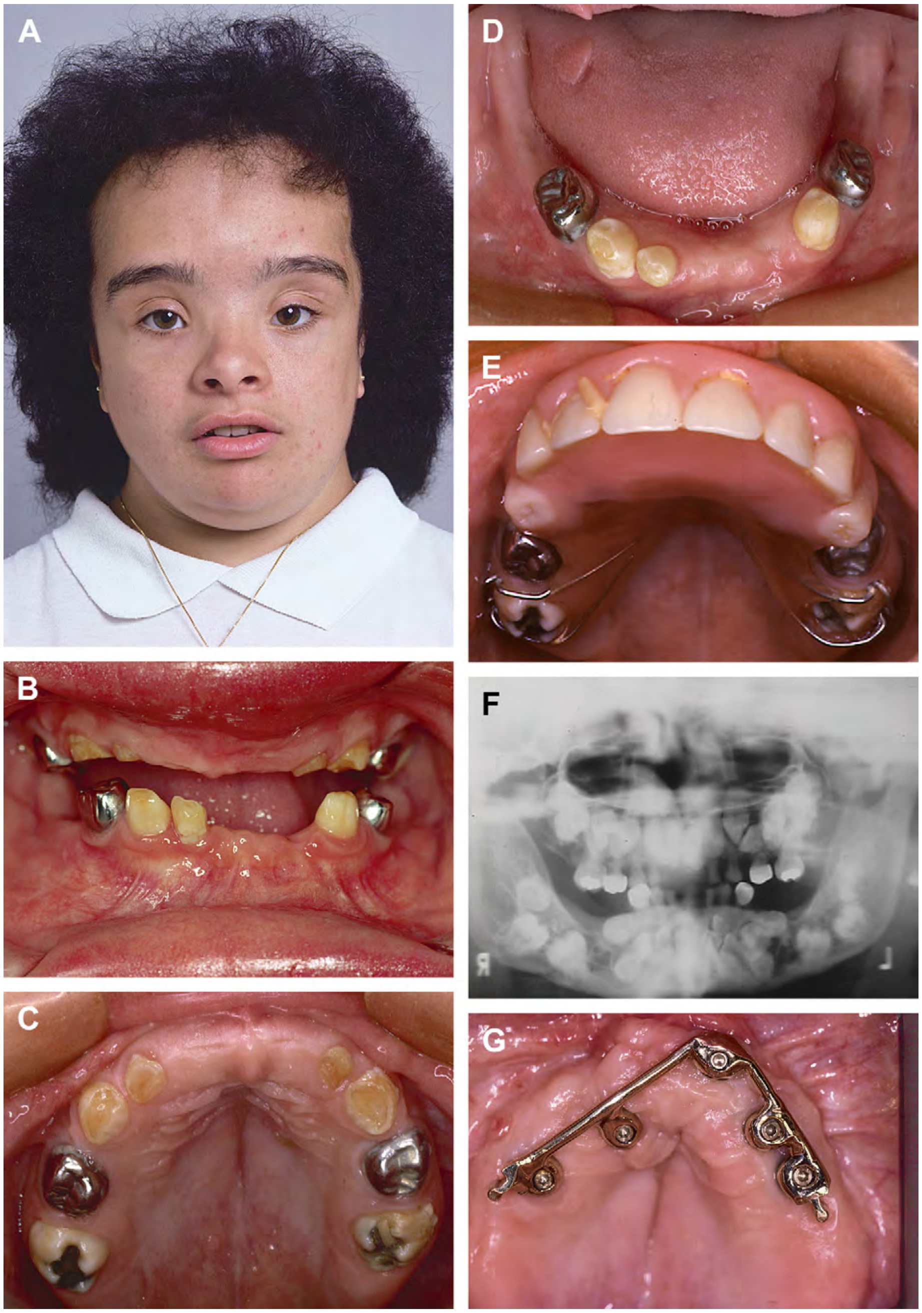

Fig. 6. A 16-year-old girl with cleidocranial dysplasia who presented with a mostly unerupted permanent dentition. She was treated with partial edentulation, alveolar augmentation using coral granules, reconstruction with an implant-retained complete upper overdenture and mandibular fixed bridge and followed for 10 years. (*A*) Facial view demonstrates brachycephaly with frontal bossing, midfacial hypoplasia, low nasal bridge, and hypertelorism. (*B*) Front view of teeth demonstrates partially retained, worn primary dentition. (*C*) Maxillary occlusal view demonstrates the two sole erupted permanent teeth—the first molars. (*D*) Mandibular occlusal view demonstrates partial retention of primary dentition. (*E*) Maxillary occlusal view of acrylic partial upper denture. (*F*) Panoramic tomograph demonstrates deep impaction of permanent dentition and supernumerary teeth. (*G*) Posttreatment maxillary occlusal view of implant-supported bar assembly. (*H*) Intaglio surface of bar-retained complete upper overdenture with a cast titanium framework and horizontal and vertical vinyl attachments. (*I*) Frontal view of complete upper overdenture and mandibular implant-supported fixed bridge. (*J*) Occlusal view of mandibular implant-supported fixed bridge. (*K*) Posttreatment facial view.

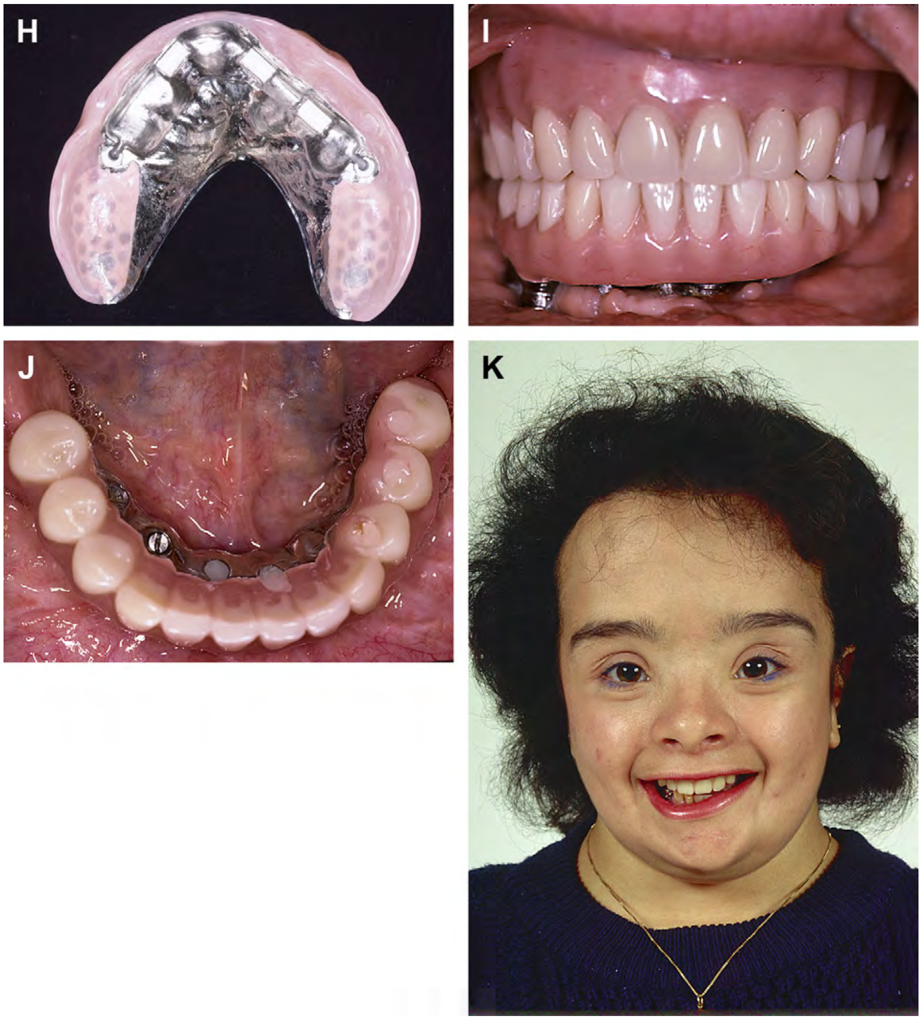

Fig. 6 (*continued*)

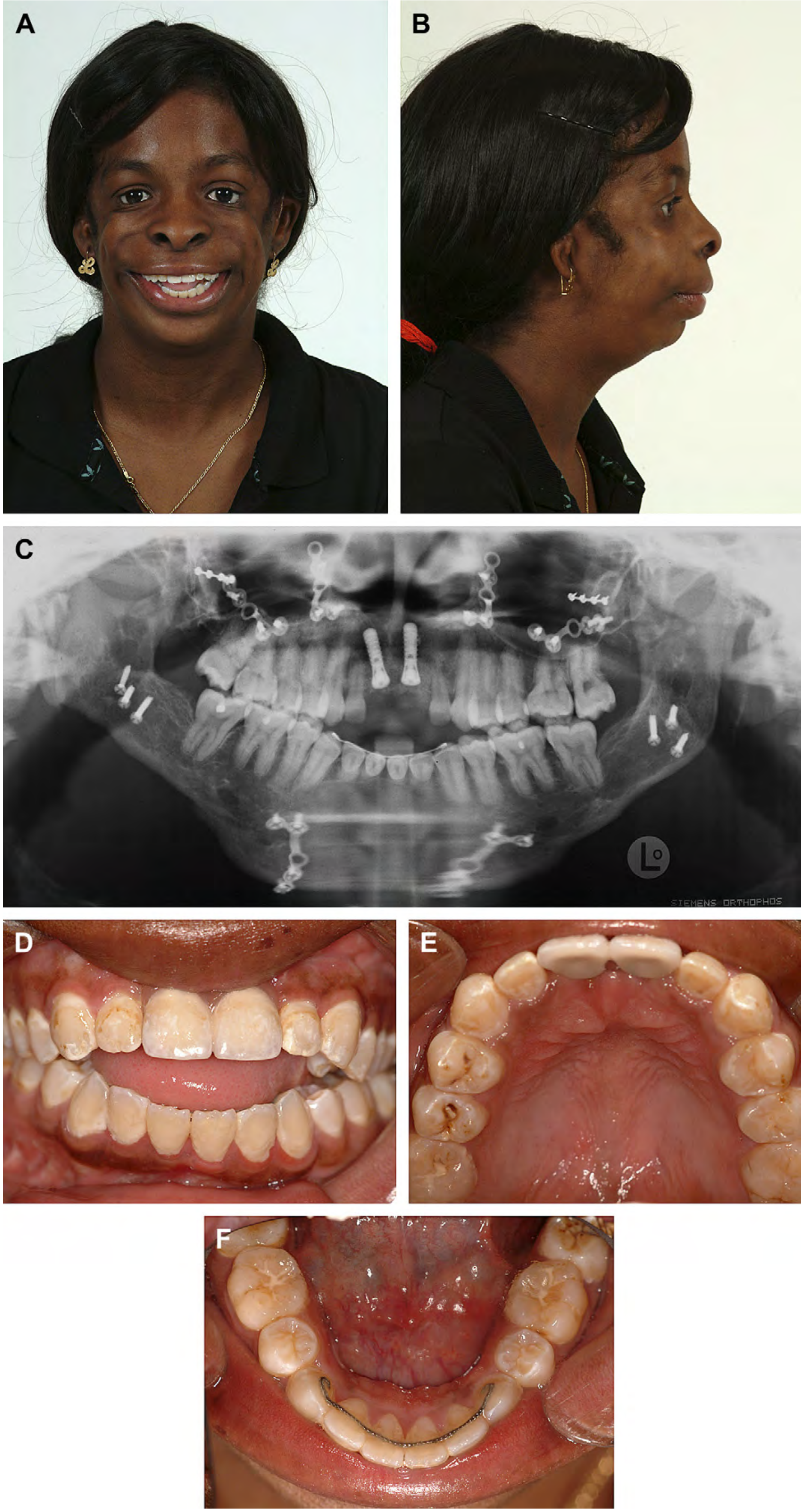
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Fig. 8. A 22-year-old woman with hemifacial microsomia (oculo-auriculo-vertebral spectrum, Goldenhar syndrome) after mandibular reconstruction involving free-tissue transfer and dental implant replacement of missing teeth. (*A*) Facial view demonstrates right side hypoplasia of malar, maxillary, and mandibular regions, especially ramus and condyle. (*B*) Right profile demonstrates mild microtia. (*C*) Left profile demonstrates normal appearance. (*D*) Frontal view demonstrates up-to-right cant of occlusal plane, implant replacement of right maxillary lateral incisor, canine, first premolar, and mandibular incisors, and mandibular second premolars. (*E*) Maxillary occlusal view. (*F*) Mandibular occlusal view.

Fig. 7. An 18-year-old girl with Treacher Collins syndrome (mandibulofacial dysostosis) after Le Fort I and bilateral sagittal split osteotomies, genioplasty, and replacement of missing maxillary central incisors with dental implant-supported crowns. (*A*) Postoperative facial view demonstrates malar hypoplasia and residual anterior open bite. (*B*) Right profile view demonstrates residual mandibular retrognathia, malformation of auricle, absence of lower eyelashes, and projection of scalp hair onto lateral cheek. (*C*) Panoramic tomography demonstrates orthognathic reconstruction hardware and dental implants at maxillary central incisor sites. (*D*) Frontal view demonstrates splinted implant-supported porcelain/gold crowns replacing maxillary central incisors. (*E*) Maxillary occlusal view demonstrates splinted crowns at central incisor sites, cemented to compensate for buccal angulation of implants. (*F*) Mandibular occlusal view.

Fig. 9. A 21-year-old woman with frontonasal dysplasia sequence (median cleft face syndrome). (*A*) Facial view demonstrates result of complex craniofacial reconstruction to correct hypertelorism, broad nasion with a midline cleft in the bony dorsum, midline defect of the frontal bone, absence of the nasal tip, and deformities in the nasal alar region. (*B*) Right profile. (*C*) Frontal view of oral cavity demonstrates near total anodontia. (*D*) Maxillary occlusal view after reconstruction with implant-supported bar assembly for retention of complete upper overdenture followed for 10 years. (*E*) Mandibular occlusal view at 10-year follow-up of implants used to support fixed bridge. (*F*) Mandibular fixed bridge at 10-year follow-up. (*G*) Facial view at 10-year follow-up. (*H*) Right profile at 10-year follow-up. (*I*) Smile at 10-year follow-up.

Fig. 9 (*continued*)

studies have reported the successful use of osseointegrated implants to support bone-anchored hearing aids in children who have Treacher Collins syndrome (Fig. 7) and hemifacial microsomia (Fig. 8) but not to support dental prostheses in these patients.

Figs. 1 to 8 in this article were included as representatives of the most commonly encountered examples of chromosomal syndromes detailed in the foregoing discussion. Other rarer syndromes (Fig. 9) and nonsyndromal diseases and disorders were not included because of lack of space. From the small collection of cases reported here and despite the poverty of data documenting survival of dental implants in these diverse clinical populations, it can be seen that implant therapy can have a lasting and profoundly positive impact on patients with craniofacial anomalies. By their very nature, these patterns of malformation are rarely encountered, even by teams at large tertiary centers. It behooves those of us charged with their care to report treatment outcomes to facilitate the process of patient selection in accordance with an integration of best research evidence with clinical expertise and patient values.

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Atlas Oral Maxillofacial Surg Clin N Am 16 (2008) 49–59

Atlas of the
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# Use of Dental Implants in the Management of Dental Malformations

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Dental anomalies include structural defects in enamel and dentin, fusion of teeth, and hamartomas such as odontomas. Enamel defects occur as a heterogenous spectrum of types, with different genetic etiologies, known collectively as amelogenesis imperfecta. They range in severity from barely discernible to aplasia. They may occur as a single defect or as but one defect in a recognizable pattern of defects such as epidermolysis bullosa or generalized odontodysplasia. Dentin defects are much less clinically heterogeneous, and can occur alone or in association with osteogenesis imperfecta.

## Amelogenesis imperfecta

Amelogenesis imperfecta (AI) is a heterogeneous group of hereditary disorders that adversely affects enamel development and causes abnormalities in the amount, structure, and composition of enamel without evidence of systemic disease. Winter and Witkop and coworkers have delineated at least 12 distinct types of AI using a combination of clinical, radiographic, histologic, and genetic criteria.

Transmission of the responsible gene may take place by autosomal dominant, autosomal recessive, X-linked dominant, and X-linked recessive modes. More recently, some defective enamel proteins and their causative genes have been identified. Mutations of the enamelin gene (ENAM) located on chromosome 4q21 have been identified in autosomal dominant forms. Smooth hypoplastic AI and local hypoplastic AI are two clinically distinct phenotypes of autosomal dominant forms associated with ENAM mutations. The X-linked form results from mutations in the Amelogenin protein with the causative gene AMELX located on chromosome Xp21.12. Different mutations have been identified, and depending on the mutations, phenotypes can vary. The genes responsible for autosomal recessive AI types have not been identified, and it is not known whether their diverse phenotypes are the result of either allelic gene mutations or mutations in multiple genes.

Three broad groups of AI can be distinguished on clinical and radiographic grounds alone. First there exists a hypoplastic group in which the enamel is reduced in quantity but is relatively well mineralized. The enamel may present with white flecks, narrow horizontal bands, lines of

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pits, grooves, and discoloration of the teeth that varies from yellow to dark brown. In the second group, hypocalcification is noted. The enamel is formed in relatively normal amounts but is poorly mineralized. In this form, the enamel is soft and friable and may show a chalky, dull color or cheesy consistency. In the third group there is hypomaturation of the enamel. In this group, the final stages of the enamel mineralization process are abnormal. The enamel is harder with a mottled, opaque white to yellow-brown or red-brown color. The prevalence of AI is reported as being 1 in 700 in northern Sweden, 1 in 14,000 in the United States, and 1 in 2000 in the United Kingdom.

The primary clinical problems of AI are atrrition and shear fractures of enamel, susceptibility to caries, sensitivity, pain, periodontitis, endodontic infections and compromised esthetics (Fig. 1). The severity of these problems varies among the different types of AI. Several reports have described malocclusion that occurs in some patients with AI that is characterized by an anterior open bite. Rowley and colleagues found 20% of subjects with severe anterior open bite and 44% with a severe vertical dysgnathia characterized by large gonial and maxillary-mandibular plane angles together with increased lower facial height (Fig. 2A). With such steep mandibular plane angles, it is not surprising to find occlusal stops on only the first or second molars. There may also be multiple retained deciduous teeth and unerupted and impacted permanent teeth. Extraoral findings may also include a short upper lip and incompetent lips. Local factors, such as abnormal tongue activity and deglutition pattern, are the effects rather than causes of vertical dysgnathia. The anterior open bite is skeletal rather than dental in origin (Fig. 2A–C).

The psychological effects of living with a grossly malformed dentition cannot be underestimated. Besides the problems delineated above, patients who have AI often complain of relentless teasing at school by their peers.

There may be a strong family history of similar affliction. For example, the patient in Fig. 2 had a history involving his mother, mother's brother and sister, and a maternal grandfather and great-grandfather. In that case, a diagnosis of AI–hypocalcified, autosomal dominant type was made.

### *Management of amelogenesis imperfecta with dental implants*

It is crucial that patients who have AI be informed of their diagnosis and the mode of inheritance of their particular condition. Treatment may range from doing nothing in mild cases, to full- or partial-mouth restoration with crowns in moderately severe cases. The 75% survival rate for crowns has been estimated at 11 years. Other studies have reported 8- to 10-year survival rates of between 85% and 95% for crowns and cast inlays/onlays. Some authors have reported median survival time for crowns of 14 years. It is likely that survival rates for crowns in patients who have AI are significantly worse. In severe cases where clinical crown lengths are deficient because of generally incomplete eruption, crowning of the teeth may prove impossible because of the inability to create adequate resistance and retention form in tooth preparations. Moreover, in cases of severe penetrance of the hypomature or hypocalcified type of AI, well-defined, smooth finish line may be impossible to produce in the weak, pitted and flaking enamel thus increasing the likelihood of producing a crown margin deficiency that is less

Fig. 1. Appearance of the dentition in a patient afflicted with AI, type hypomaturation.

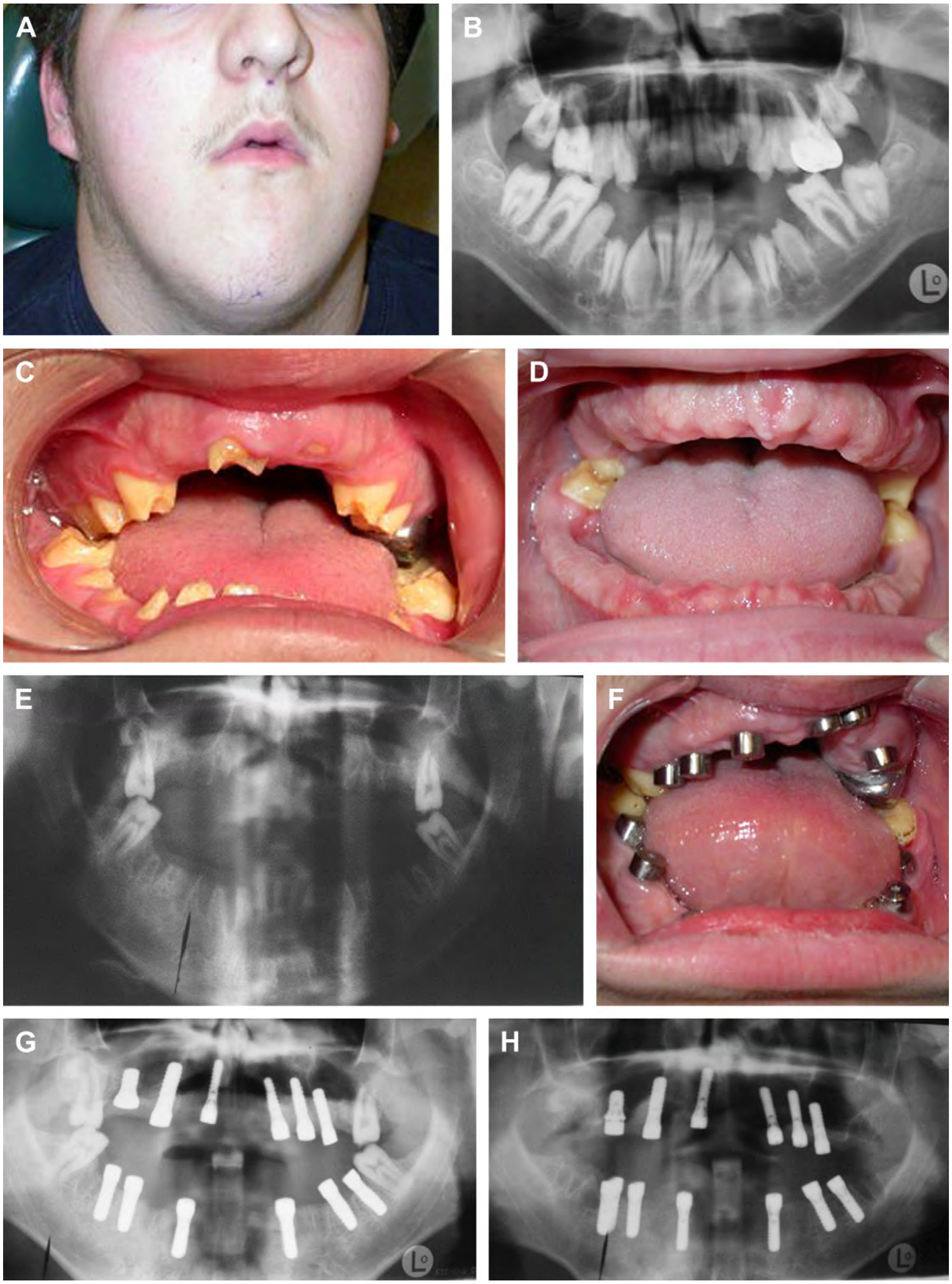

Fig. 2. (*A*) This patient with AI presented with an increased lower vertical face height. (*B*) The orthopantomogram at the time of presentation shows multiple impacted permanent canines and a thin shell of enamel on all the teeth. (*C*) The state of the dentition before edentulation. (*D*) Clinical photograph shows how subtotal edentulation left the four permanent second molars to provide the patient with occlusal stops. (*E*) Orthopantomogram shows the results of subtotal edentulation. (*F*) Single-stage implants were placed 2 months following tooth extractions. Note the way in which preservation of second molars protects implants from occlusal loading. (*G*) Panoramic tomogram of dental implants during healing. (*H*) Six months after placement of the implants, the four permanent second molars were removed. There was a dramatic 12-mm decrease in the patient's lower vertical face height. The patient underwent restoration without orthognathic surgery using conventional prosthodontic techniques.

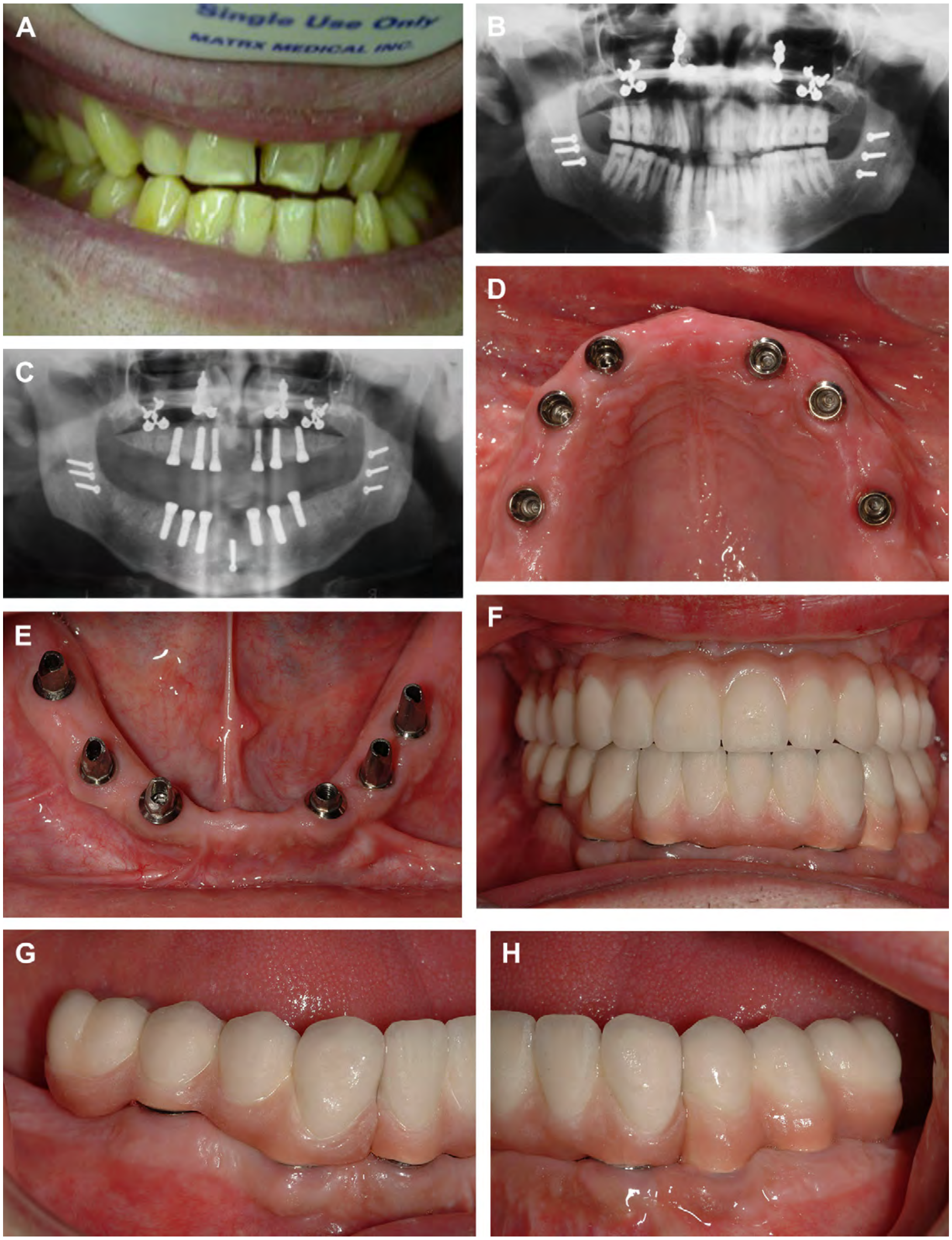

Fig. 3. (*A*) Photograph shows the appearance of a dentition affected with hypoplastic AI. (*B*) Orthopantomogram shows the state of the jaws and dentition after orthognathic repositioning. (*C*) Orthopantomogram shows six implant fixtures in each jaw. (*D*) Maxillary occlusal view shows healed one-stage dental implants ready for final impression. (*E*) Mandibular occlusal view shows healed one-stage fixtures with customized abutments. (*F*) Try-in of fixed bridges in biscuit bake stage. Each arch is restored in three sections. (*G*) Posterior right mandibular biscuit bake. (*H*) Posterior left mandibular biscuit bake. (*I*) Occlusal view of the maxillary reconstruction installed onto the maxillary dental implants. (*J*) Occlusal view of the mandibular reconstruction installed onto the mandibular dental implants. (*K*) Broad smile from a distance. (*L*) Right profile view of the lower face.

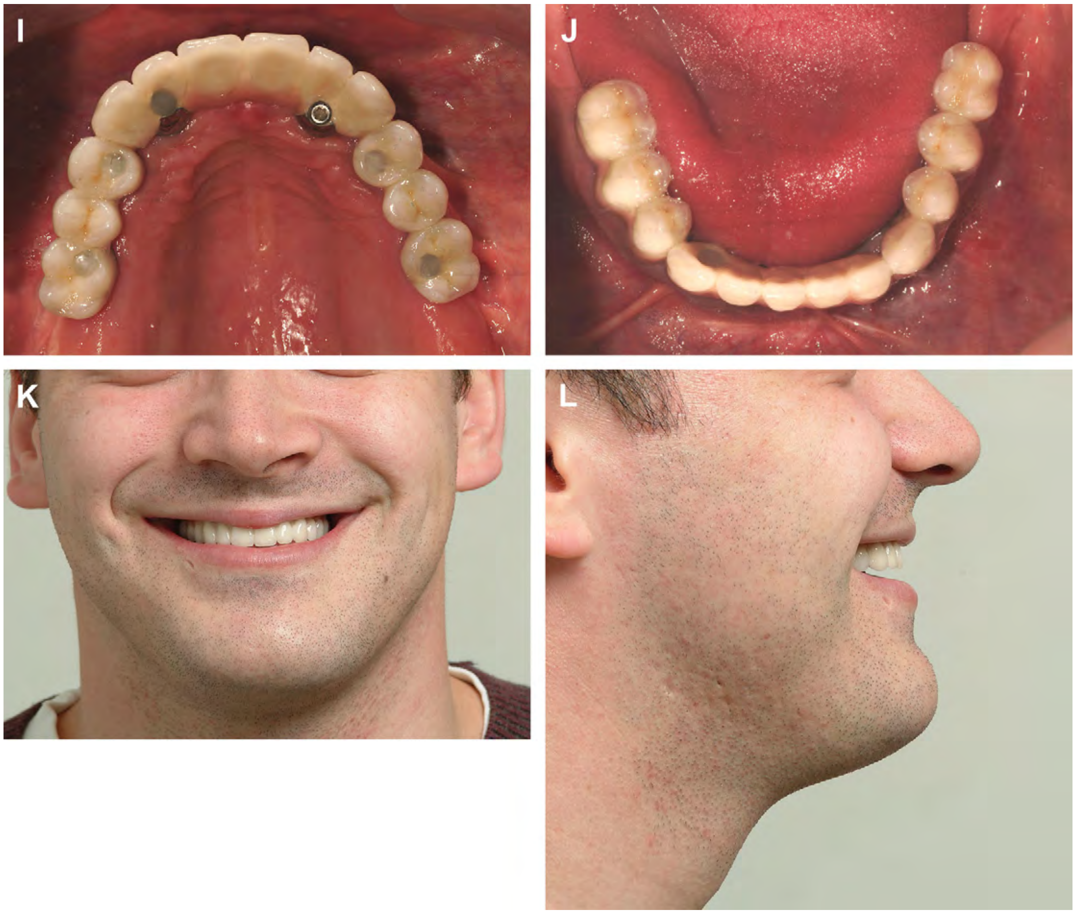

Fig. 3 (*continued*)

resistant to caries. When a clinically acceptable finish line is created, the enamel may fracture intra-operatively or following cementation of the crown.

Periodontitis is commonly found in association with AI, in part because roughness of the enamel promotes bacterial plaque retention. This is only exacerbated by placement of crown margins near the gingival margin, particularly when they are made to invade the gingival sulcus in an attempt to increase clinical crown length or in search of less fragile, less porous enamel on which to fashion a smooth finish line.

Surgical orthodontics may be impeded by the inability to bond orthodontic brackets securely to dysplastic enamel, and attempting to circumvent this problem by temporizing the dentition with acrylic resin crowns prior to application of fixed orthodontic hardware exposes the patient to a heightened risk of cement washout and caries. Furthermore, insecure temporary crowns introduce the possibility that intermaxillary fixation may be ineffectual. Unless orthodontic treatment can be conducted reliably, surgical orthodontics in patients who have AI is ill-advised.

We reckon that in young patients with AI a conventional oral reconstruction using crowns, if possible in the first place, would have to be replaced multiple times over the course of his or her lifetime, and may in the end condemn the patient to edentulation anyway. The costs of implant- and tooth-supported reconstructions are comparable in many jurisdictions, therefore, it may be most cost-effective to edentulate the unrestored dentition and rehabilitate with implant-supported restorations from the outset of skeletal maturity (Fig. 3). This strategy presupposes that implant-supported restorations can last many years without costly maintenance, and indeed that the implants on which they rest can remain functional for the better part of a lifetime, suppositions which have yet to be proven.

The patient in Fig. 2 had initial treatment that involved the extraction of all retained deciduous teeth. Exposure and bonding of the impacted permanent canines was planned to aid in establishing an occlusal plane orthodontically. The defective enamel impaired bonding of orthodontic hardware to the teeth, and so the impacted permanent canines were extracted and the patient was debonded. As the pubertal growth spurt continued, the anterior open bite continued to increase dramatically. Prior to cessation of growth, when it became obvious that surgical orthodontics was untenable, an alternative to the original treatment plan was offered. The alternate treatment plan was subtotal edentulation, placement of dental implants, provisionalization with acrylic fixed bridges, reassessment following cessation of skeletal growth of the need for orthognathic surgery, and finally, construction of definitive implant-supported fixed bridges.

Edentulation, with the exception of the occluding second molars, was performed under general anesthesia. These teeth were left to serve as occlusal stops to protect the dental implants during initial healing (Figs. 2F, 2G). Two months after edentulation, six ITI solid screw dental implant fixtures (Straumann Ag, Waldenburg, Switzerland), varying in length from 6 mm to 12 mm, were placed in the jaws. Bilateral sinus lifts were performed using bone particles harvested intraorally with a suction trap. After complete cessation of skeletal growth, the need for orthognathic surgery was reassessed. A decrease in anterior open bite of 12 mm, with a corresponding decrease in lower face height and improvement in lip competency, had been effected by extraction of the sole occluding second molars (Fig. 2H). As a result, the facial profile improved greatly. Implant-supported prostheses were fabricated, which resulted in immediate improvement in chewing function and aesthetics. Orthognathic surgery was deemed unnecessary because an acceptable occlusion could be developed prosthetically.

## Enamel aplasia

Enamel aplasia may appear at first glance to be clinically similar to AI but close clinical and radiographic examination will reveal total absence of enamel, and as a result will be characterized by extreme dental sensitivity to cold and pain. Teeth with enamel aplasia, for example in generalized odontodysplasia, may not erupt normally so tend to lie ectopically in the jaws. The reasons for treating patients who have enamel aplasia by edentulation and implant placement may be even more compelling than for patients who have AI, primarily because of the failure of teeth to erupt normally.

## Epidermolysis bullosa

Patients who have epidermolysis bullosa have dentitions grossly similar to enamel aplasia. The reconstruction of patients who have epidermolysis bullosa is difficult (Figs. 4A–4F). They have fragile skin and mucosa that must be protected during treatment to minimize bulla formation (see Fig. 4C). These bullae are painful and may lead to scarring. Moreover, these patients often have severe trismus which severely limits the access for reconstruction. To make matters worse, at least in our experience, local anesthetic is less effective in achieving depth and duration of anesthesia in patients with epidermis bullosa (and also in patients with AI in general).

## Dentinogenesis imperfecta

Dentinogenesis imperfecta (DI) is an inherited malformation of the dentin. The teeth appear blue-gray or amber brown and opalescent. Radiographically, the roots are narrow with little or no evidence of a pulp chamber or root canal. The crowns are ‘‘bell shaped’’ and bulbous with a wide emergence profile. The enamel may shear from the dentin when subjected to occlusal forces. There are three types of DI, all with an autosomal dominant pattern of inheritance. Types I and II are distinct from each other in that Type I is associated with osteogenesis imperfecta. Type III DI is the Brandywine form, named for the city in Maryland where there was a large population of patients with a less severe form of DI without osteogenesis imperfecta.

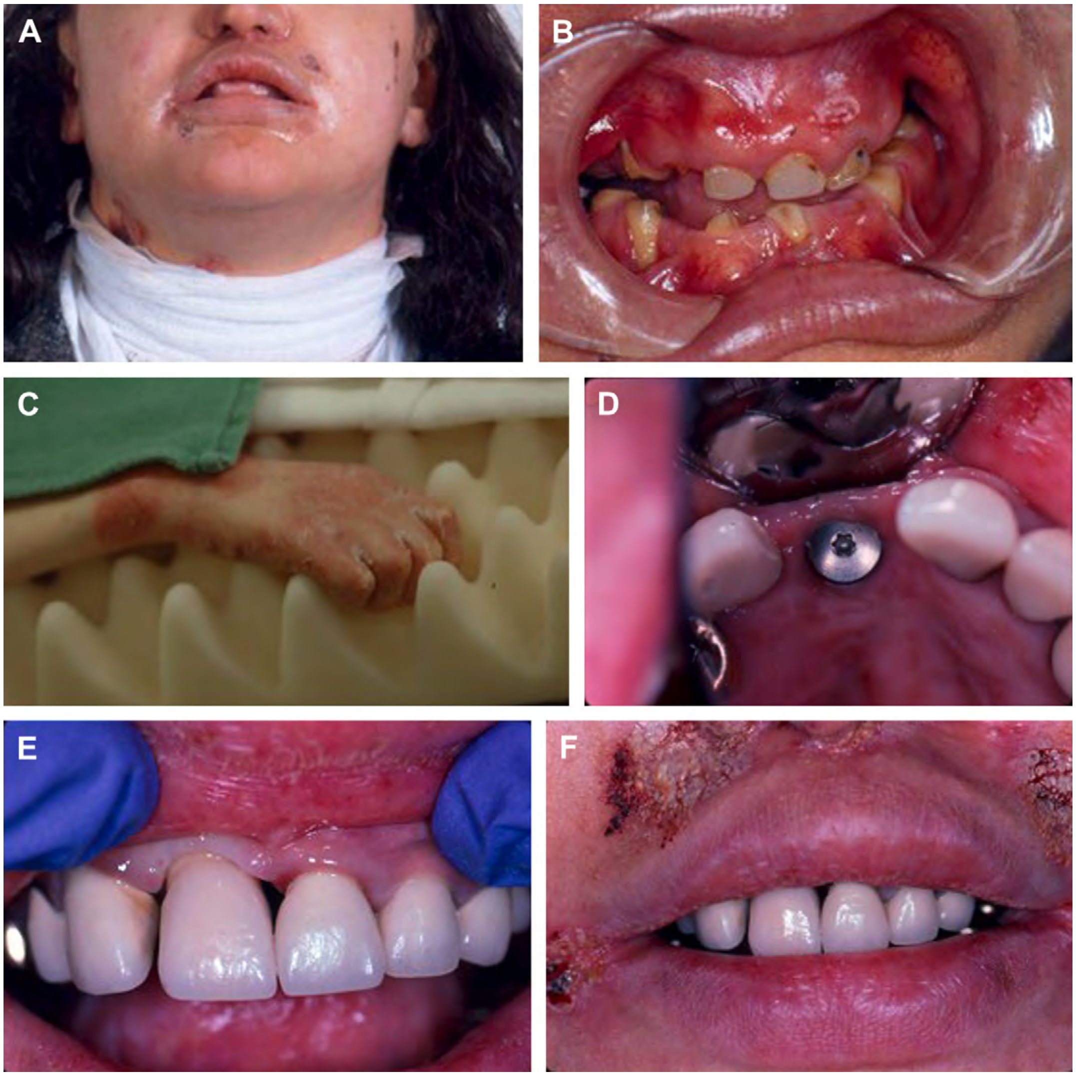

Fig. 4. (*A*) Patient who has epidermolysis bullosa exhibits multiple crusted bullae of lip and extremely friable skin. (*B*) Photograph of unrestored dentition demonstrates incomplete eruption of teeth, aplasia of enamel, attrition and compensatory eruptions, severely diminished clinical crown lengths, caries and limited access for oral hygiene because of scarring. (*C*) During treatment, great care must be taken to protect the skin overlying the limbs. Note the state of the digits caused by repeated minor trauma and subsequent scarring. An egg crate mattress is helpful for these patients. (*D*) At 10 years following oral rehabilitation with clinical crown lengthening, crowns and fixed bridges, the maxillary right central incisor is lost and replaced by a dental implant. (*E*) Close-up photograph of right maxillary central incisor crown supported by maxillary dental implant. (*F*) Appearance of newly inserted crown. Note lips caused by healing bullae, which is typical for patients with epidermolysis bullosa.

Inherited defects of dentin occur in 5 types: 3 types of dentinogenesis imperfecta (DI), and 2 types of dentin dysplasia (DD). DI Type I occurs in association with osteogenesis imperfecta. Type I DI is caused by mutations in the 2 genes coding for type I collagen (COL1A1, COL1A2). In contrast, DD-II, DI Type II and DI Type III have been found to be caused by various defects in dentin sialophosphoprotein, the major non-collagenous protein of dentin. The genetic etiology of DD I, a rare condition featuring short, blunt roots with obliterated pulp chambers, remains unknown.

When penetrance is high, DI is characterized by attrition and shear fracture of enamel away from the defective dentin, obliteration by secondary dentin formation of the pulp chamber and root canals, strangulation of the pulpal blood supply and pulpal necrosis. Attrition is invariably accompanied by compensatory eruption, and because the two processes can occur together so rapidly, clinical crown length can quickly become insufficient to retain a crown, and interarch space can diminish to the point where a crown cannot be accommodated. Fractured teeth may

Fig. 5. (*A*) Frontal facial photograph of patient with DI Type II with lips in repose. (*B*) Full smile frontal photograph of patient shows fixed orthodontic appliances on maxillary and mandibular dentition. Note vertical maxillary excess and excess display of gingivae. The dentition was in a terminal state and failed to provide sufficient dental anchorage to prepare patient for orthognathic surgery. (*C*) Profile of the same patient. (*D*) Frontal view of broken down DI Type II-affected dentition in terminal state. Note edge-to-edge incisor relationship. (*E*) Maxillary occlusal view. (*F*) Mandibular occlusal view. (*G*) Right buccal view. Note skeletal class III relationship and edge-to-edge incisal relationship. (*H*) Frontal view following edentulation and placement of dental implants. Note reduction in gingival display secondary to alveolectomy (compare to Fig. 5B). (*I, J*) Maxillary and mandibular occlusal views of dental implants 2 weeks after their insertion. (*K*) Right buccal view. Note skeletal class III relationship. (*L*) Facial view following restoration of implants with maxillary and mandibular acrylic/gold fixed bridges. (*M*) Right half-profile view. (*N*) Right profile view demonstrates correct vertical dimension of occlusion. (*O*) Frontal view of maxillary and mandibular fixed bridges. Note arrangement of teeth in full crossbite in order to maintain advantageous access to prosthetic screws in both arches. (*P, Q*) Maxillary and mandibular occlusal views.

be restorable by crowning, but oftentimes part or all of the natural crown fractures off at or below gingival level making the tooth unrestorable. Even crowned teeth restored using a relatively conservative preparation technique can fracture, and when this happens it usually means the tooth has to be extracted. Pulpal necrosis follows from spontaneous secondary dentin

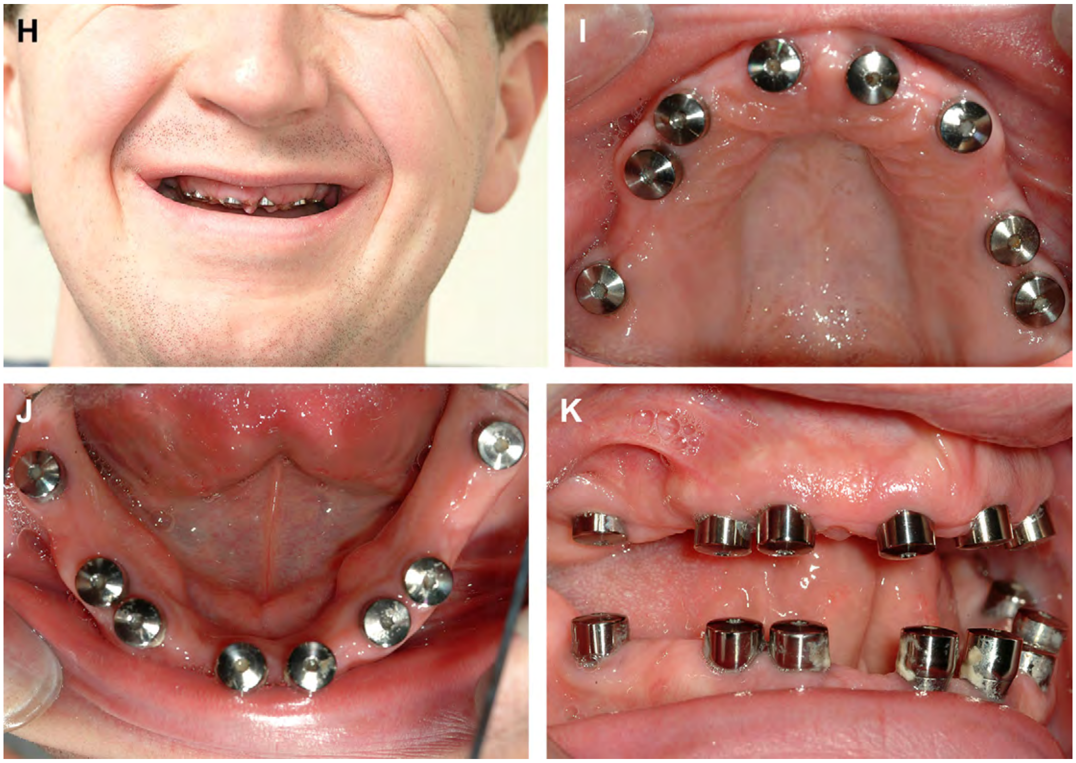

Fig. 5 (*continued*)

formation, and usually occurs asymptomatically. Consequently, periapical lesions are usually discovered serendipitously, and because the root canals become obliterated with secondary dentin, it is usually impossible to provide endodontic therapy, so the tooth has to be removed. It is believed by many clinicians that orthodontic and restorative interventions may hasten pulpal necrosis. Our own observation that patients who have DI type II also exhibit elevated periodontal disease activity is supported by the finding that an autosomal-dominant form of juvenile periodontitis is linked to DI type III. The combination of ways in which a dentition severely affected by DI deteriorate in spite of best restorative efforts to protect it, through attrition, fracture, pulpal necrosis, periodontitis, may culminate at a very early age during the late teens or early 20s. In less severely affected individuals, dentitions may remain more or less intact for many years.

Our recommendation is to initiate treatment early in development of the primary dentition using preformed crowns and composite resin to prevent deterioration of the teeth and to enhance esthetics. This strategy is continued through the mixed and into the adult dentitions. As the patient and/or the parents become more conscious of appearance, usually in the mid to late teens, crowns may be placed on teeth in the esthetic zone of the maxilla and, less often, mandible and on pairs of occluding posterior teeth to protect against attrition. The choice of teeth to be crowned is an individual one, and will depend on esthetic demands, pattern and severity of breakdown, and financial considerations. Tooth loss can be dealt with using tooth supported fixed bridges; however, it may be prudent to consider the use of dental implant supported crowns to replace single missing teeth in the expectation that isolated implants can be incorporated into larger implant supported reconstructions - fixed or removable - in the event of further loss of adjacent teeth. Depending upon severity of DI and the success of conventional restorative interventions to stave off deterioration, sooner (Fig. 5) or later a patient may become a candidate for edentulation of the residual dentiton and replacement with implant supported fixed bridges and/or dentures.

Patients who have DI type I also have osteogenesis imperfecta. These patients are much more severely afflicted from a systemic point of view, with multiple fractures of almost any bone. They

Fig. 5 (*continued*)

may have severe respiratory problems secondary to the chest malformation best described as kyphoscoliosis. Patients may be confined to a wheelchair. In an effort to decrease the skeletal morbidity of their disease, patients may be treated with bisphosphonates. Oral and intravenous bisphosphonates have been used in these patients, which may put them at risk for bisphosphonate-related osteonecrosis of the jaws. We caution readers to ensure that patients are able to undergo dentoalveolar surgery safely before making plans for any complex reconstructions.

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Atlas of the
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# Use of Dental Implants in the Management of Cleft Lip and Palate

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Slightly more than 1 child in 900 is born with cleft lip with or without cleft palate. Among children born with cleft lip and palate, approximately 37% are born with an isolated cleft lip, and approximately 63% are born with cleft lip and palate. Most cases of cleft lip and palate—approximately 70%—occur as isolated anomalies, whereas approximately 30% occur in association with other congenital anomalies and recognized syndromes. Most large tertiary care centers offer interprofessional care for children who have orofacial clefts. Numerous specialists take part in cleft rehabilitation, with most teams including a plastic surgeon, pediatrician, pediatric dentist, oral and maxillofacial surgeon, orthodontist, prosthodontist, social worker, speech and language pathologist, otolaryngologist, audiologist, psychologist, psychiatrist, and clinical coordinator nurse. Interprofessional care is designed to integrate physical, social, and psychological rehabilitation.

Primary corrective surgery is usually accomplished within the first year after the birth of a baby who has a cleft anomaly: repair of the lip is usually performed at 3 months, and repair of the palate is usually performed at 6 months. Repair of the alveolar process is performed much later—between the ages of 9 and 11 years. When bone grafting of the alveolus is performed during the mixed dentition stage before eruption of the permanent canine—that is, between the ages of 9 and 11 years—it is called secondary alveolar bone grafting (Fig. 1). When it is performed after eruption of the canine, it is called tertiary alveolar bone grafting. The most widely accepted protocol for repair of the alveolar process is secondary alveolar bone grafting because it allows for eruption of the cleft-adjacent teeth—usually the lateral incisor and canine—through the graft (Fig. 2). Eruption of teeth through the graft into a functional occlusion provides physiologic stress, which promotes remodeling of the graft. Satisfactory results have been reported after tertiary alveolar bone grafting when the transplanted bone is stressed functionally by placement of a dental implant into the grafted alveolar cleft. Alveolar bone grafting should not be considered an isolated procedure but integral to comprehensive orthodontic therapy. An important condition for a successful alveolar bone graft may include the forces of orthodontic treatment, which are thought to subject the graft to additional functional stresses, promote a physiologic remodeling, and ultimately prevent its resorption.

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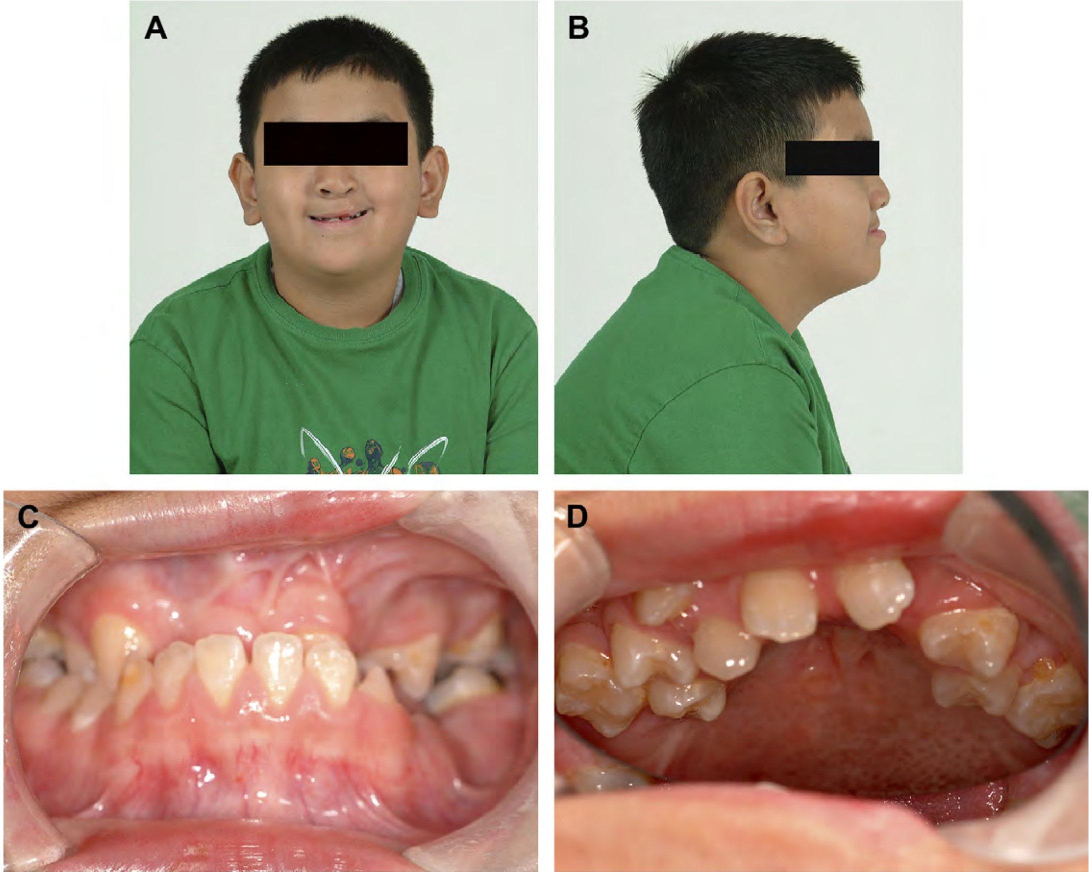

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Fig. 1. A 10-year-old boy with a repaired left complete cleft of the lip and palate. Secondary alveolar bone grafting was performed at 9 years of age. (*A*) Facial view. (*B*) Profile view demonstrates hypoplasia of maxilla. (*C*) Frontal view of teeth demonstrates crossbite anteriorly and posteriorly. (*D*) Maxillary occlusal view demonstrates grafted alveolar cleft through which the left lateral incisor and canine soon will erupt.

Comprehensive orthodontic therapy is usually initiated after eruption of the permanent canines and premolars. General goals of orthodontic therapy include expanding the maxilla and correcting cross bites, facilitating eruption of teeth, establishing a class I canine and molar relationship, and establishing correct midlines and alignment. A choice must be made to close the cleft dental gap orthodontically or open it for prosthodontic habilitation, in which case the list of orthodontic goals must be lengthened to include optimizing the dimensions of the edentulous gaps and achieving root parallelism adjacent to edentulous gaps. Whenever possible, management of the alveolar cleft should involve a strategy to avoid prosthodontic treatment as long as facial profile, dental aesthetics, and function are unlikely to be compromised. In any case, invasive traditional crown and bridge procedures should be avoided when possible (Fig. 3). Orthodontic gap closure and substitution of a mesialized canine for a missing maxillary lateral incisor would be considered if a reasonable aesthetic and functional outcome could be expected. In order for a canine substitution to provide an acceptable result, factors such as skeletal pattern, occlusal relationships, tooth size/arch length coordination, and size, shape, and color of the canine relative to the central incisor should be favorable.

The size of the maxilla may govern the decision to close the gap orthodontically or open it and fill the space prosthodontically. Most clefts are associated with an element of maxillary hypoplasia; if the maxilla is marginally retrusive and gap closure cannot be accomplished orthodontically without adversely affecting the jaw relationship, overjet, and facial profile, then the gap should be opened and the missing tooth—usually the lateral incisor—should be replaced (Figs. 4–8). Similarly, tooth-size discrepancies may contribute to the tendency of maxillary retrusion to influence the decision whether to close or open the gap. The enamel of cleft-adjacent


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Fig. 2. An 18-year-old woman with a repaired right complete cleft of the lip and palate. Secondary alveolar bone grafting facilitated eruption of the cleft-adjacent teeth into a correct occlusion and promoted development of a normal alveolar process. Orthodontic treatment provides functional stresses that help prevent resorption of the graft. (*A*) Facial view. (*B*) Profile view. (*C*) Frontal view of teeth. Note hypoplastic, notched enamel of cleft-adjacent right central incisor and negligible evidence of the cleft alveolus. (*D*) Right lateral view of teeth demonstrates class I canines and molar relationships. (*E*) Left lateral view demonstrates class I canines and molars.

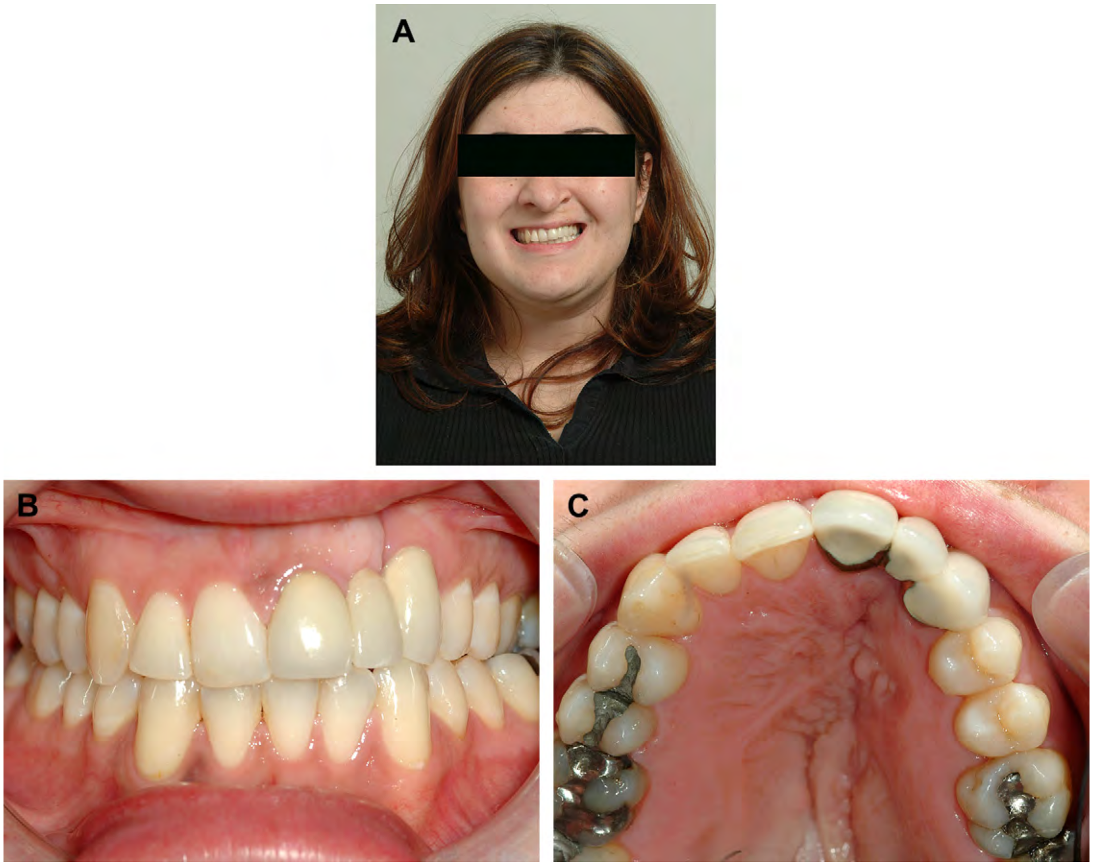

Fig. 3. A 25-year-old woman with a repaired left cleft of the lip and palate and congenital absence of the maxillary left lateral incisor. (*A*) Facial view. (*B*) Frontal view of teeth. The lateral incisor has been replaced using conventional porcelain/gold fixed bridge. (*C*) Maxillary occlusal view.

teeth is commonly hypoplastic, which results in them being smaller than normal, so orthodontic consolidation typically results in retraction of anterior teeth, loss of overjet, and deviation of the maxillary midline toward the side of the cleft.

After secondary alveolar bone grafting, in the absence of a lateral incisor, the canine usually erupts mesially toward the central incisor. If the decision to open the gap is made, distalization of the canine into its native site can be difficult. Once accomplished, its position must be retained until growth ceases, when a dental implant may be placed. During this time the graft may resorb to the point at which revisionary bone grafting is required before or at the same time as implant placement. It has been pointed out that revisionary bone grafting, sometimes in several stages, is necessary to achieve an acceptable aesthetic result.

If reasonable goals cannot be met through orthodontic treatment alone, then surgical orthodontics may be used to correct misalignment of the arches and close the alveolar cleft (Figs. 9–12). Occasionally, surgical orthodontics is unable to achieve closure of the dental gap as a result of an inability to coordinate the arches (Fig. 13), a gap that exceeds the limits of a segmental advancement (Fig. 14), or objections of the patient to dental substitutions. In such cases, the alveolar cleft, having been grafted as part of the orthognathic surgical procedure, can be reconstructed with an implant-supported restoration, but it usually requires revisionary bone grafting at the time of implant placement.

In patients who are old enough to receive implants but have not yet undergone grafting of the cleft alveolus, the recommended surgical protocol is tertiary bone grafting followed after 3 months of graft consolidation by implant placement. Graft dimensions diminish rapidly after 4 months of placement. Revisionary bone grafting in several stages is often necessary to place an implant and obtain an acceptable aesthetic result. Implant healing is given a full 6 months before commencement of crown fabrication.

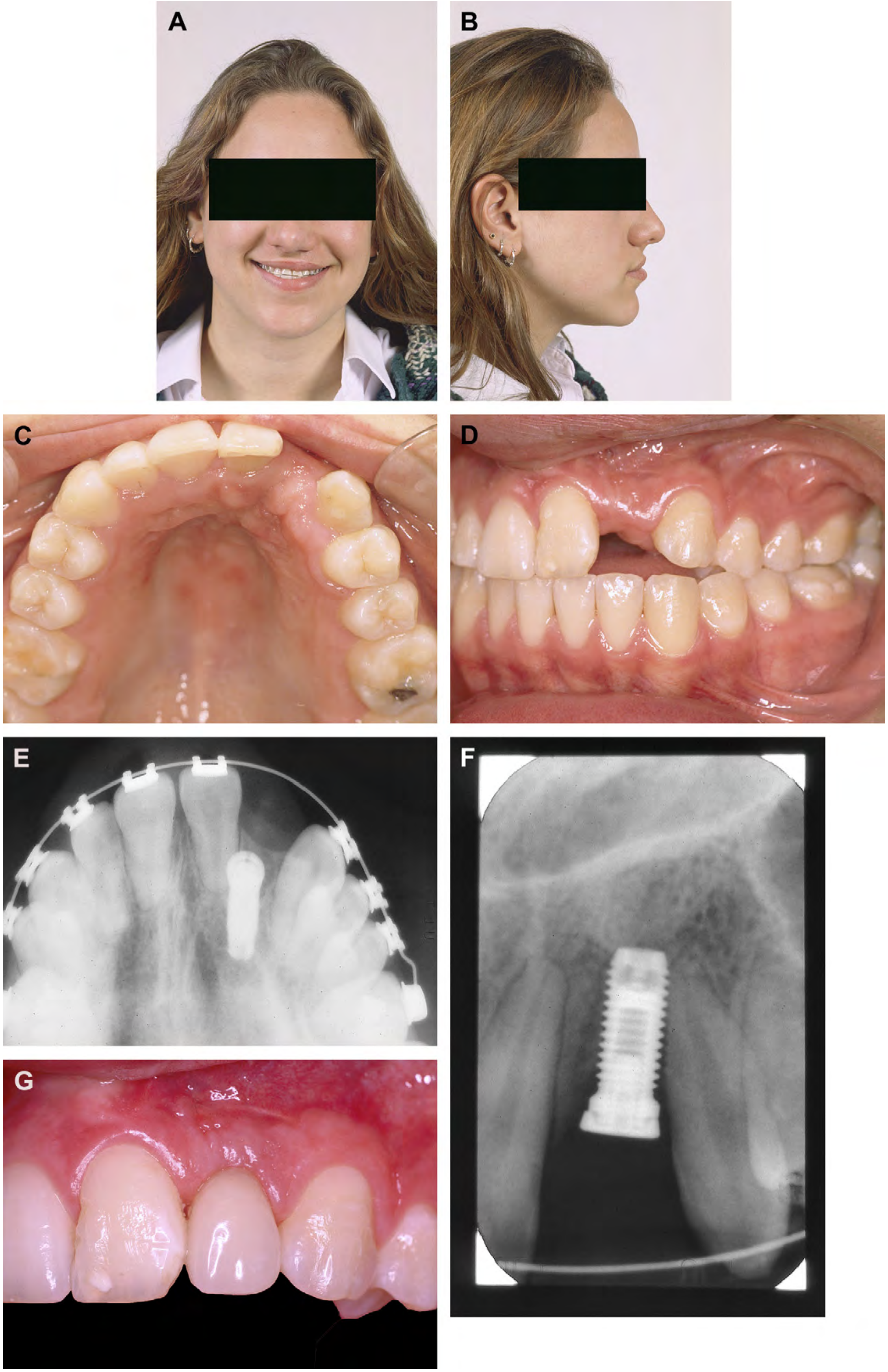

Fig. 4. An 18-year-old woman with a repaired left cleft of the lip and primary palate, secondary alveolar bone grafting, orthodontic gap opening, and replacement of congenitally missing maxillary left lateral incisor with an implant-supported crown. (*A*) Posttreatment facial view. (*B*) Posttreatment profile view demonstrates borderline maxillary hypoplasia. (*C*) Maxillary occlusal view. (*D*) Lateral view of grafted cleft alveolus before uncovering of implant. (*E*) Maxillary occlusal radiograph demonstrates smooth threaded implant in grafted alveolar cleft. (*F*) Periapical radiograph of implant. (*G*) Close-up view of implant-supported left lateral incisor crown.

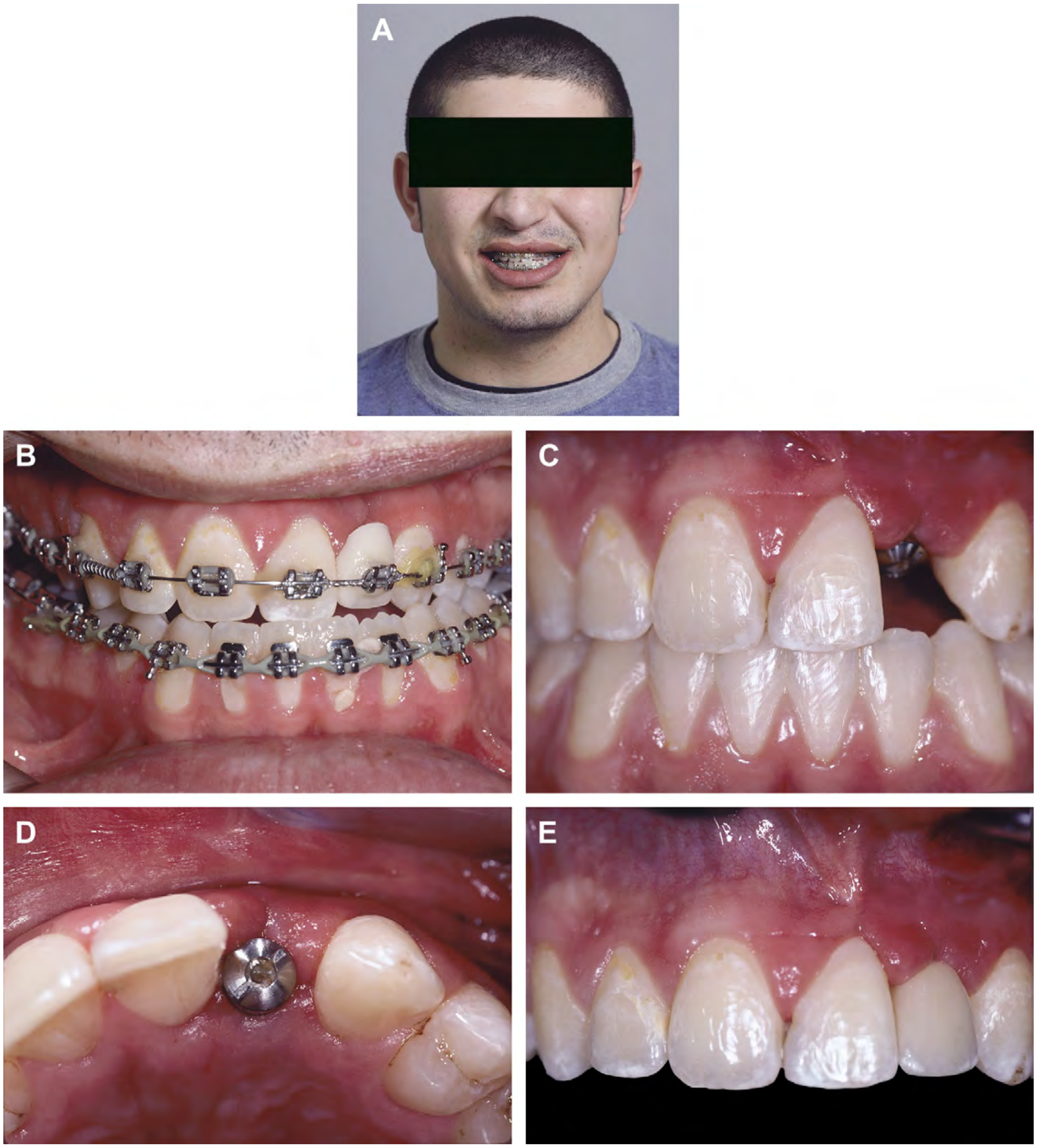

Fig. 5. A 20-year-old man with a repaired left complete cleft of the lip and palate after surgical orthodontics and tertiary grafting of the cleft alveolus. (*A*) Facial view. (*B*) Front view of teeth. A prosthetic tooth suspended from maxillary arch wire temporarily replaces congenitally missing left lateral incisor without loading the recently placed bone graft and healing dental implant. (*C*) Close-up view of healing dental implant. (*D*) Maxillary occlusal view of dental implant. (*E*) Close-up of implant-supported maxillary left lateral incisor crown in grafted cleft alveolus.

Dental implants can be placed and maintained successfully in patients with various special needs and rare conditions, including cleft lip and palate (see Figs. 14–16). A growing number of publications in recent years have demonstrated the use of dental implants to replace congenitally missing teeth in the grafted cleft alveolus, including case reports with limited follow-up and small and medium case series with follow-up lasting 1 to 10 years. Several larger studies have documented upwards of 70 implants in 45 patients or more over 2 to 10 years. These studies reported success rates of 82% to 99%. In one study, 5-year success rates for implants in grafted clefts (88%) were not significantly different from rates for implants in traumatic defects.

Studies have pointed to several factors that predict implant survival in grafted clefts, including sufficient graft volume to provide the implant with primary stability, a limit of 3 to

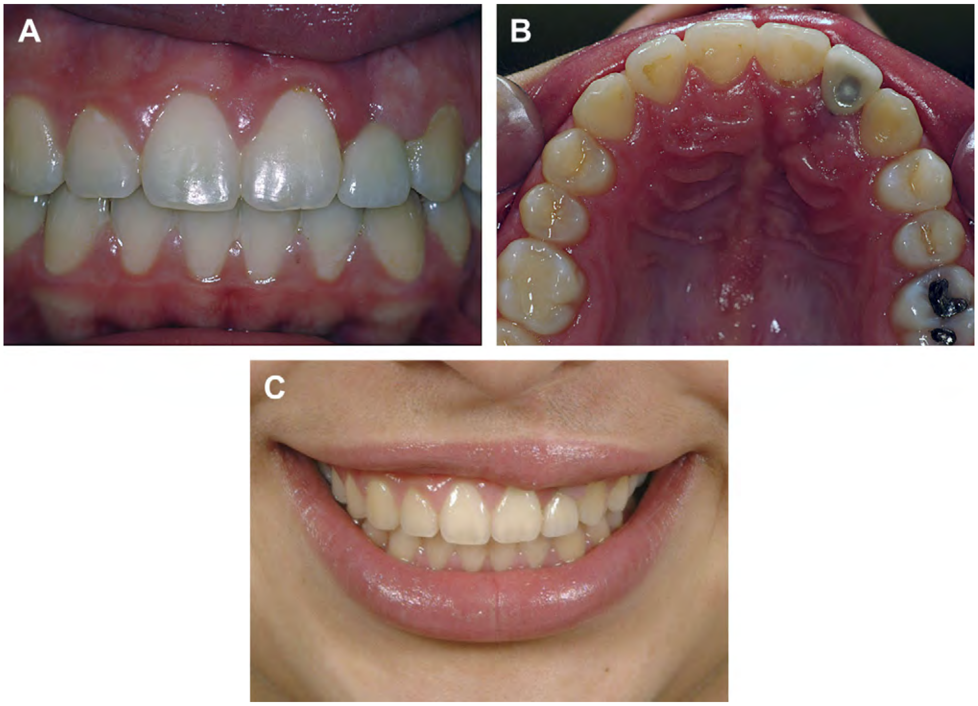

Fig. 6. A 17-year-old girl with a repaired left complete cleft of lip and primary palate and incomplete cleft of secondary palate after orthodontic treatment, secondary grafting of alveolar cleft, and implant placement in repaired cleft alveolus. (*A*) Front view of teeth demonstrates implant-supported maxillary left lateral incisor crown in grafted alveolar cleft. (*B*) Maxillary occlusal view. (*C*) Close-up of smile.

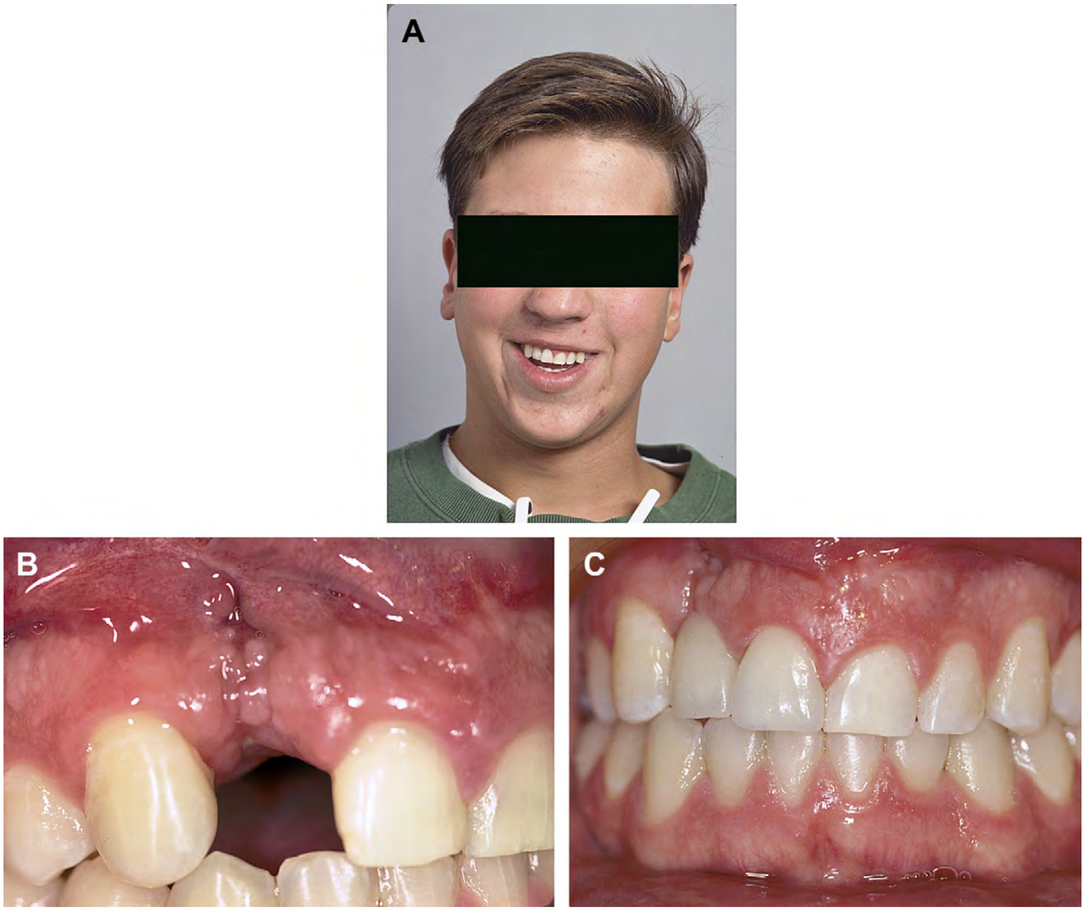
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Fig. 7. A 19-year-old man with a repaired right complete cleft of lip and palate after orthodontic treatment, tertiary grafting of the cleft, and placement of an implant in repaired cleft alveolus. (*A*) Posttreatment facial view. (*B*) Close-up right lateral view of teeth after grafting and implant placement. (*C*) Frontal view of teeth demonstrates implant-supported right lateral incisor crown in grafted cleft alveolus.

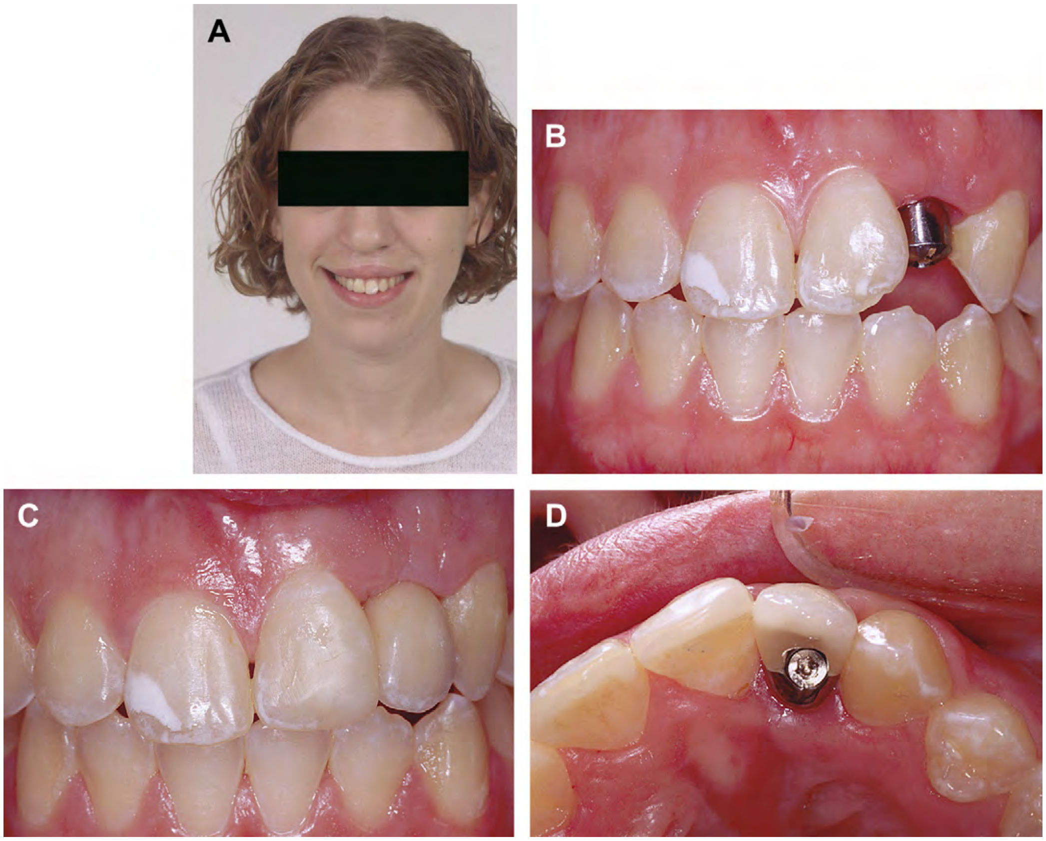

Fig. 8. An 18-year-old woman with a repaired left cleft of lip and primary palate after secondary grafting of cleft alveolus and placement of dental implant with simultaneous revisionary grafting around the implant to replace congenitally missing left lateral incisor. (*A*) Posttreatment facial view. (*B*) Frontal view of teeth after placement of implant in grafted alveolar cleft. Note hypoplastic cleft-adjacent left central incisor. (*C*) Frontal view of teeth demonstrates implant-supported left lateral incisor crown and composite resin–bonded left central incisor. (*D*) Maxillary occlusal view.

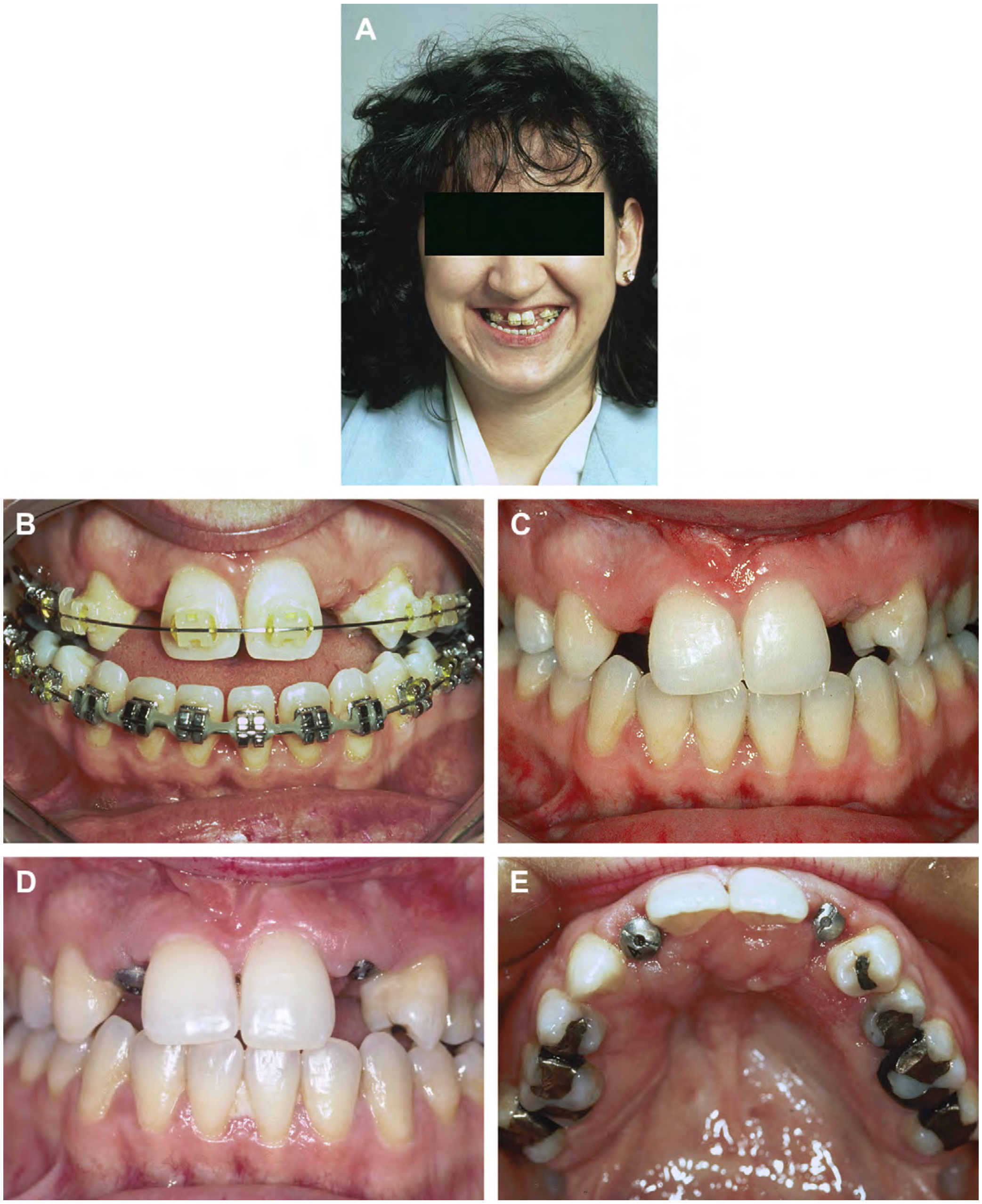
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Fig. 9. A 25 year-old woman with a repaired left cleft of the primary and secondary palates and congenital absence of both maxillary lateral incisors and the left maxillary canine after secondary alveolar grafting and orthodontic treatment. (*A*) Facial view demonstrates maxillary hypoplasia and anterior open bite. (*B*) Frontal view of teeth demonstrates substitution of the maxillary left first premolar for the canine, anterior open bite, and negative overjet. (*C*) Frontal view of teeth after Le Fort I advancement of maxilla demonstrates closure of anterior open bite, correction of maxillary midline, and right class I canine relationship. (*D*) Frontal view of teeth after placement of dental implants at site of missing maxillary right lateral incisor and in left secondarily grafted cleft alveolus. (*E*) Maxillary occlusal view of dental implants. (*F*) Posttreatment facial view. (*G*) Posttreatment maxillary occlusal view demonstrates porcelain/gold implant–supported lateral incisor crowns. (*H*) Posttreatment close-up view of maxillary anterior teeth.

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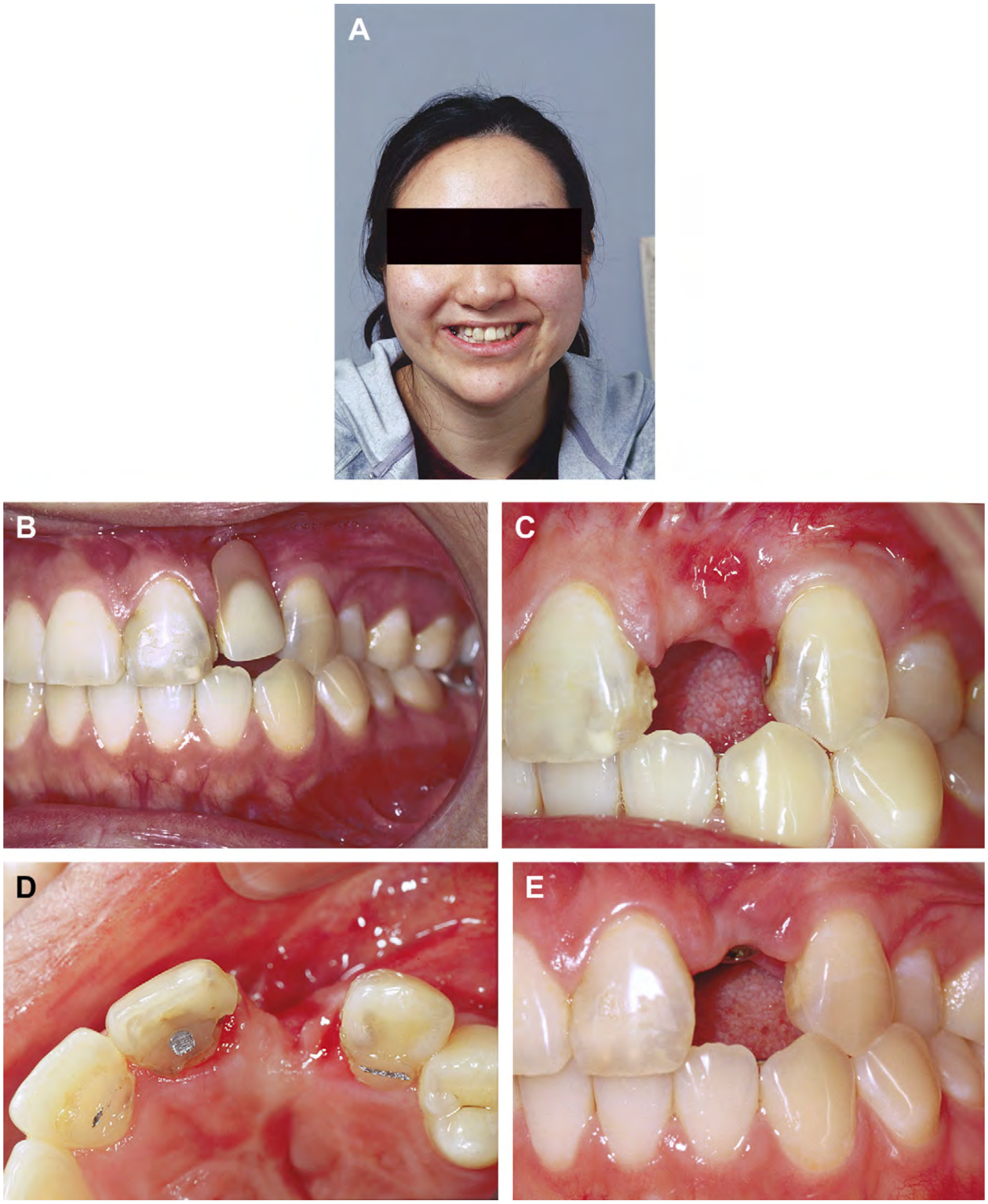
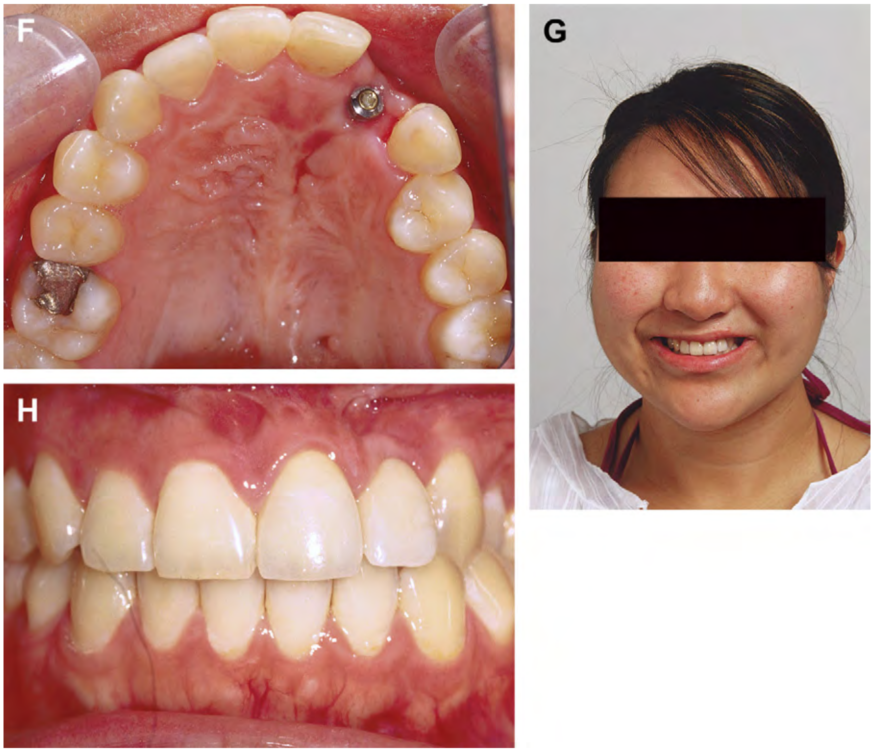


Fig. 10. A 22-year-old woman with a repaired left complete cleft lip and palate and congenital absence of maxillary left lateral incisor after secondary bone grafting and orthodontic treatment. (*A*) Facial view. (*B*) Right lateral view of teeth demonstrates advanced caries of cleft-adjacent central incisor and canine secondary to prolonged retention of unhygienic acrylic resin bridge replacing lateral incisor. (*C*) Left lateral close-up view of carious cleft-adjacent teeth after removal of bridge. (*D*) Maxillary occlusal view of carious cleft-adjacent teeth. (*E*) Left lateral close-up view of teeth demonstrates cleft-adjacent teeth restored with composite resin and dental implant in grafted cleft alveolus. (*F*) Maxillary occlusal view of implant in grafted cleft. (*G*) Posttreatment facial view. (*H*) Frontal view of teeth demonstrates implant-supported maxillary left lateral incisor crown in grafted alveolar cleft.



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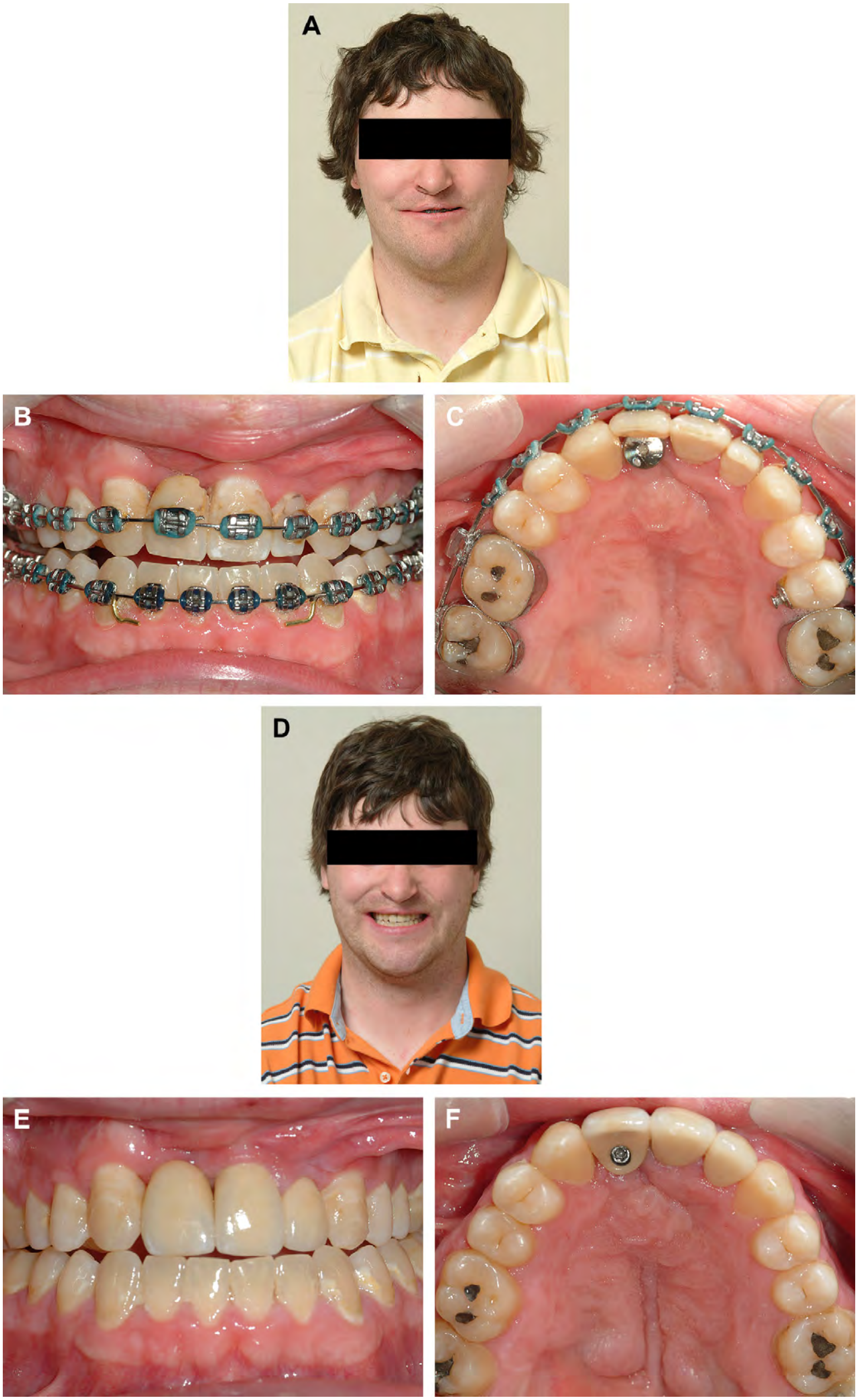
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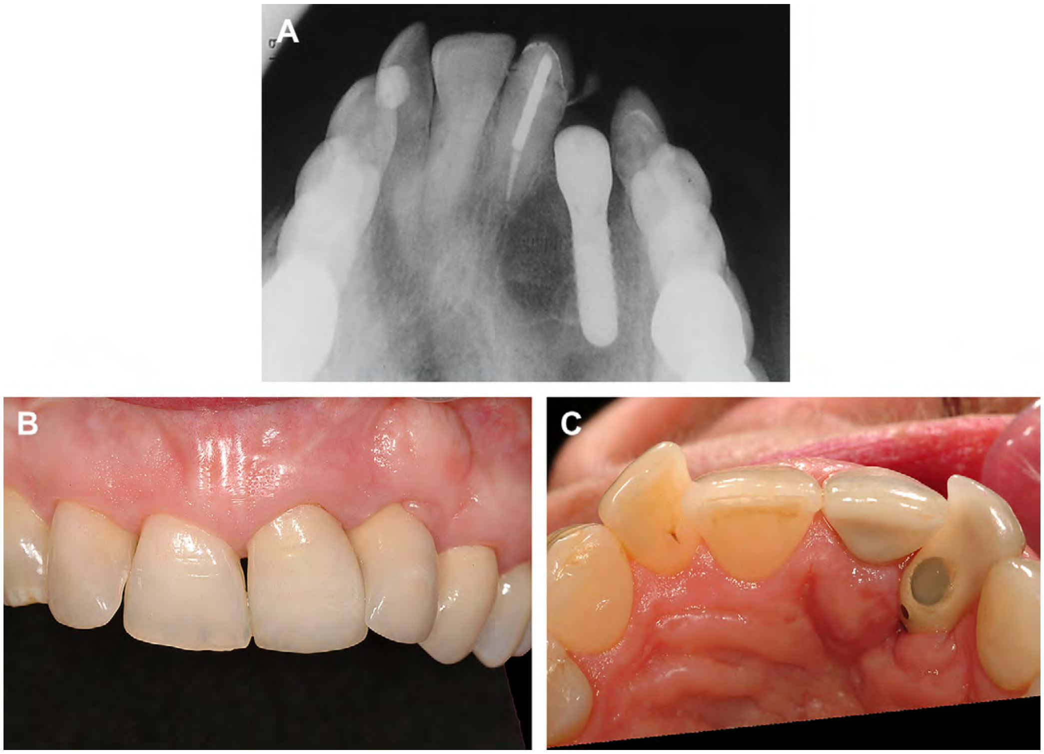


Fig. 12. A 45-year-old woman after removal of a cariously undermined three-unit fixed bridge spanning an ungrafted cleft and replacing a congenitally missing lateral incisor. The cleft was grafted, and an implant was placed 6 months later. (*A*) Occlusal radiograph demonstrates dental implant in grafted cleft alveolus. (*B*) Posttreatment frontal view of maxillary teeth demonstrates implant-supported left lateral incisor crown and right central incisor and canine restored with porcelain crowns. (*C*) Posttreatment occlusal view.

Fig. 11. A 24-year-old male with a repaired right complete cleft lip and palate and absence of the maxillary right central and lateral incisors, status post surgical orthodontics that involved a LeFort I segmental advancement of the right lesser segment. (*A*) Facial view. (*B*) Frontal view of teeth. Note substitution of maxillary right canine for lateral incisor, prosthetic right maxillary central incisor suspended from arch wire, and caries in the left central and lateral incisors. (*C*) Maxillary occlusal view demonstrates implant in secondarily grafted cleft alveolus. (*D*) Post-treatment facial view. (*E*) Post-treatment frontal view of teeth demonstrates implant-supported maxillary right central incisor crown in grafted cleft alveolus and maxillary left central and lateral incisors restored with porcelain crowns. (*F*) Post-treatment maxillary occlusal view.

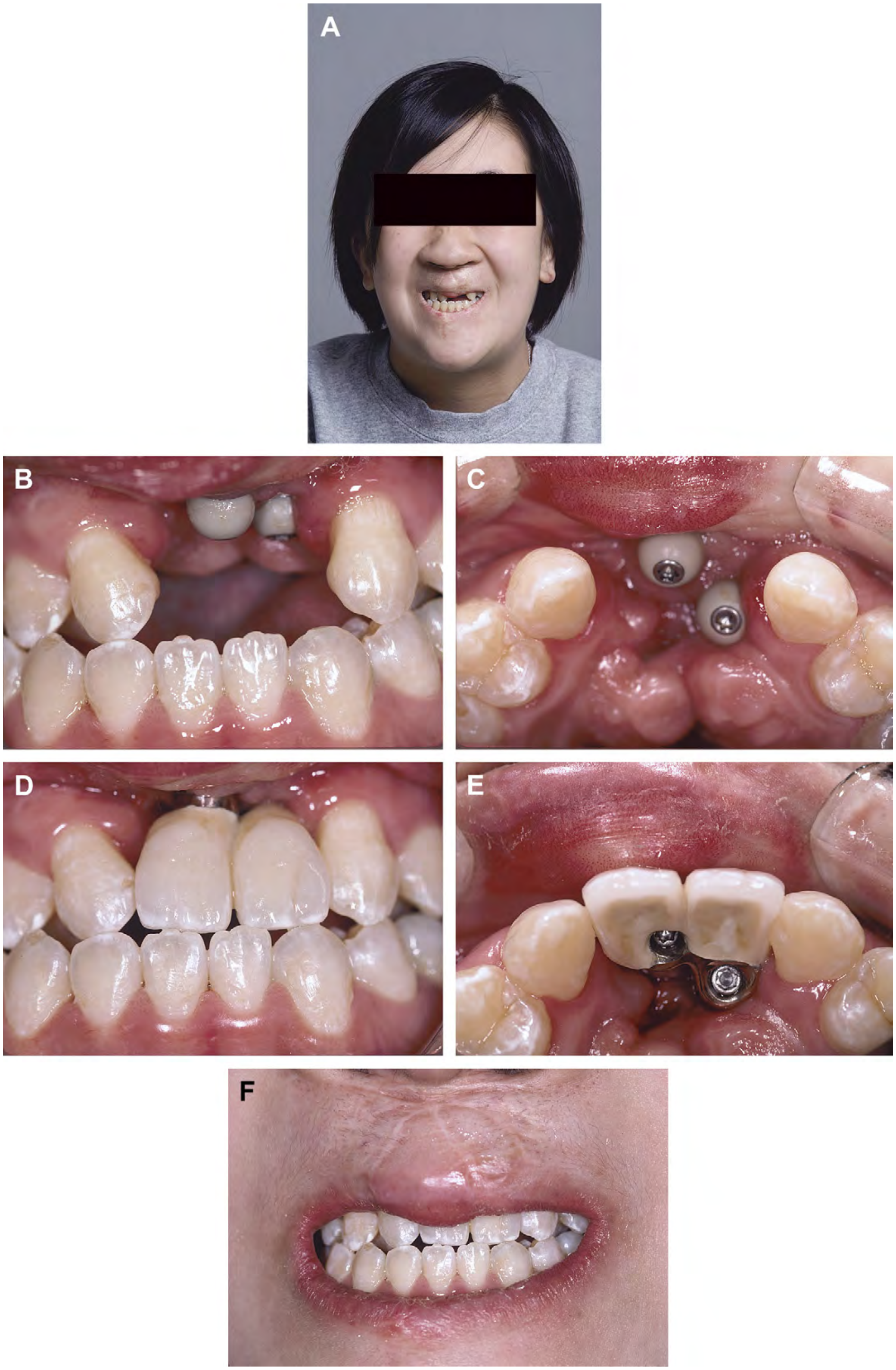


Fig. 13. An 18-year-old woman with a repaired complete bilateral cleft of the lip and palate and congenital absence of both maxillary lateral incisors after Le Fort I osteotomy with bilateral advancement of both lateral segments. Postoperatively, both maxillary central incisors and the prolabial segment were lost. After tertiary grafting of the anterior maxilla, two dental implants were placed and restored with splinted central incisor crowns. (*A*) Facial view. (*B*) Frontal view of teeth demonstrates implants in grafted alveolus. (*C*) Maxillary occlusal view. (*D*) Frontal view of implant-supported central incisor crowns in grafted alveolus. (*E*) Maxillary occlusal view. (*F*) Posttreatment view of smile.

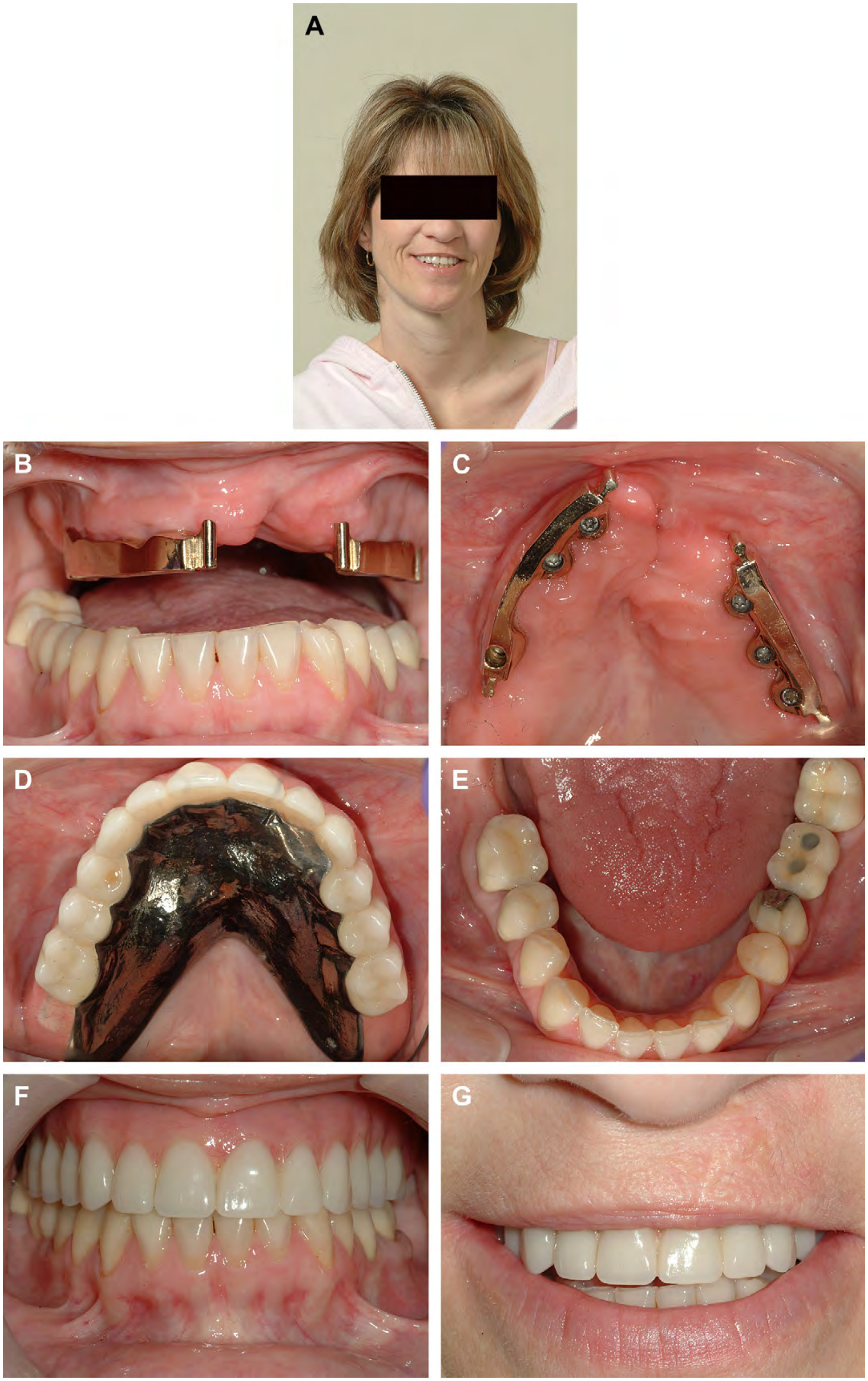


Fig. 14. A 35-year-old woman with a repaired left complete cleft of the lip and palate who had been rendered edentulous in the maxilla secondary to rampant caries during orthodontic treatment as a teenager. (*A*) Facial view. (*B*) Frontal view of teeth demonstrates implant-supported milled gold bar assemblies with terminal friction fit attachments. (*C*) Maxillary occlusal view of bar assemblies. (*D*) Occlusal view of titanium reinforced complete upper overdenture. (*E*) Mandibular occlusal view. (*F*) Frontal view of implant-retained complete upper overdenture. (*G*) View of smile.

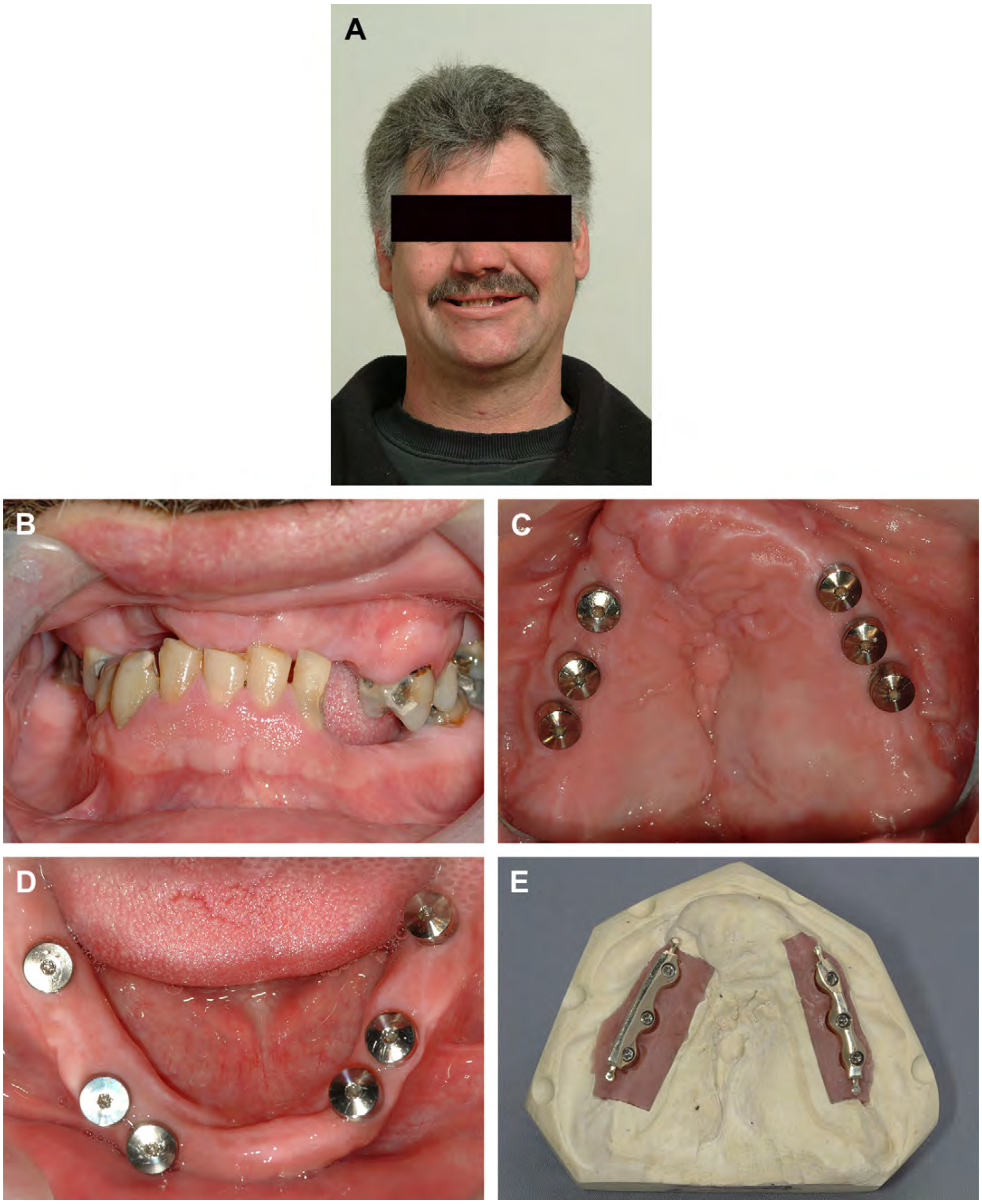
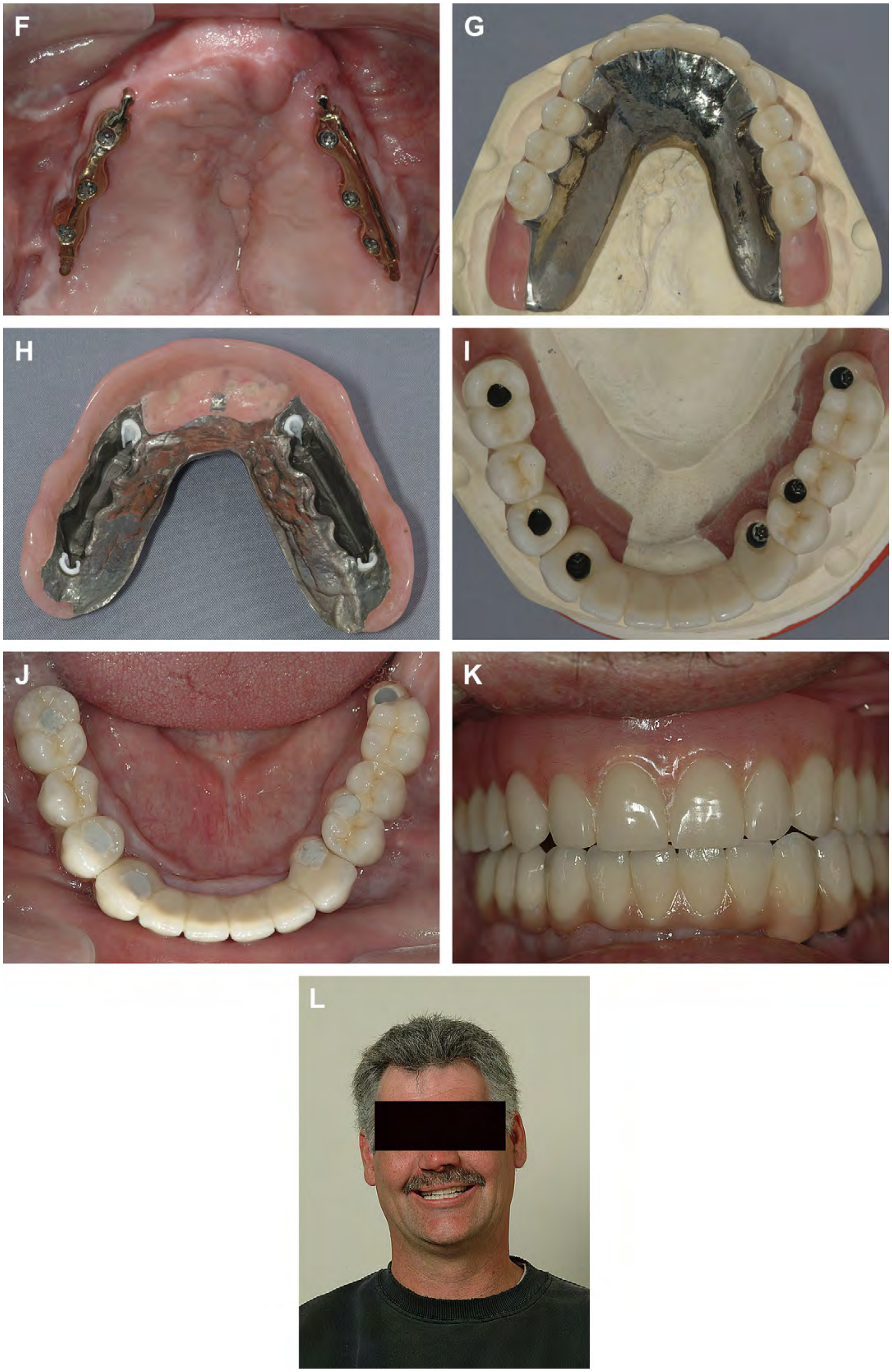


Fig. 15. A 37-year-old man with a repaired right complete cleft of the lip and palate. During and after orthodontic treatment in his teens, he was plagued by caries and tooth loss. Eventually his maxilla and mandible were rendered edentulous and restored with implant-retained complete upper overdenture and lower fixed bridge. (*A*) Pretreatment facial view. (*B*) Pretreatment frontal view of teeth. Dentition is in terminal state. (*C*) Maxillary occlusal view of implants. (*D*) Mandibular occlusal view. (*E*) Milled gold bar assemblies on maxillary master cast. (*F*) Maxillary occlusal view of gold bar assemblies. Note terminal friction fit attachments. (*G*) Titanium-reinforced complete upper overdenture on cast. (*H*) Intaglio surface of complete upper overdenture. Note interchangeable vinyl inserts designed to fit over friction fit attachments on terminal ends of gold bar assemblies. (*I*) Mandibular implant-supported fixed bridge in three pieces on master cast. (*J*) Mandibular occlusal view of bridges. (*K*) Frontal view of implant-retained complete upper overdenture and mandibular fixed bridges. (*L*) Posttreatment facial view.



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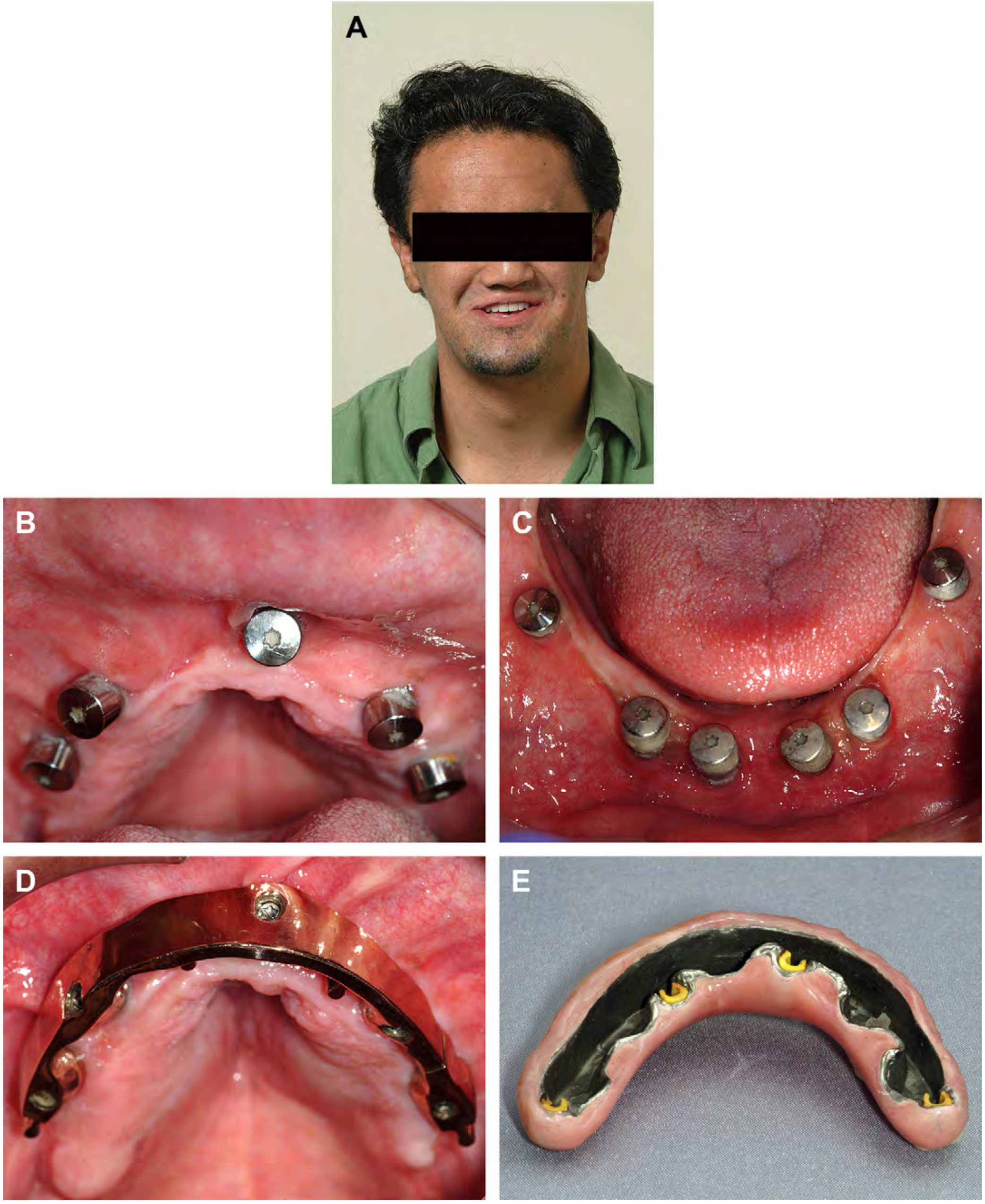

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Fig. 16. A 23-year-old man with a variant of ectodermal dysplasia, a repaired right cleft of the primary palate and partial cleft of the secondary palate, and severe oligodontia. After removal of the vestigial dentition, his mouth was restored with implant-retained maxillary removable and mandibular fixed bridges. (*A*) Posttreatment facial view. (*B*) Maxillary occlusal view. (*C*) Mandibular occlusal view. (*D*) Maxillary milled gold bar assembly with terminal and anterior palatal friction fit attachments. (*E*) Internal aspect of maxillary removable bridge. Note cast titanium framework and interchangable attachment inserts. (*F*) Maxillary occlusal view of bridge. (*G*) Mandibular porcelain/gold fixed bridge in three pieces with following configuration: 3.3-3.6, 3.3-4.3, and 4.3-4.6. (*H*) View of smile.

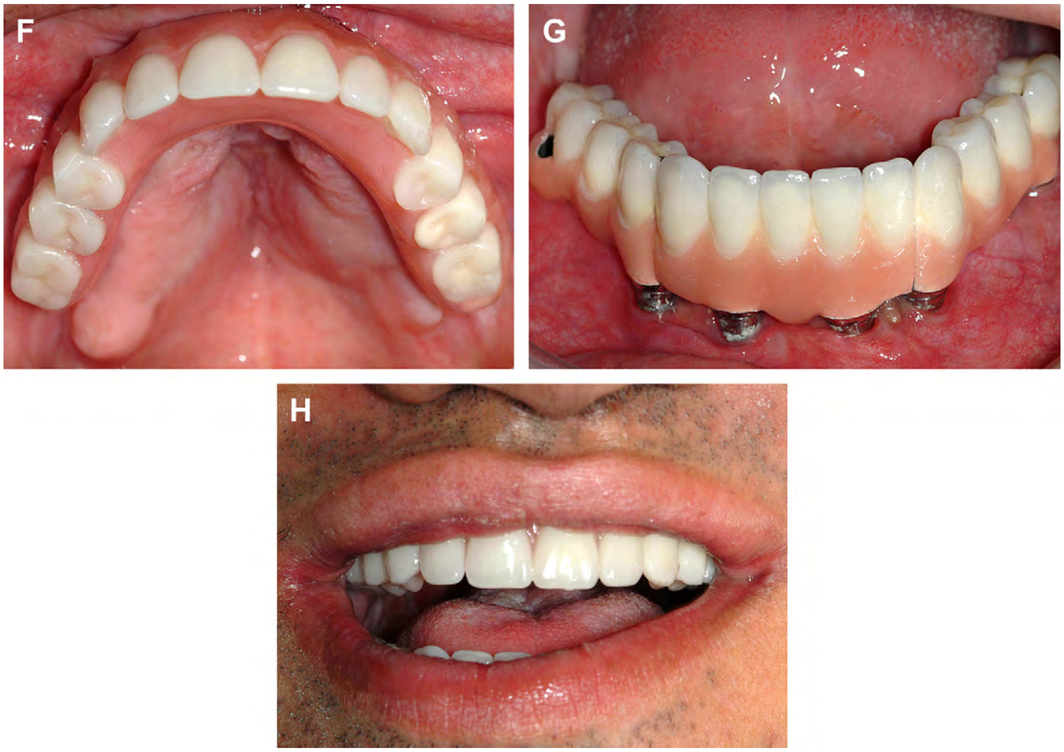

Fig. 16 (*continued*)

6 months' latency before placing the implant, implant length, implant placement in two stages, and early adulthood. Studies also have amply demonstrated that implant placement in a grafted alveolar cleft can be successful in adult patients (see Figs. 14 and 15). Palatal mucosal grafting has been recommended around rough-surfaced implants placed in the grafted cleft alveolus, where there is usually a lack of keratinized, attached mucosa, but this is not well supported by data. Negative predictive factors included milled-bone grafts, dehiscence, smoking, and anorexia.

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Atlas of the
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# Rehabilitation of Trauma Using Dental Implants

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The ability to replace teeth without damaging the residual dentition makes the use of dental implants an ideal option to consider for restoring dentitions ravaged by traumatic tooth loss (Fig. 1). Patients who suffer tooth loss resulting from traumatic injuries of the dentoalveolar complex may still be growing, and, in fact, certain injuries resulting in tooth loss are seen more commonly in young patients (for example, avulsions of anterior teeth). Dental implants, like ankylosed teeth, can have deleterious effects on the growing alveolar process (Fig. 2A–C). As a general rule, the authors' philosophy is to respect growth by delaying implant placement until the cessation of skeletal growth (Fig. 3A–E), as documented by serial lateral cephalometric radiographs taken 6 months apart.

In addition to growth, a number of other factors associated with tooth loss also must be considered when assessing a traumatized dentition (Box 1).

## Assessment of the residual dentition

No two complex fractures involving the dentition, it seems, are ever the same. The posttraumatic residual dentition must be analyzed carefully to help predict its prognosis. Teeth that have been reimplanted, suffered root fractures, or been treated endodontically will impact adversely the overall prognosis (see Fig. 2A–C), as they may be lost in the future, necessitating further costly treatment. Considerations of potential future tooth loss will often have important medicolegal implications especially as it related to insurance liability.

## Loss of hard and soft tissues

Loss of alveolar bone associated with tooth avulsion may require that ridge augmentation, perhaps using guided bone regeneration or other techniques, be incorporated into the reconstruction treatment plan (Fig. 4A–C). In addition, the deleterious effects of soft tissue scarring on the final esthetic outcome must be anticipated and communicated to the patient and family (Fig. 5A–C) and dealt with where appropriate through the use of soft tissue grafting or flaps (Fig. 6A–H).

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Fig. 1. Transverse root fracture of traumatized maxillary central incisor with poor prognosis. Treatment planning of this case must take into consideration the current state of growth and damage to surrounding teeth and their prognoses.

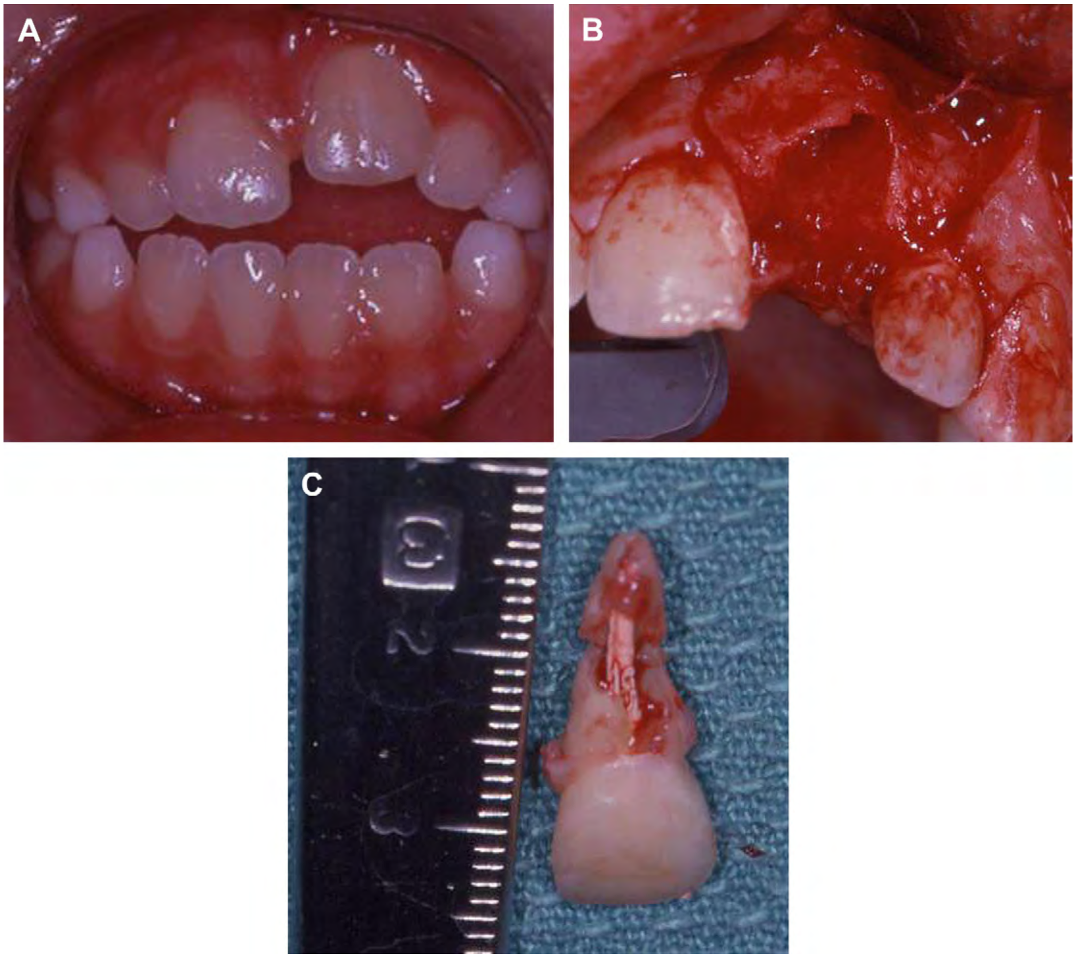

Fig. 2. (*A*) Ankylosed maxillary permanent central incisor that had been avulsed, replanted, and treated with root canal therapy. The ankylosed tooth has inhibited alveolar growth and has become submerged below the occlusal plane of the surrounding dentition. (*B*) Alveolar defect noted at the time of removal of the ankylosed permanent maxillary central incisor undergoing inflammatory root resorption. (*C*) Specimen of ankylosed permanent maxillary central incisor with evidence of inflammatory root resorption. This patient was still growing so that dental implant placement was delayed until growth cessation had been attained.

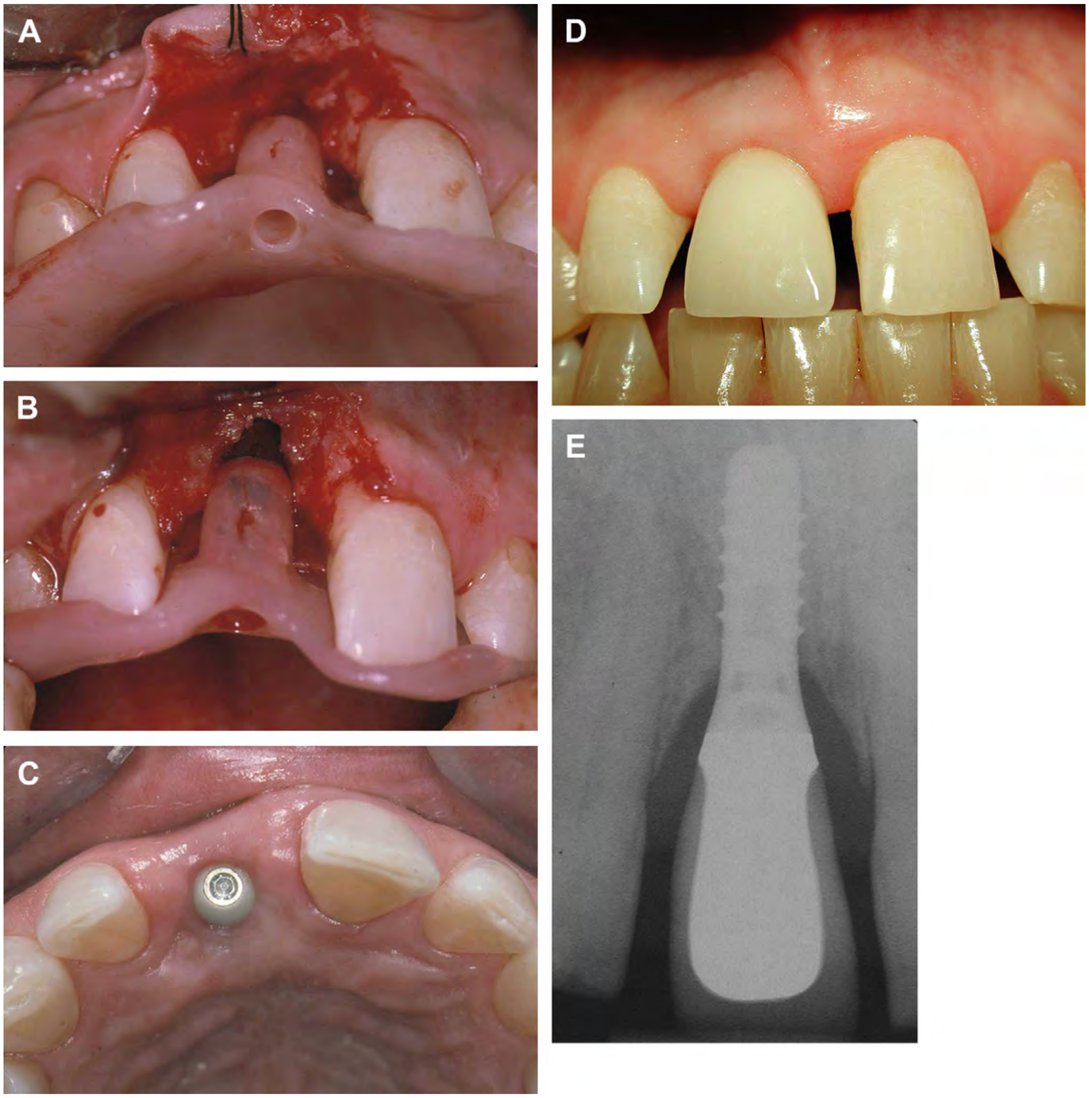

Fig. 3. (*A*) Permanent maxillary right central incisor lost in an ice hockey–related accident in a nongrowing patient. A prefabricated stent is used to communicate to the surgeon the vertical, buccolingual and mesiodistal positioning and axial inclination desired by the prosthodontist. (*B*) The stent is used to check the correct vertical positioning of the implant fixture margin. (*C*) Correctly positioned dental implant seen from the occlusal aspect after 3 months of healing. (*D*) Restored implant after 8 years of follow-up. (*E*) Periapical radiograph of restored dental implant after 8 years of follow-up.

## Orthodontic support

A posttraumatic malocclusion may necessitate a combined orthodontic, prosthodontic, and oral surgical approach to rehabilitation. Pre-existing malocclusions may also necessitate a multidisciplinary approach. The forced orthodontic extrusion of tooth roots may be helpful to conserve or produce alveolar bone vertically, as can distraction osteogenesis.

**Box 1. Factors to consider with implant-assisted reconstruction of the traumatized dental alveolus**

Cessation of skeletal growth
Single versus multiple tooth loss
Prognosis of residual dentition and likelihood of future tooth loss
Associated loss of alveolar bone
Associated soft tissue scarring and deficits
Associated fractures of the facial bones

## Associated injuries

Associated lacerations and facial bone fractures are treated acutely as necessary (Fig. 7). The conservation of dentoalveolar structure is maximized through the treatment of associated facial bone fractures. Posttraumatic malocclusions and damage to the temporomandibular joint and associated structures is identified to patients, particularly regarding long-term prognosis of dentition and temporomandibular joint function or future troublesome symptomatology.

## Immediate implant fixture placement

In certain injuries well-confined to the dentoalveolar complex, the placement of implants immediately after tooth avulsion or removal may be considered in nongrowing individuals (Fig. 8). Immediate placement offers the possible advantage of conserving alveolar bone height,

Fig. 4. (*A*) Traumatic loss of permanent maxillary left lateral incisor, canine, and first and second premolars 6 months after a boating accident. The buccolingual dimension of the residual alveolar ridge appears undiminished and the soft tissues seem to be well healed. (*B*) Panoramic radiograph shows dental implant placement. (*C*) Note elongated prosthetic crowns on the restored left side of the maxilla, compared with the natural crowns on the right, necessitated by vertically deficient alveolar bone.

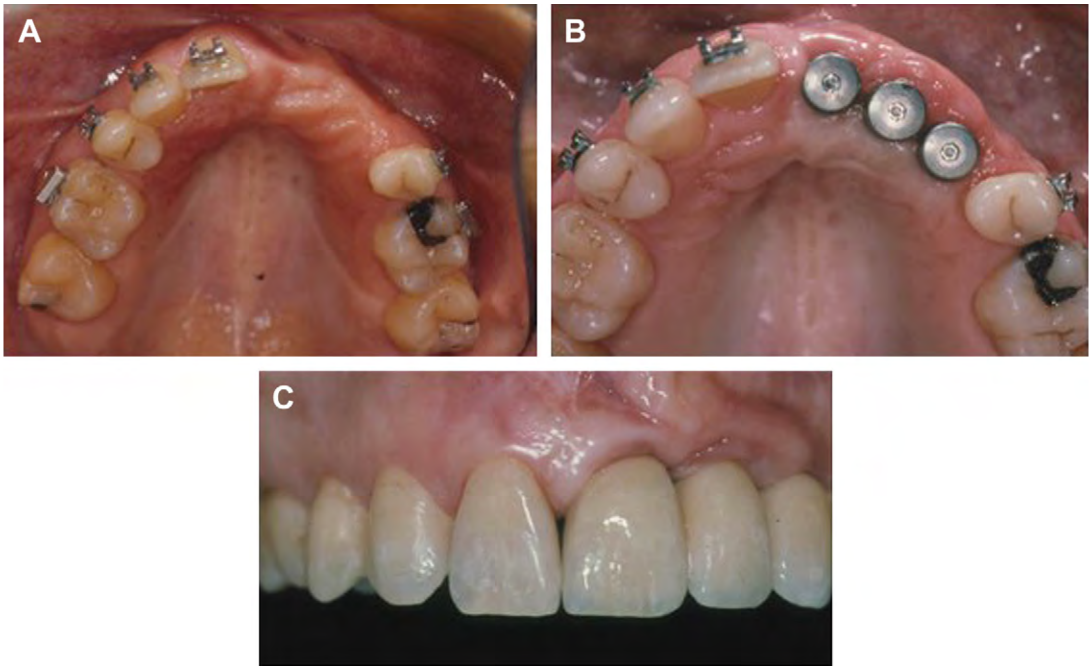

Fig. 5. (*A*) Nongrowing individual who suffered dentoalveolar trauma in a motor vehicle accident 9 months before with loss of permanent maxillary left central, lateral, canine, and first premolar teeth. The buccolingual ridge width seems adequate on the occlusal view. (*B*) Three implant fixtures have been used to replace the missing teeth. (*C*) Frontal view of the crowns supported by the three dental implant fixtures 9 months after their insertion. Note the residual posttraumatic scarring of the gingival mucosa. Also note the blunted papillae between the implant-supported crowns. Another option would have been to place only two implant fixtures and span the edentulous segment with a fixed bridge, which we now recognize may have resulted in a more ideal formation of the papillae.

which could otherwise be lost as a result of posttraumatic remodeling. Although immediate placement of implants after tooth extraction has been studied extensively, it has not been studied after tooth avulsion.

## Injuries involving damage to preexisting implant-supported restorations

With the growing popularity of dental implants as a modality for the replacement of missing teeth, especially in young individuals with active lifestyles, indeed in anyone who exposes themselves to risk of trauma of any kind, it is inevitable that dental implants and/or the restorations they support will be damaged. In the few cases of trauma involving dental implants that these authors have encountered over the last two decades, damage has been restricted to the dental restorations, abutment and retaining screws, leaving the supporting dental implants themselves unscathed (Fig. 9).

## Massive facial injuries

Certain injuries to the face and jaws, such as gunshot or missile wounds may be devastating (Fig. 10). These injuries require complex reconstructive techniques involving microvascular surgery, transfer of uninjured tissues to areas of damage, avulsion or devitalization. Patients who have suffered such injuries require reconstructive techniques similar to those used in patients who have undergone tumor ablation. Missile wounds may also result in devascularized tissue, necessitating vascularized grafting techniques, or ischemic areas that require the use of hyperbaric oxygen therapy to salvage marginal tissue.

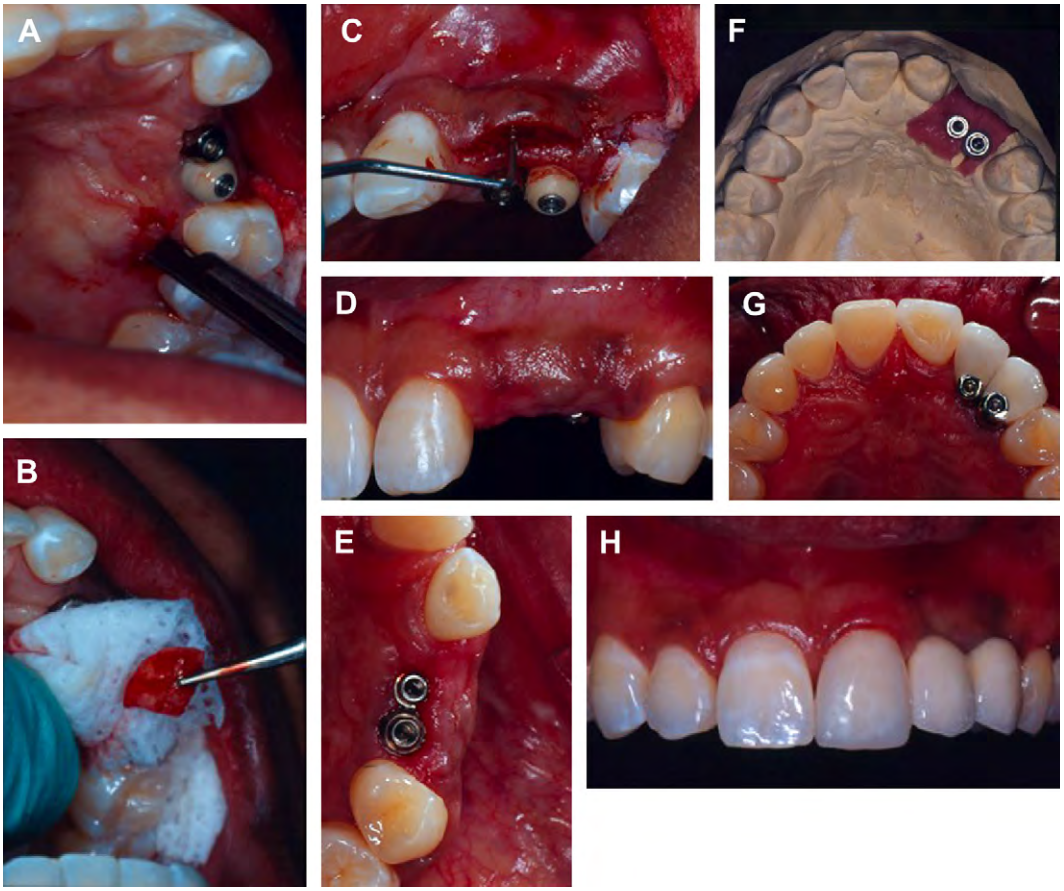

Fig. 6. (*A*) Connective tissue graft harvested from palatal mucosa to restore soft tissue bulk associated with permanent teeth at the left maxillary lateral incisor and canine sites. (*B*) The harvested connective tissue graft. (*C*) The connective tissue graft is inserted into a pocket created on the labial aspect of the implants at the lateral incisor and canine sites. (*D*) The healed site 3 months after graft placement seen from the labial aspect. (*E*) The healed site seen from the occlusal view. (*F*) Model showing the position of the healed implant fixtures. (*G*) Occlusal view of the restored implants. (*H*) Labial view of the restored implants and the surrounding soft tissues.

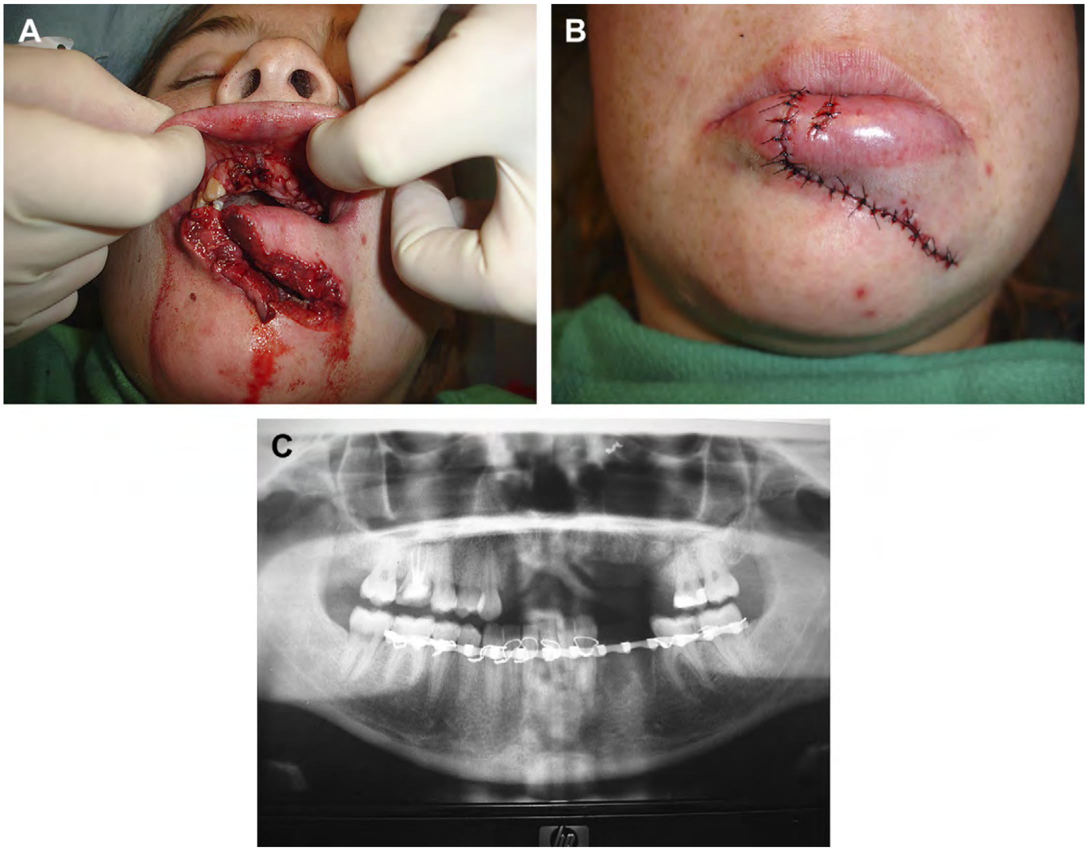

Fig. 7. (*A*) Severe facial laceration; nasal, maxillary Le Fort I level fracture; and multiple maxillary and mandibular dentoalveolar fractures with avulsed teeth after a kick to the face by a horse in a 16-year-old female patient. (*B*) Laceration of lower lip repaired along with the other first aid measures provided to manage acutely this extensive injury. (*C*) Panoramic radiograph showing the extent of the initial posttraumatic tooth loss. (*D*) Premorbid facial photograph of the patient 1 month after the completion of orthodontic treatment, just before the horse-kick accident. (*E*) Smiling frontal facial photograph of patient after reduction of facial fractures, healing of soft tissues, and delayed placement of 11 implant fixtures. (*F*) Right profile photograph. (*G*) Anterior view of teeth in occlusion showing implant positioning. (*H*) Occlusal view of the maxillary teeth and dental implants. (*I*) Occlusal view of mandibular teeth and dental implants. (*J*) Occlusal view with healing screws removed in preparation for impression. (*K*) Occlusal view of reconstructed maxillary arch. (*L*) Occlusal view of reconstructed mandibular arch. (*M*) Postreconstruction appearance of maxillary teeth with fixtures restored from the anterior view. Note the small amount of pink porcelain that was necessary. (*N*) Full smile showing reconstruction. (*O*) Facial view with full smile. (*P*) Left profile view.

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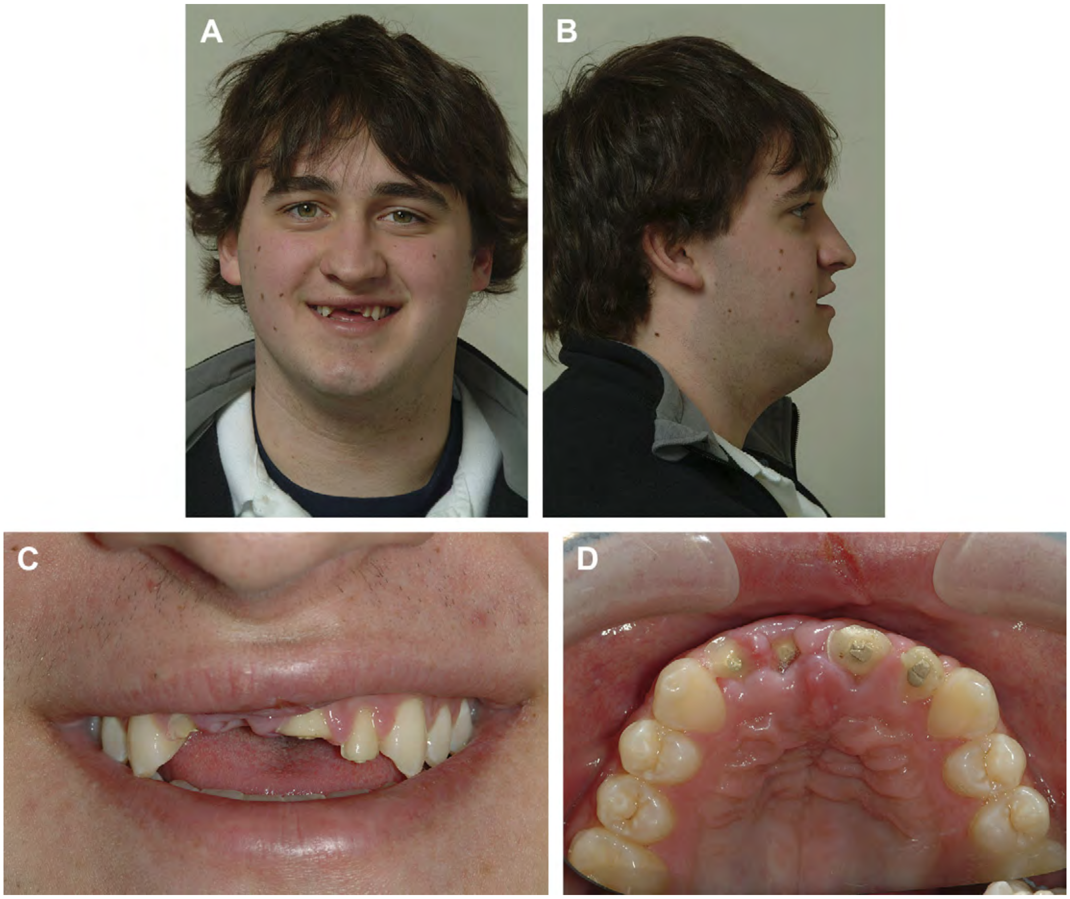
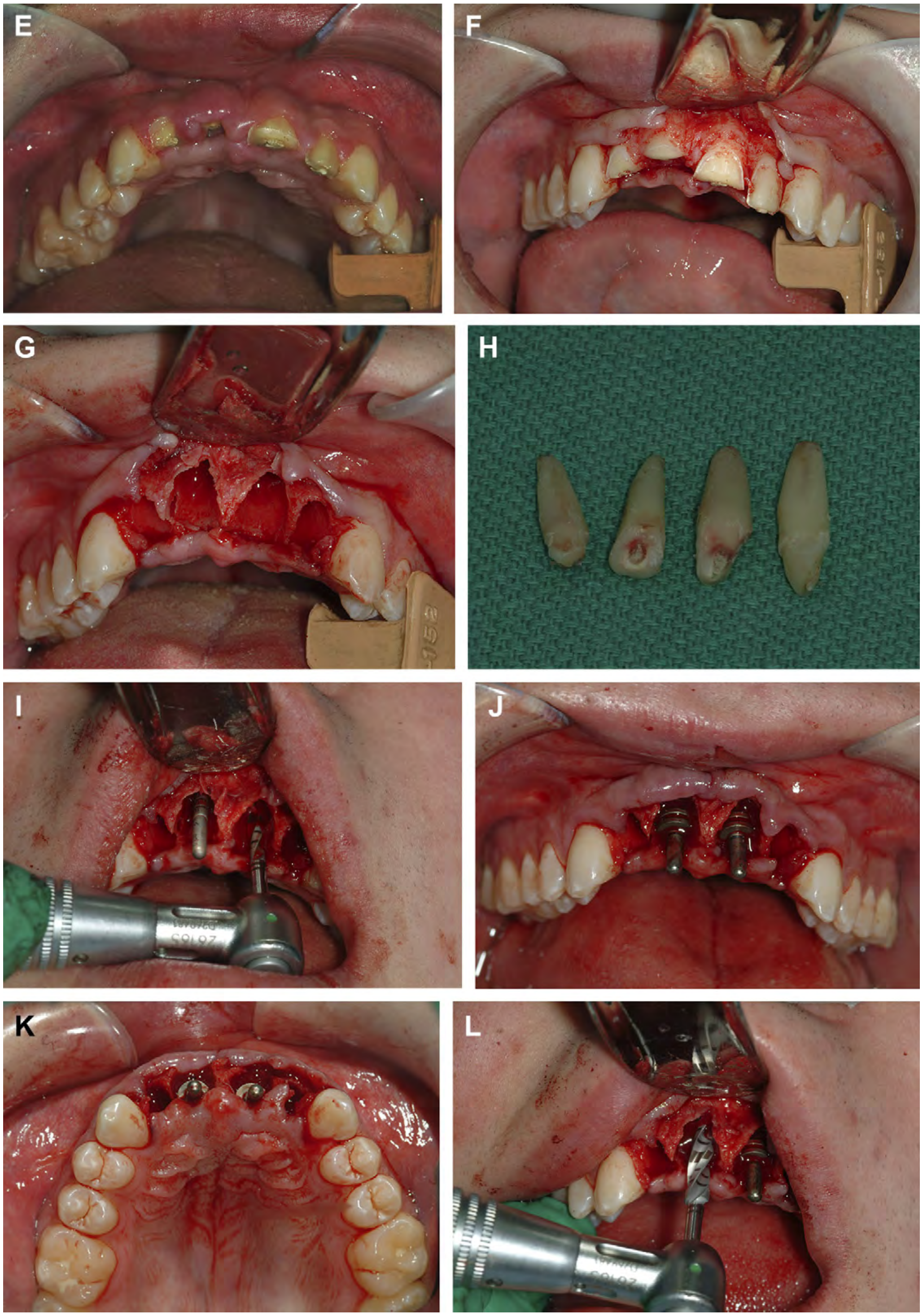


Fig. 8. (*A*) Frontal facial photograph of 18-year-old male victim of a fall accident who had severe fractures of maxillary anterior teeth. (*B*) Right profile view. (*C*) Frontal view showing four severely traumatized maxillary permanent incisors. (*D*) Occlusal view of the traumatized maxillary incisors with subgingival fractures. (*E*) Frontal view of the teeth at the time of surgery. (*F*) Full-thickness mucoperiosteal flap elevated to expose the cementoenamel junctions of the fractured incisor teeth. (*G*) Tooth extraction sockets immediately after removal of the teeth. (*H*) The extracted severely traumatized teeth. (*I*) The decision was made to replace the four teeth using two implants to support a bridge cantelevered distally from the central to lateral incisors bilaterally. Narrowest spiral drill used to engage the apical bone of the alveolus above the extraction socket with drill guide inserted into right central incisor socket while the left one is being drilled. (*J*) Parallelism check from labial view with two medium-sized drill guides in the two central incisor sockets. (*K*) Occlusal view of the two drill guides to check buccolingual and mesiodistal positioning. (*L*) Widening of the right central incisor socket while the smaller drill guide is left as a parallelism guide in the left central incisor socket. (*M*) Spiral drill flutes full of alveolar bone particles perfect for suction trap harvesting. (*N*) Right central incisor socket being drilled for maximal implant width. The widest diameter drill guide is already in the left central incisor prepared socket. (*O*) 4.8-mm diameter implant (Straumann AG, Basel, Switzerland) being inserted into the right central incisor preparation. (*P*) Both implants have been inserted into the right and left central incisor preparations. The implant shoulder depths are compared to ensure a proper emergence profile. The wrench can be replaced on the implant mount and the vertical position of the implant can be readjusted if necessary. (*Q*) Occlusal view of the inserted implants with fixture mounts still attached. Ideally, the fixture mounts should project to the cingulum positions of the future crowns. (*R*) Gingival tissues retracted showing the bony defect between the socket and the dental implant. (*S*) Suction trap used to collect autogenous bone (CSMT, Mississauga, Ontario, Canada). (*T*) Suction trap blown apart showing its components. (*U*) Particulate bone graft collected by suction trap. (*V*) Alveolar defect grafted with autogenous particulate bone. (*W*) Labial view showing the wound closure. (*X*) Occlusal view of the wound closure. (*Y*) Postoperative periapical radiograph showing satisfactory positioning of the dental implants in the reconstructed maxillary alveolus. (*Z*) Occlusal view of the wound 3 weeks after implant placement. A slight dehiscence exists exposing the occlusal aspects of the healing screws on top of the two implants. (*AA*) Appearance of healing screws 4 months after implant placement. (*BB*) Impression copings attached to implants. (*CC*) Impression copings united by methyl methacrylate resin applied in two stages to minimize polymerization shrinkage. (*DD*) Custom impression tray in position on the maxilla. (*EE*) Maxillary impression with transfer copings united by pattern resin. (*FF*) Shade selection. (*GG*) Labial view of maxillary and mandibular models in occlusion with prosthesis at biscuit bake stage. (*HH*) Labial view of final prosthesis. (*II*) Palatal view of final prosthesis. (*JJ*) Anterior view of final prosthesis inserted in the mouth and in occlusion. (*KK*) Occlusal view of final prosthesis installed on the maxillary central incisor implants. (*LL*) Close-up of smile. (*MM*) Frontal facial view. (*NN*) Right profile view.



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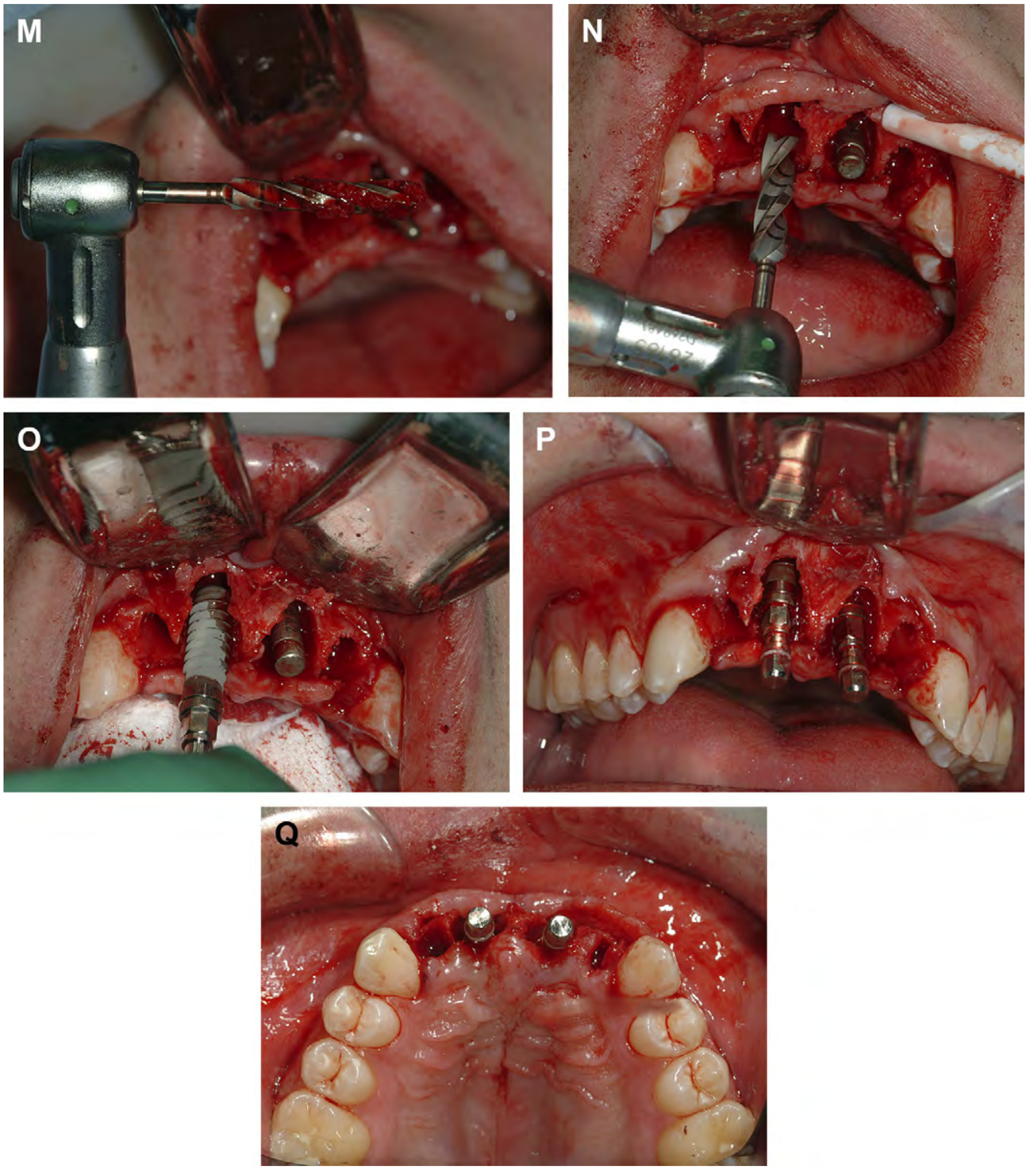

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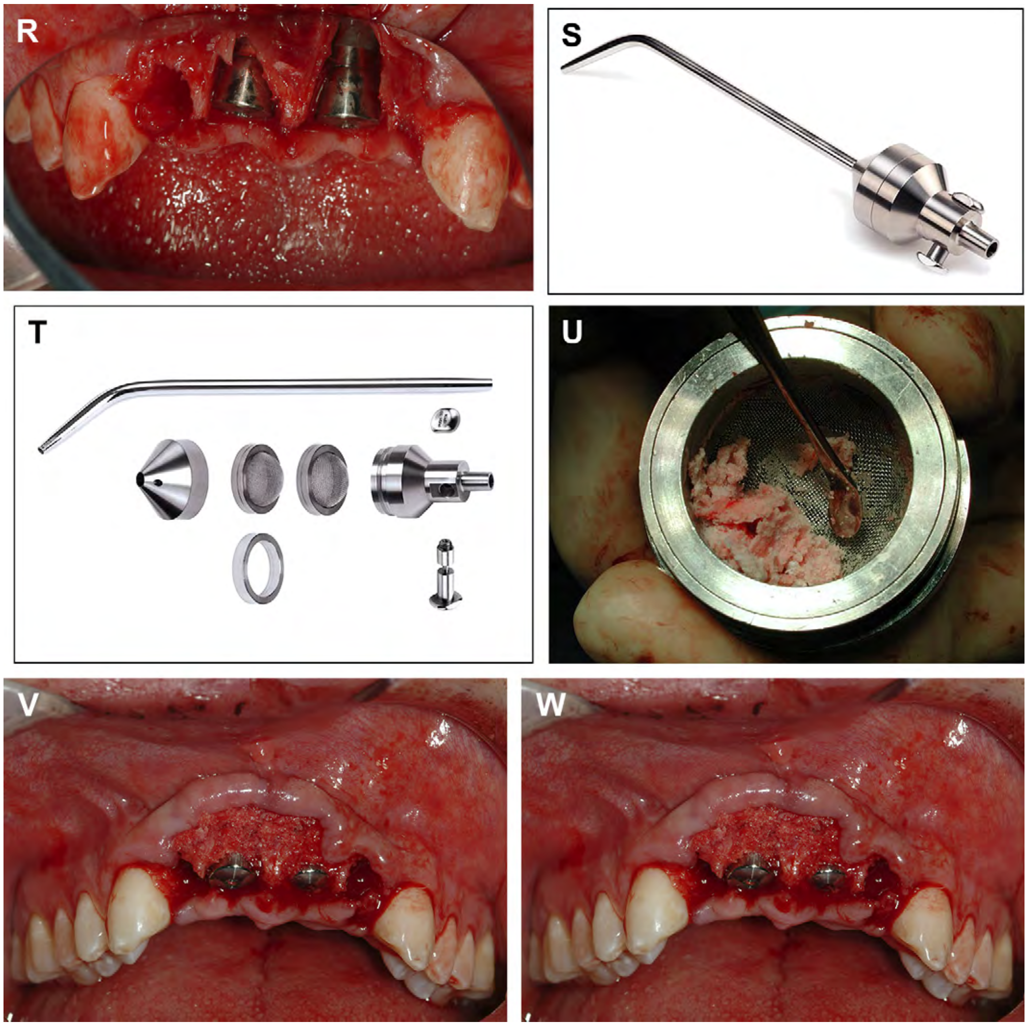

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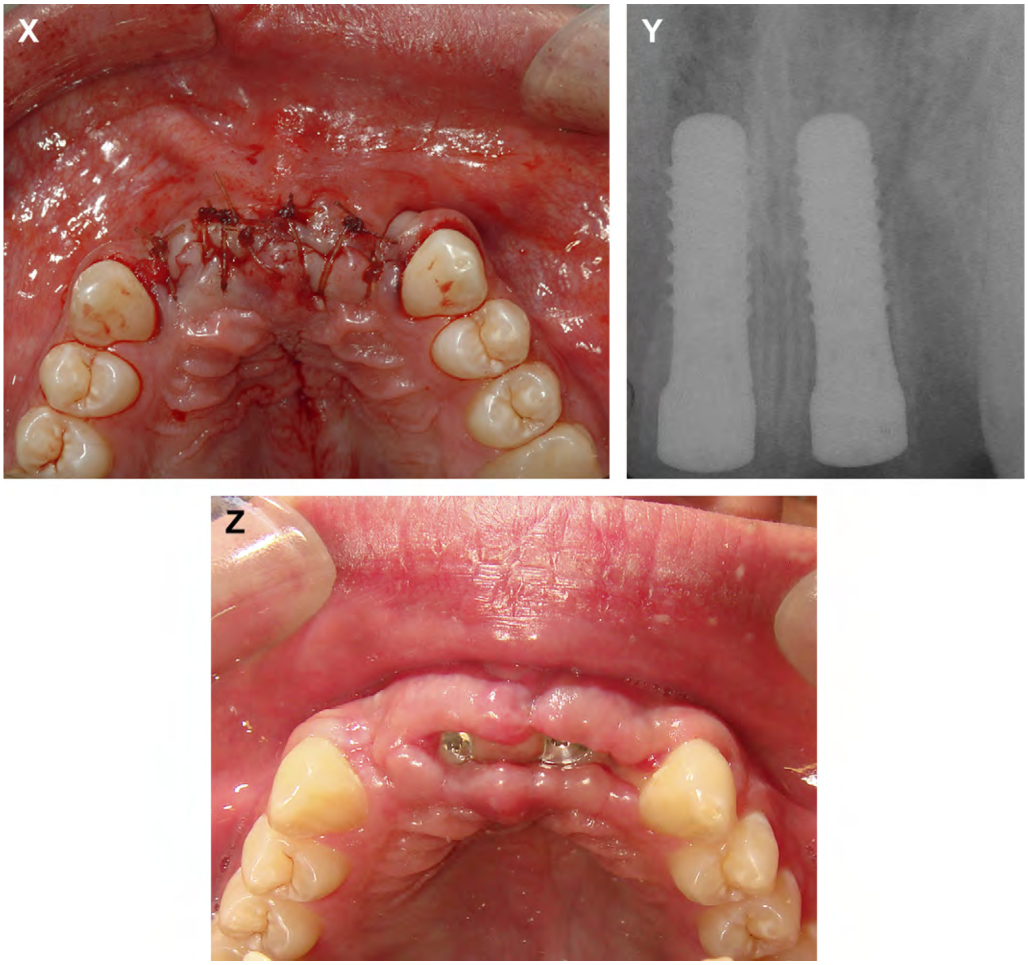

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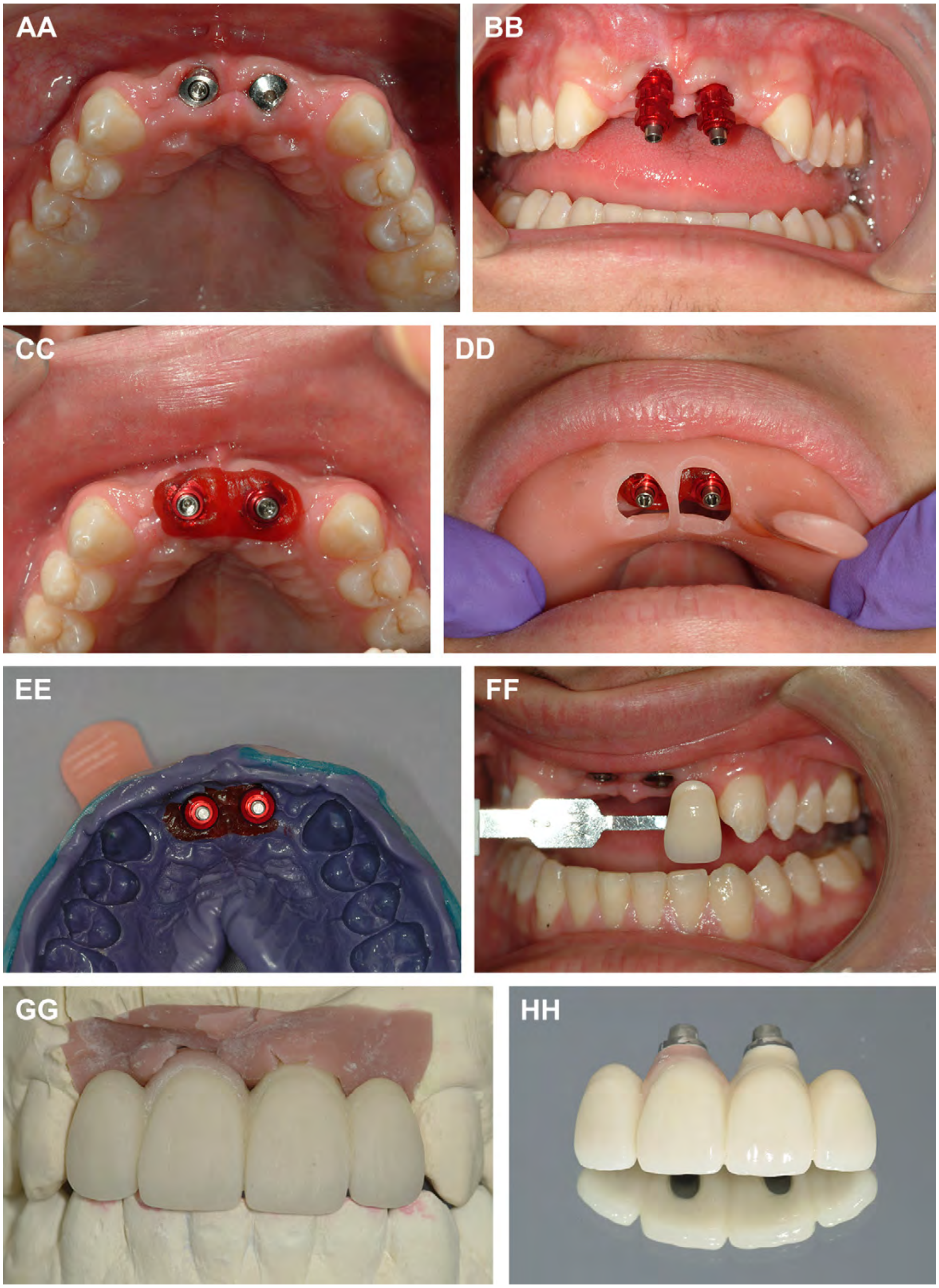

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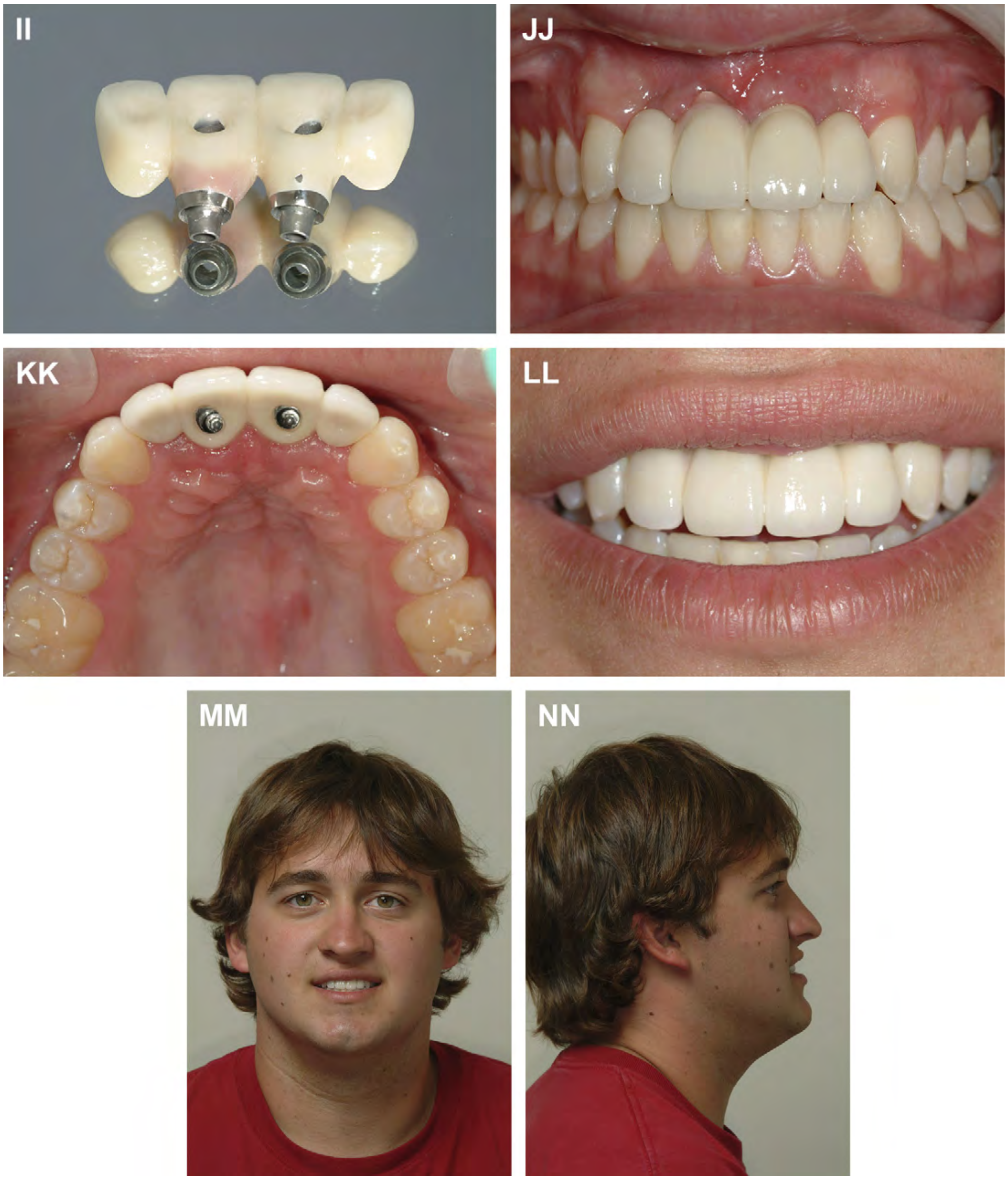

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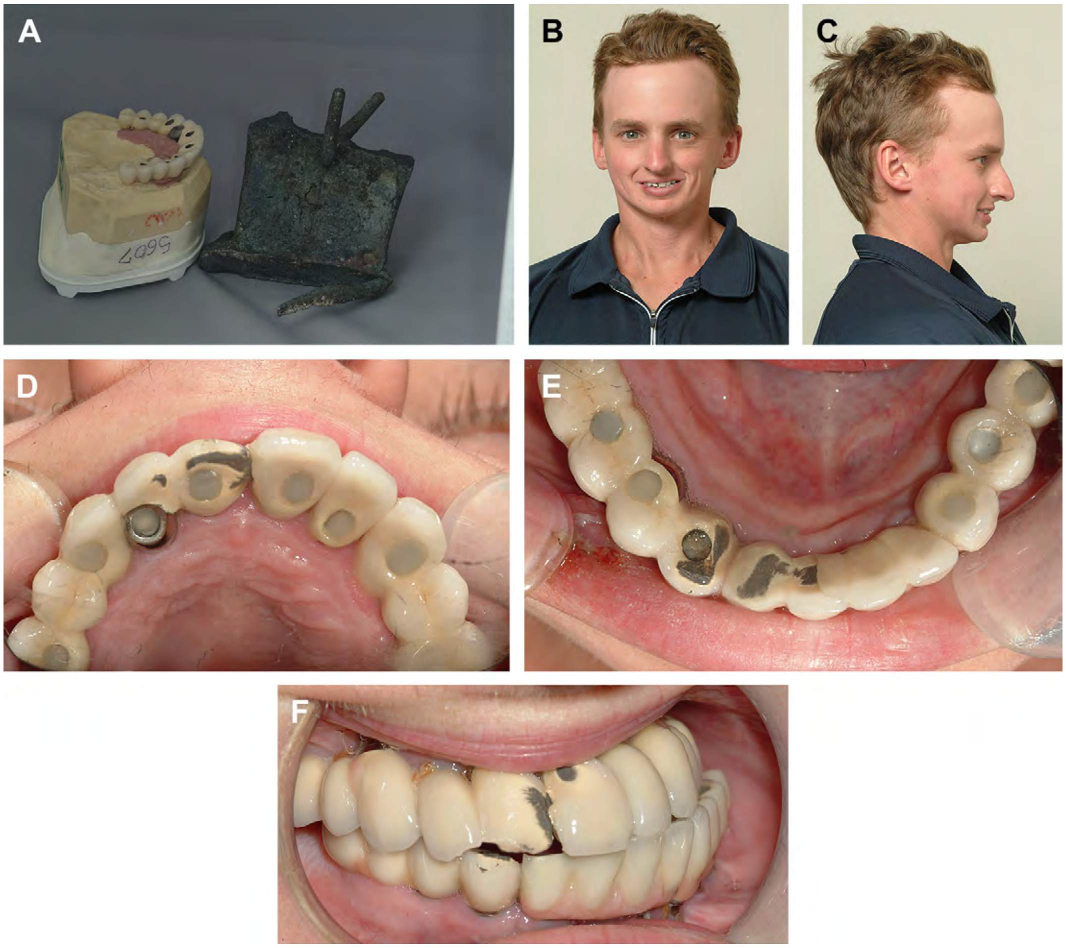
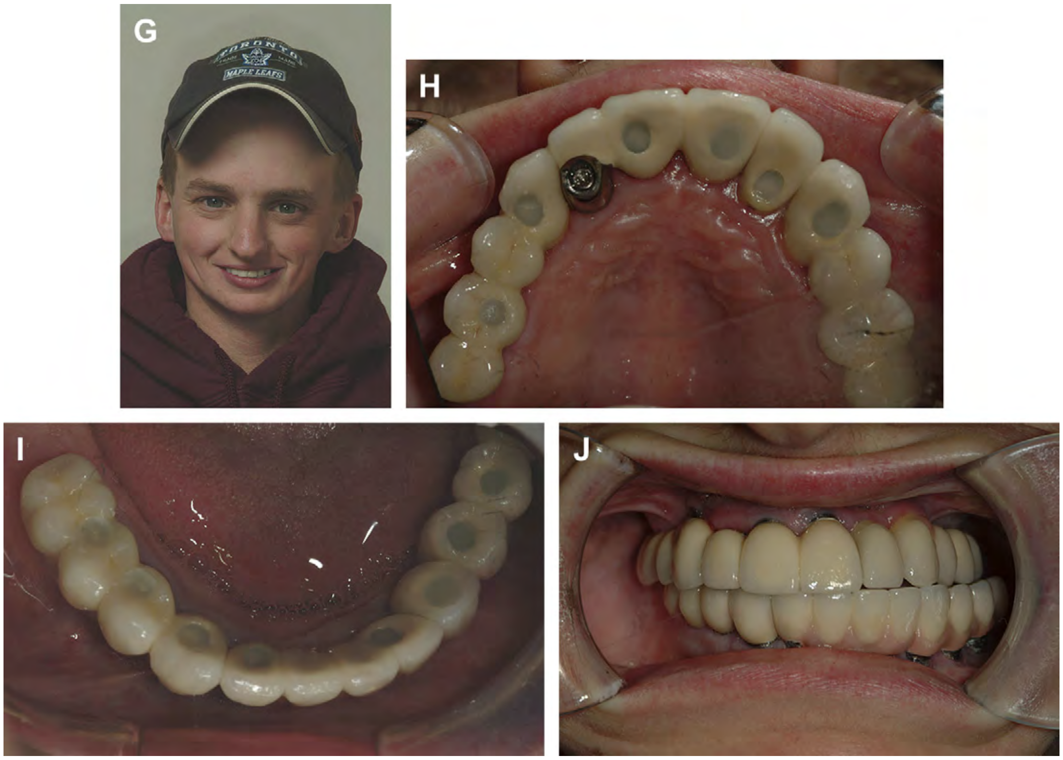


Fig. 9. (*A*) A 23-year-old man who had previous radiation treatment to floor of mouth for rhabdomyosarcoma as an infant subsequently was treated with combined orthognathic surgery and complex dental implant–supported maxillary and mandibular prostheses. Five years later the patient was struck in the face by the steel ingot shown here while working at a smelting plant. (*B*) Frontal facial photograph showing evidence of dental trauma 5 years after his orthognathic surgery and reconstruction. (*C*) Right profile photograph. (*D*) Occlusal view of maxillary reconstruction with multiple porcelain fractures on the palatal and labial aspects. (*E*) Occlusal view of mandibular implant–supported reconstruction with multiple porcelain fractures. (*F*) Right buccal segment view demonstrating bent superstructure framework. (*G*) Frontal facial view after maxillary and mandibular fixed bridges were remade and installed. (*H*) Occlusal view of maxillary implant–supported fixed bridge. (*I*) Occlusal view of mandibular implant–supported fixed bridge. (*J*) Anterior view of reconstructed teeth in occlusion.



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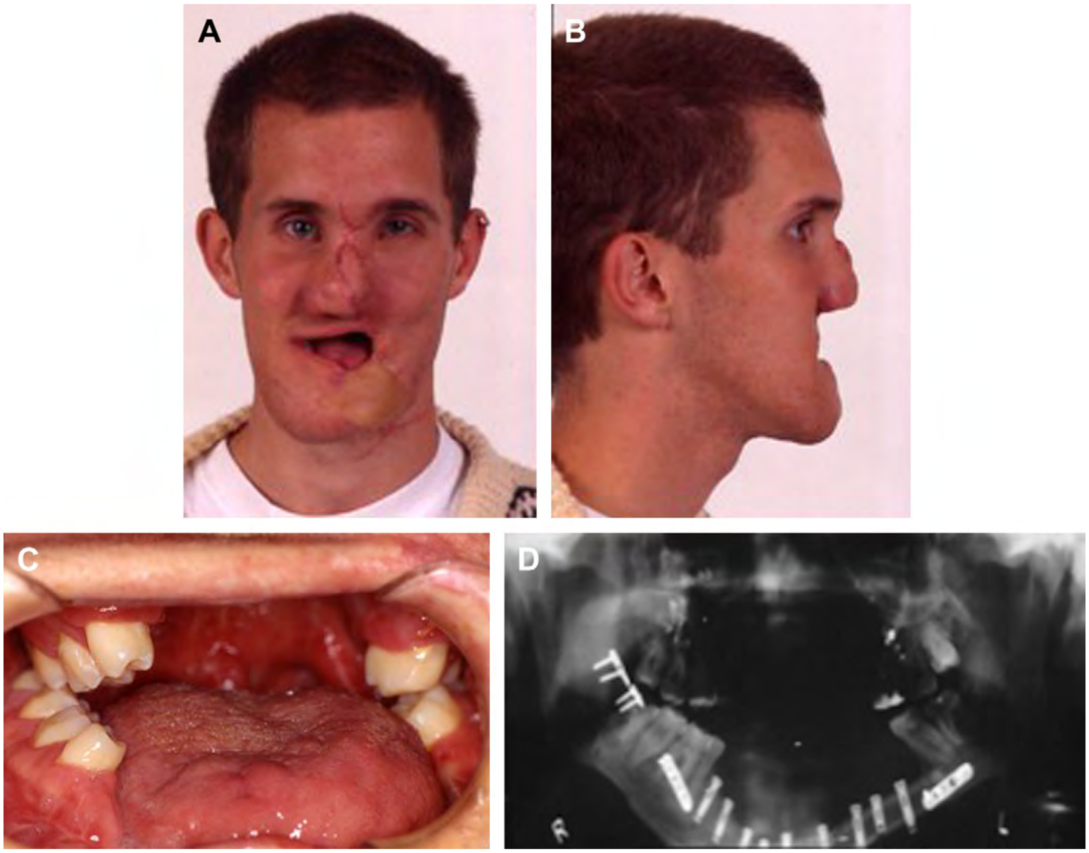
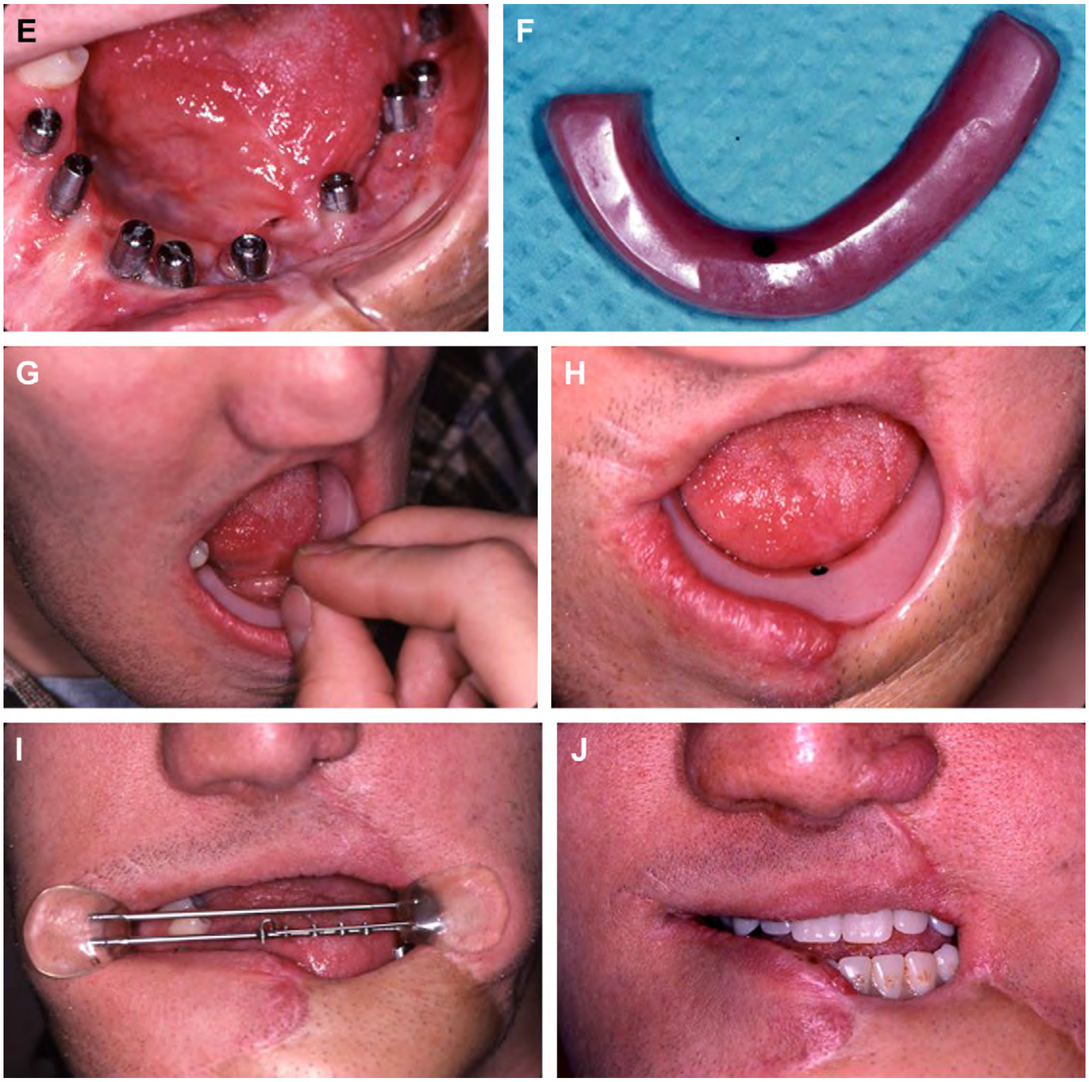


Fig. 10. (*A*) Full face frontal photograph of unfortunate 17-year-old male injured by a shotgun blast. (*B*) Profile photograph showing tremendous loss of midface support and extensive facial scarring with remarkable mandibular prognathism. (*C*) Anterior view of maxillary defect with large oronasal fistula and two separate maxillary buccal segment alveolar fragments with marginal circulation. Mandibular segments had been repaired acutely at the time of trauma with a microvascular fibular transfer. (*D*) Ten dental implants were placed into the mandible and healed fibular graft with great difficulty due to extensive scarring of the lower lip. (*E*) Osseointegrated fixtures in mandible. (*F*) Implant-retained mandibular occlusion rim was used by the patient to help stretch the lower lip for many hours at a time. (*G*) The patient was taught how to insert and secure the implant-supported lip-stretching device independently. (*H*) Occlusal view of lip-stretching device in situ, stretching the lower lip. (*I*) The patient also was asked to wear this lip commisure–stretching device in addition to the implant-borne lip stretcher. (*J*) The lips were stretched sufficiently to allow the wearing of interim maxillary and mandibular prostheses. (*K*) Left-sided view of the mounted models. (*L*) Maxillary and mandibular prosthesis were attached to the models and used in the model surgery to help determine the spatial orientation of the jaws. (*M*) Left-sided view of the mounted models. (*N*) Anterior view of mounted models after model surgery was performed. Intermaxillary fixation devices were secured to the prosthetic teeth to aid with maxillomandibular fixation. (*O*) Left lateral view of model surgery results. (*P*) Resected segment from left mandible allowing retrusion of the prognathic mandible. (*Q*) Mandibular prosthesis ready for insertion onto the resected mandible. (*R*) New mandibular prosthesis inserted onto the repositioned mandible. (*S*) Maxillary molars were extracted bilaterally after the development of extensive root dehiscences. Hyperbaric oxygen therapy was provided to help these wounds with marginal vascularity heal. Four dental implants were placed into each maxillary segment. (*T*) Panoramic radiograph showing the complex mandibular reconstruction and the implants in the maxillary buccal segments. (*U*) Custom maxillary impression tray with perforations to allow access to the nine maxillary implants. (*V*) Occlusal view of maxillary model with implant analogs. (*W*) Intraoral view of gold prosthetic copings incorporated into a resin framework seen sectioned into individual elements, then joined again (*X*) prior to pick-up impression. (*Y*) Right and left maxillary retentive bar assemblies on master cast. (*Z*) Bar-retained maxillary overdenture on master cast. Note lack of palatal coverage intended to avoid compression of fleshy lateral arm flap which obturates the oronasal fistula. (*AA*) Retentive bar fixed to the implants of the right buccal segment. (*BB*) Retentive bar on implants in left buccal segment. Note terminal friction-fit attachments. (*CC*) Intaglio surface of maxillary overdenture. Note cast titanium sleeve which houses attachment mechanisms. (*DD*) Maxillary prosthesis inserted into the mouth. Note the fleshy lateral arm flap immediately posterior to the prosthesis. (*EE*) Frontal photograph with lips in repose after prosthesis insertion. (*FF*) Frontal view of lip function with patient puckering after prosthesis insertion. Lip has been revised to excise a major portion of the fibular skin in order to reconstitute the vermillion border and mucosal aspect of the left lower lip (see Fig. 10J for comparison). (*GG*) Close-up of smile.



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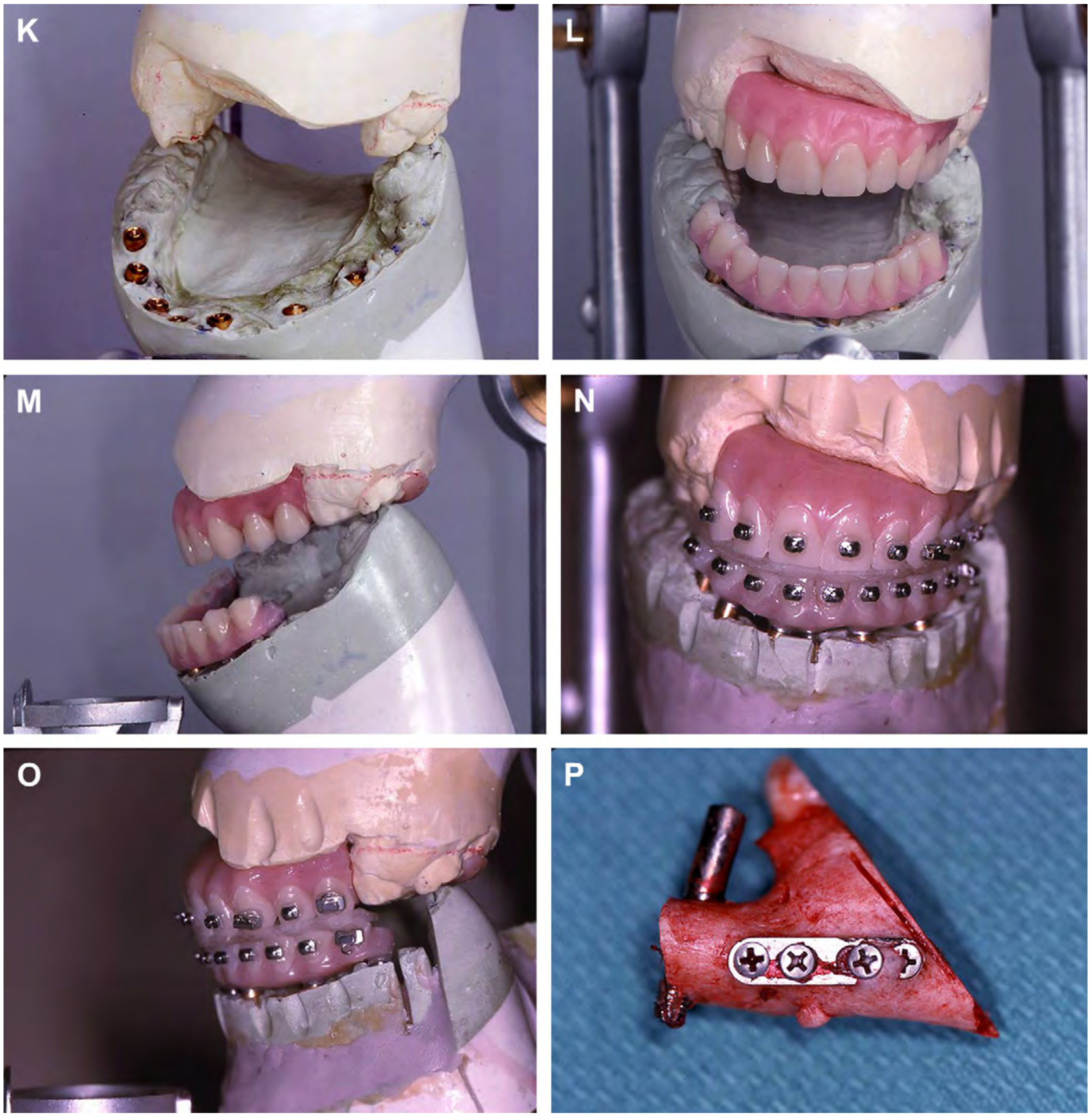

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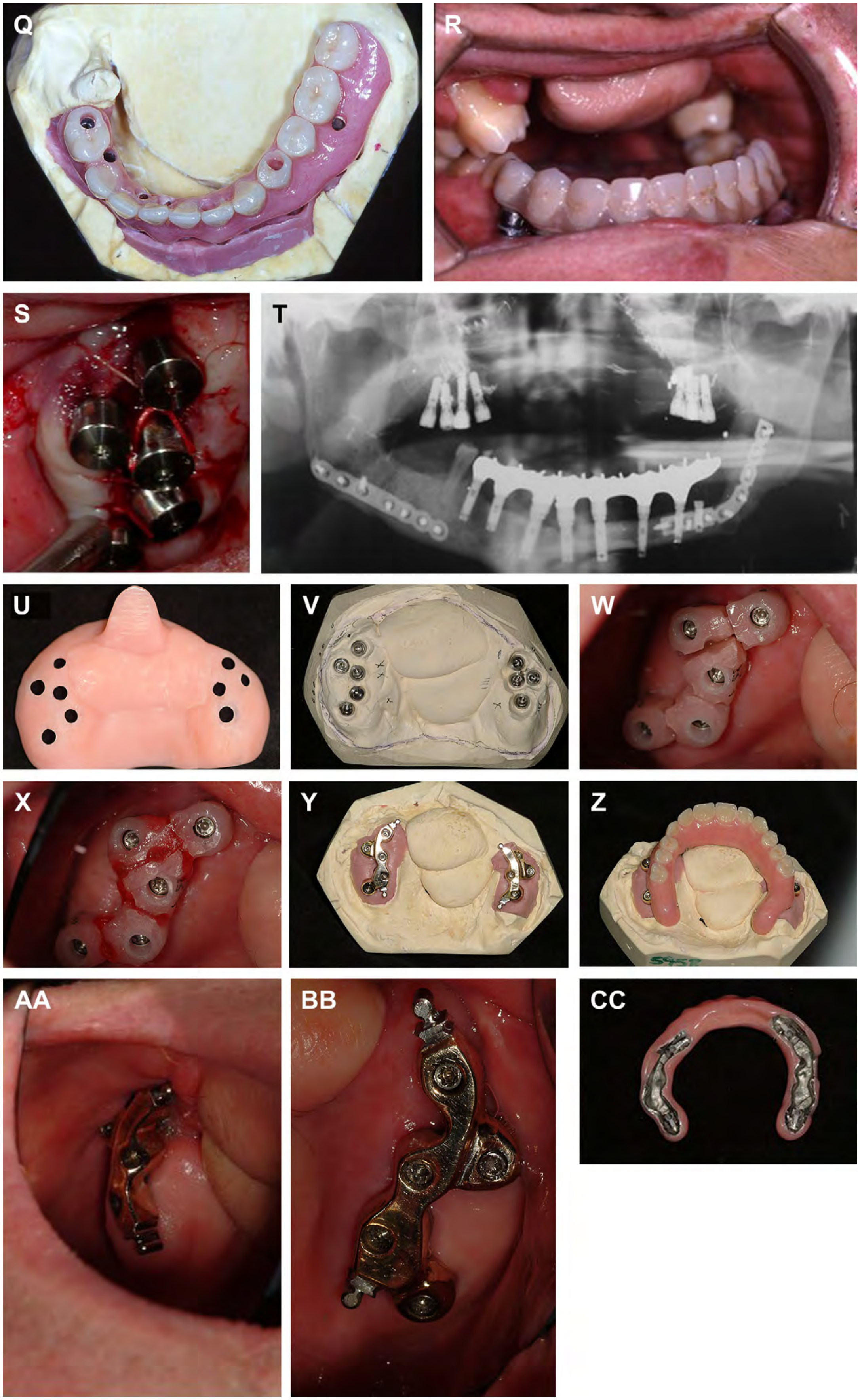

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# Reconstruction of Ablative Defects Using Dental Implants

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Excision of benign and malignant orofacial lesions often extends into tooth bearing portions of the jaws in order to provide for adequate disease control. Aggressive cystlike lesions of the jaws may destroy large areas of the dentoalveolar process and underlying structures, resulting in the loss of teeth. Removal of tumors such as ossifying fibroma, aggressive fibromatosis, central giant cell granuloma, and ameloblastoma may create defects that are challenging to restore. This article examines the reconstruction of ablative defects and of regions of the jaws arrested in development by delivery of radiotherapy in childhood to treat tumors such as rhabdomyosarcoma, retinoblastoma, or neuroblastoma.

## Odontogenic keratocysts

Odontogenic keratocysts can be aggressive, and their removal can lead to major dentoalveolar loss requiring future reconstruction. The management of odontogenic keratocysts is made more difficult because they tend to recur. The syndromic association of multiple odontogenic keratocysts with basal cell carcinomas is called basal cell nevus (Gorlin) syndrome. The gene responsible for this condition has been identified and is known as the sonic hedgehog gene. The management of both new and recurrent lesions in these patients is challenging. The risk of recurrences is elevated in adolescence and early adulthood so dental reconstruction should be postponed until growth has ceased (Figs. 1A–1I).

Other aggressive lesions such as the widespread recalcitrant pyogenic granulomas of the maxilla can also be challenging to manage and reconstruct (Figs. 2A–2H).

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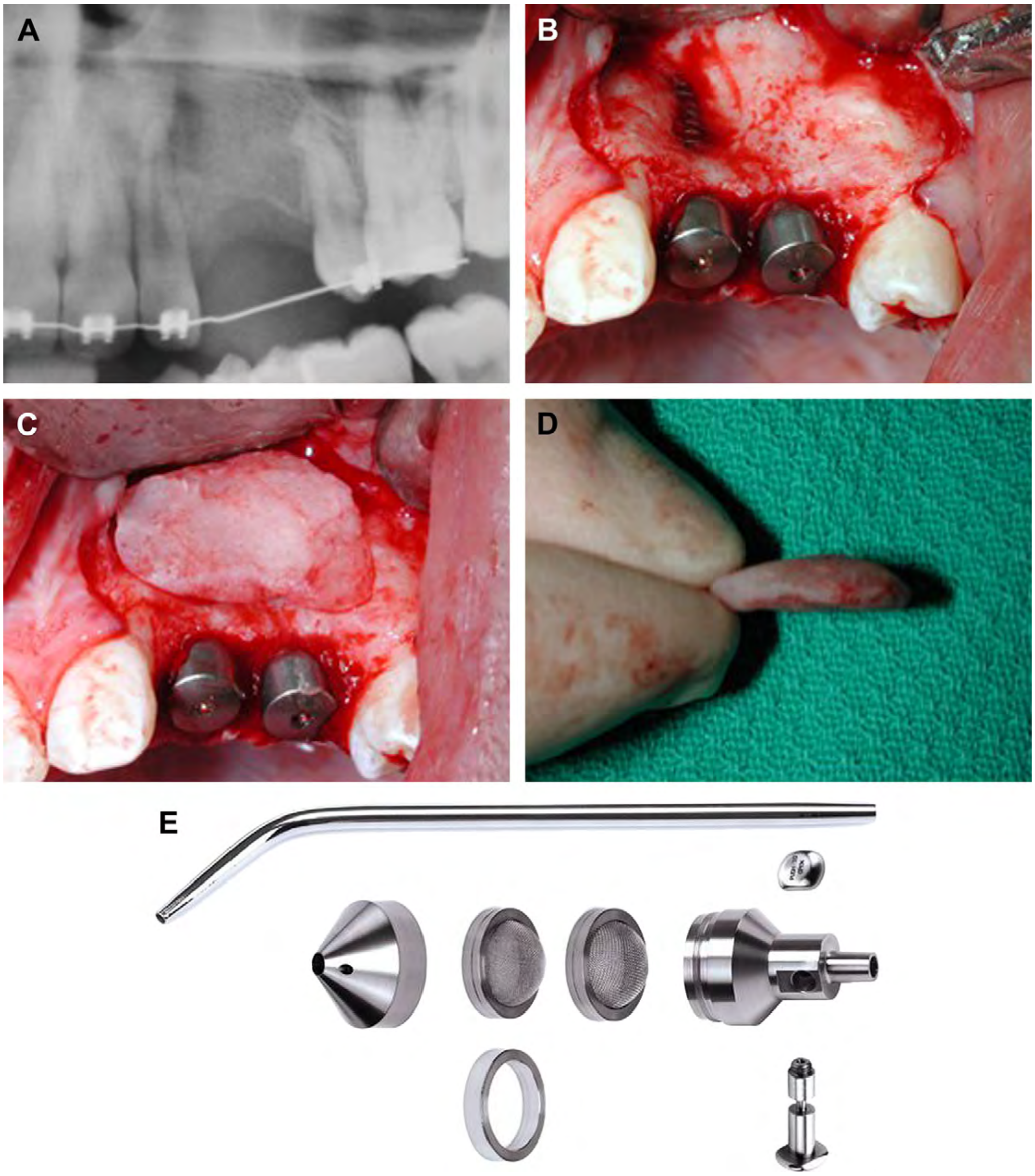


Fig. 1. (*A*) Radiograph of maxillary alveolus in an 18-year-old male who had a large maxillary odontogenic keratocyst treated by enucleation and Carnoy's solution. The maxillary left permanent lateral incisor and canine teeth are missing. (*B*) Two implants placed with labial dehiscences of bone. (*C*) A piece of bone wax is adapted to estimate the size of the ridge defect. (*D*) The estimated size of the ridge defect. (*E*) The suction trap in a blown apart view showing its various components. (*F*) When maxillary implants are being placed, bone can be harvested from the nearby zygomatic process. (*G*) The particulate bone graft harvested by the suction trap. (*H*) The particulate bone graft placed over the labial dehiscences. (*I*) Labial view of the restored implants with a small porcelain flange to correct for some vertical deficiency.

## Fibro-osseous and giant cell lesions of the jaws

In children who are congenitally missing one or more teeth, treatment is usually postponed until after the cessation of skeletal growth in order to avoid disturbing normal dentoalveolar development. In contrast, in children with certain pathologies, the lesion must be removed irrespective of the stage of growth of the patient. If growth is incomplete at the time of surgery, then some disruption of normal development is inevitable either as a result of scarring or constraint caused by reconstruction hardware or because of failure of a free tissue transfer such

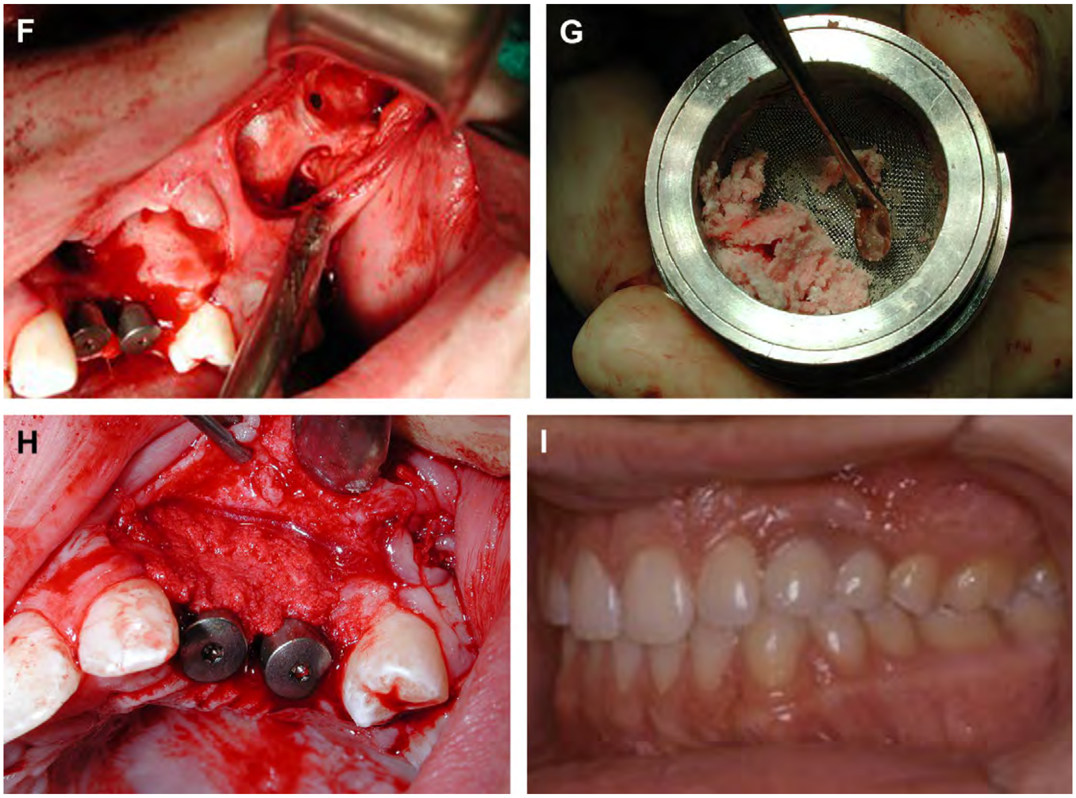


Fig. 1 (*continued*)

as a fibula to grow. In cases such as these, where the ablative surgery itself is expected to impede or restrict growth of the jaws, and little or no further restriction would be expected to be superimposed by dental implants placed into the ablative defect, then a decision to proceed with the placement of implants may be made if there is sufficient functional and psychosocial justification to do so. Certain fibro-osseous lesions of the jaws may require resection during childhood. One such lesion is the ossifying fibroma. Large areas of the tooth-supporting alveolus may be lost when these lesions are resected (Figs. 3A–3D). Another such lesion is the giant cell granuloma when it cannot be successfully treated with serial steroid injections so that jaw resection is required to gain control of the lesion.

Placement of implants into an ablative defect reconstructed using plates and screws permits the removal of the reconstruction hardware at the time of implant placement. Removal of reconstruction hardware while the patient is still growing may in some instances permit growth of the affected areas of the jaws to resume as long as it is not further constrained by dental implants or by an implant supported prosthesis. In reconstructions involving the mandibular symphysis we have employed a prosthesis designed with a split at the midline to accommodate potential transversal growth. However, in a series of five young children reconstructed with cross-arch implant-supported fixed bridges split at the midline in vascularized free fibular grafts, we have seen no separation of the right and left sides of the bridges as might be expected were the mandibles to have grown transversally in the intercuspid regions. Implants and implant supported reconstructions are not expected to grow vertically together with the rest of the developing arch. Consequently, the implant reconstruction should be remade periodically in order to avoid distortion of the occlusal plane and overeruption of the opposing dentition.

Such reconstructions can be performed in vascularized bone grafts (Figs. 4A–4K) or in free nonvascularized bone grafts (Figs. 5A–5L). The maintenance of good oral hygiene around implant reconstructions is extremely important in young children; despite parental attempts,

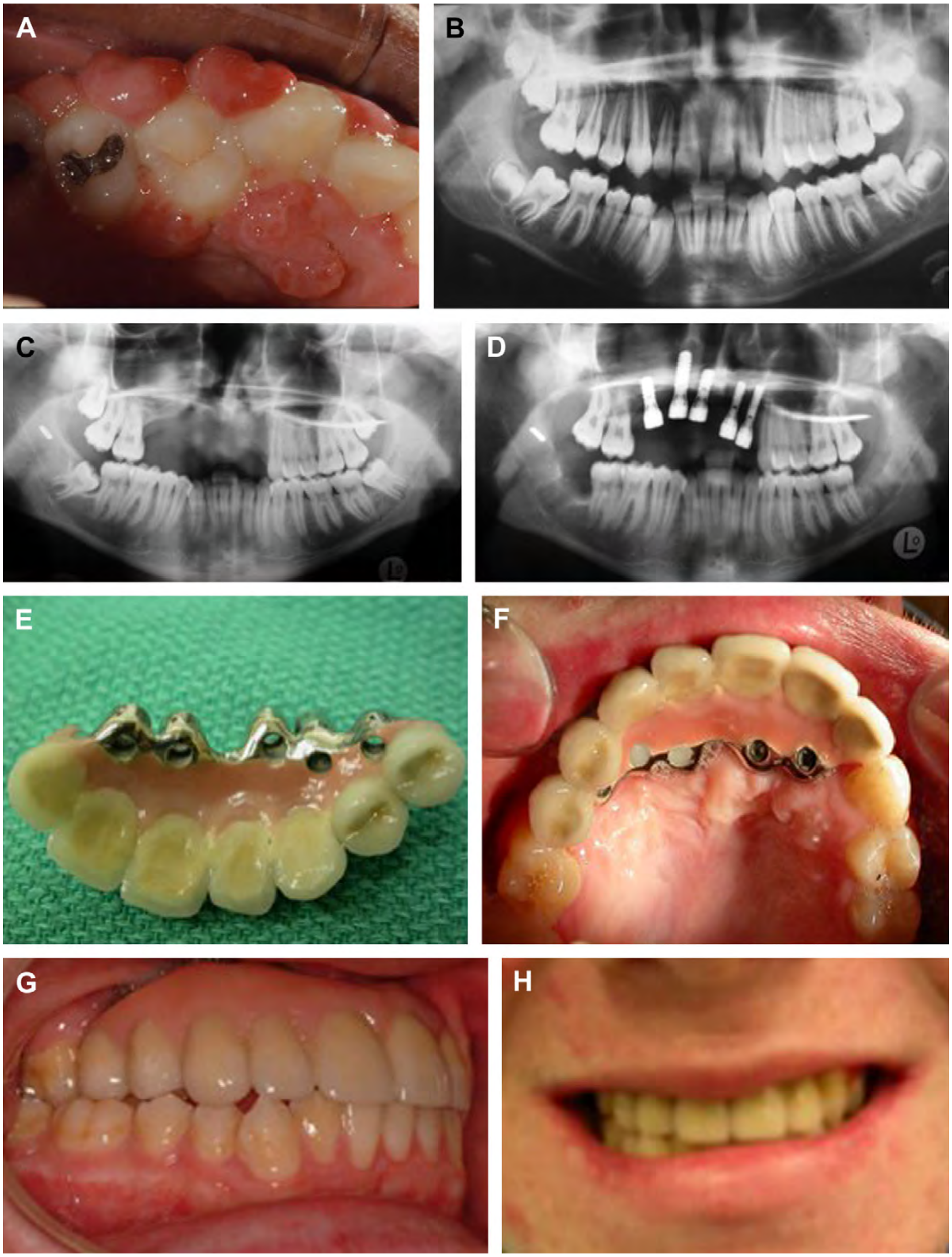


Fig. 2. (*A*) Recalcitrant recurrent pyogenic granuloma-like lesions on both sides of the maxilla. The child presented at the age of 8 years with recurrent bleeding necessitating multiple soft tissue procedures and then extractions to gain control of lesions that caused chronic hemorrhage. (*B*) Panoramic radiograph taken at 11 years of age. (*C*) Panoramic radiograph at age 13 years after removal of further recurrences of the lesion and the permanent right and left incisors, right canine, and premolar teeth. (*D*) A total of five dental implants were placed at the age of 17 years to replace the missing maxillary teeth. Areas of bone deficiency were treated with particulate bone grafts harvested using the suction trap from the third molar extraction sites. (*E*) The prosthesis was fabricated to replace the missing teeth and alveolus. (*F*) Palatal view of the prosthesis after insertion. (*G*) Labial view of the inserted prosthesis. (*H*) Patient smiling with prosthesis in situ.

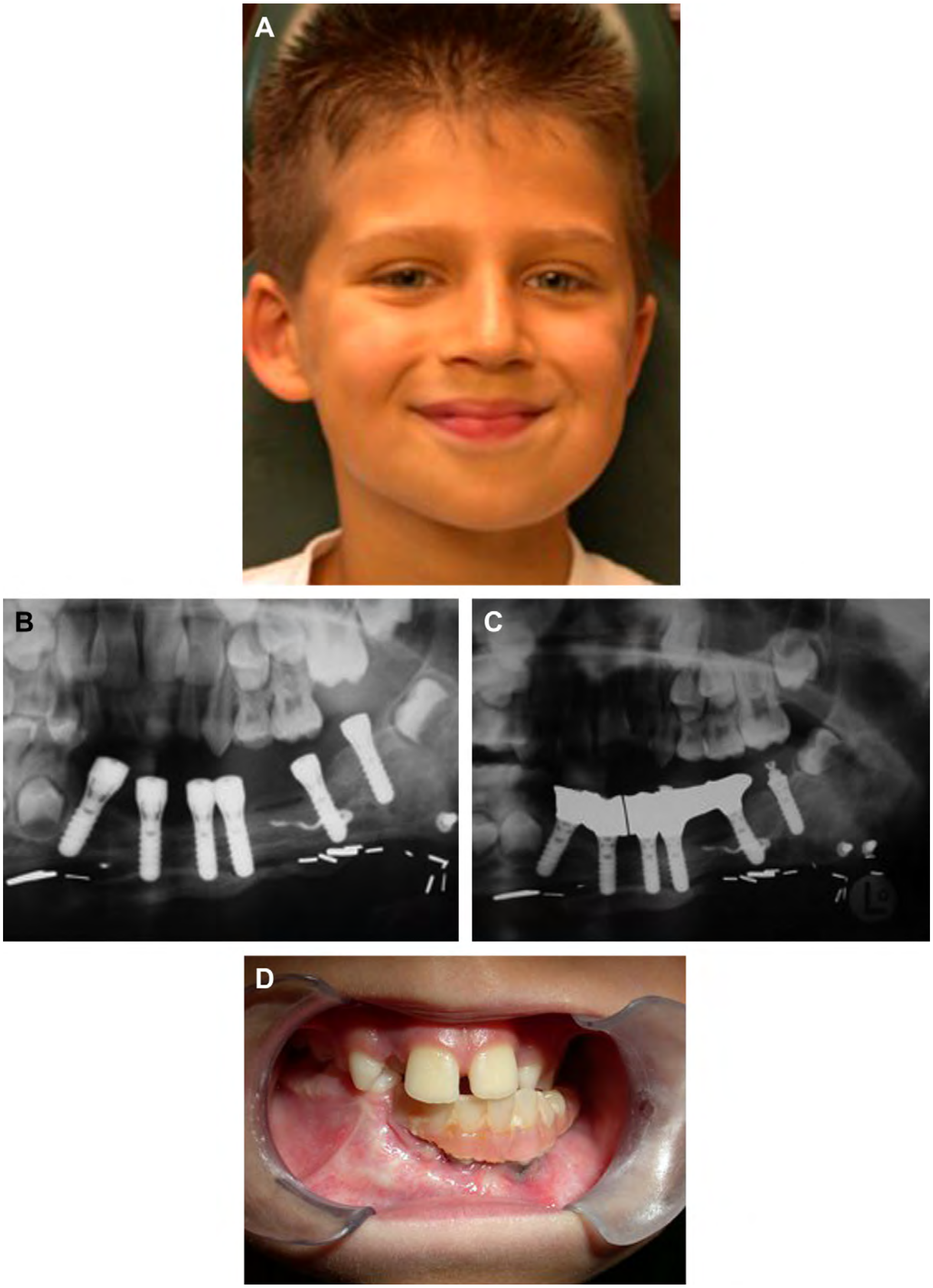


Fig. 3. (*A*) Frontal view of an 8-year-old child following resection of an aggressive ossifying fibroma with ablative defect reconstructed with a vascularized fibular graft. (*B*) At the age of 8 years, a total of six dental implants were placed to replace the missing permanent teeth, a gap which extended from the right permanent canine to the left second permanent molar. (*C*) The superstructure of the prosthesis was split in the midline to accommodate potential transverse mandibular growth. The most posterior implant was not restored. (*D*) Labial view of the restored prosthesis.

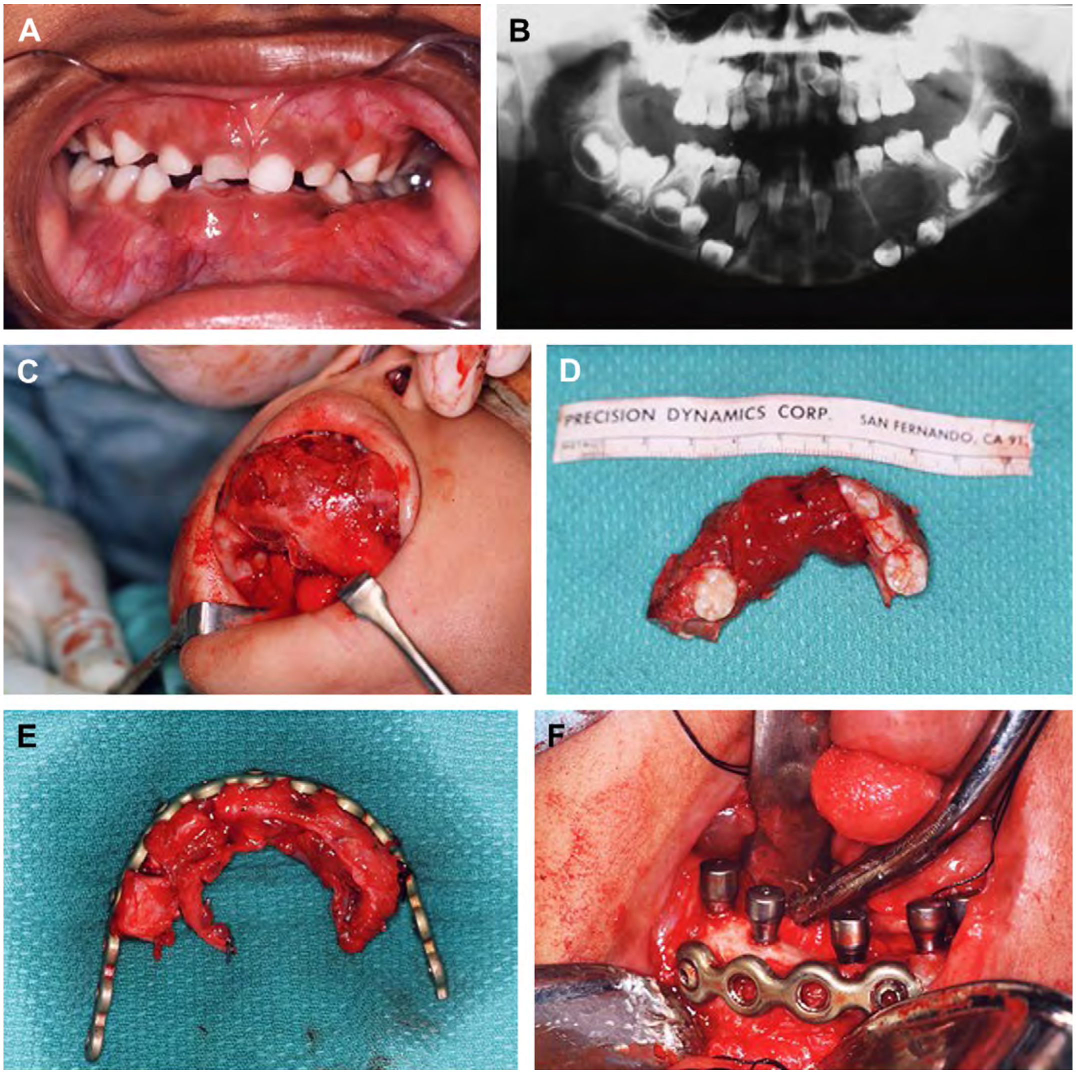
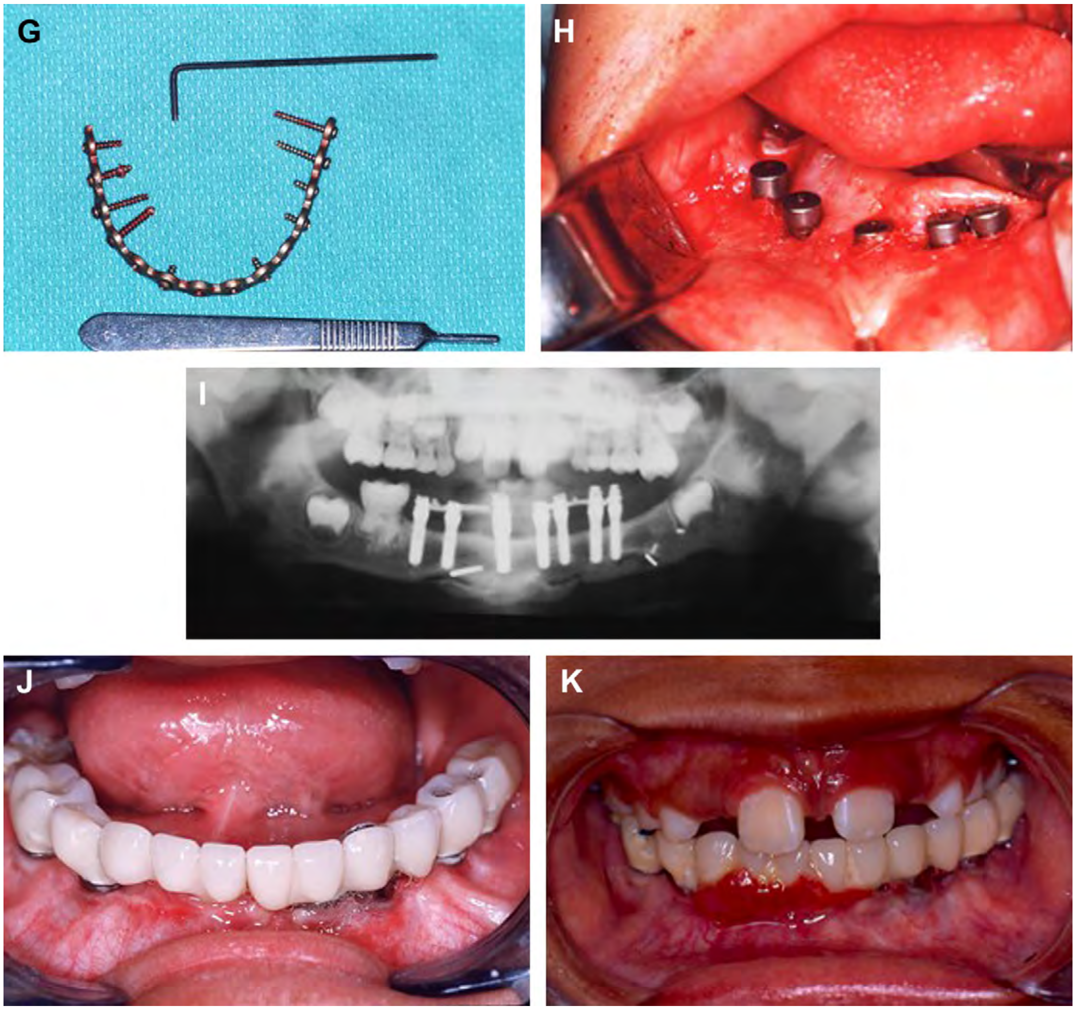


Fig. 4. (*A*) An aggressive central giant cell granuloma of the mandible in a 5-year-old boy seen from the labial view. (*B*) Panoramic radiograph of lesion extending from the right first premolar tooth bud to the left second premolar tooth bud. (*C*) The lesion was exposed through an intraoral chin degloving approach. (*D*) The resected mandibular specimen. (*E*) The vascularized free fibular graft is shown with the adapted reconstruction plate. (*F*) Implant placement into the fibular graft at the age of 6 years. (*G*) The reconstruction plate was removed at the time of the implant placement. (*H*) The implants were inserted as a one-staged placement. (*I*) Panoramic tomograph of the restored implants. Note that the restoration does not cross the midline. (*J*) The completed provisional restoration in the mouth. Note the split of the prosthesis at the mandibular midline. (*K*) Two years after insertion of the prosthesis, the patient began to develop inflamed areas of granulation tissue. Oral hygiene had always been a difficult issue in this child. It imperative that the reconstructive team focus on this issue from the outset.

these patients may find it challenging to keep the tissue around the implants in a healthy state (see Fig. 4K).

## Ameloblastoma

Like other cystlike lesions and tumors, ameloblastoma may result in the loss of a great portion of the tooth-bearing portion of the jaws. These tumors tend to occur in teenagers or later in adulthood. Their management from an implant planning point of view is similar to that



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for other ablative defects, with the goal being a timely return to function with adequate recurrence surveillance (Figs. 6A–6F).

These reconstructions can take the form of vascularized tissue transfer or free bone grafts depending on the specifics of the defects. Vascularized grafts have the advantage of being able to reconstruct large defects in wound beds that may be compromised. They have the disadvantage of lacking the bone volume for facial esthetics and subsequent implant insertion.

The outcomes of vascularized and nonvascularized bone grafts have been compared in the reconstruction of mandibular continuity defects in adults. Vascularized grafts were more successful in larger defects over 9 cm in length and in irradiated tissue beds. Nonvascularized grafts created a better contour and bone volume for facial esthetics and subsequent implant insertion.

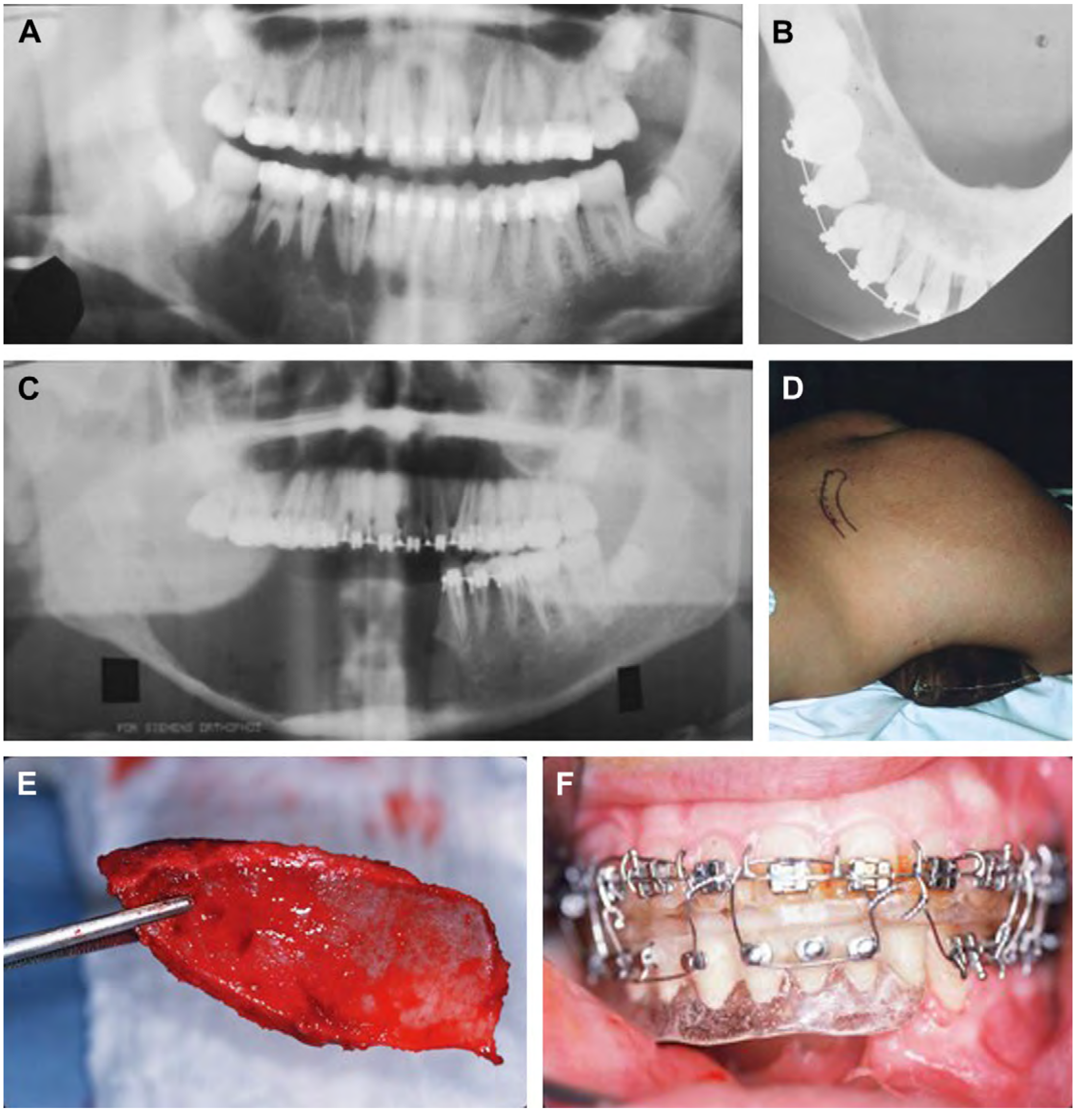
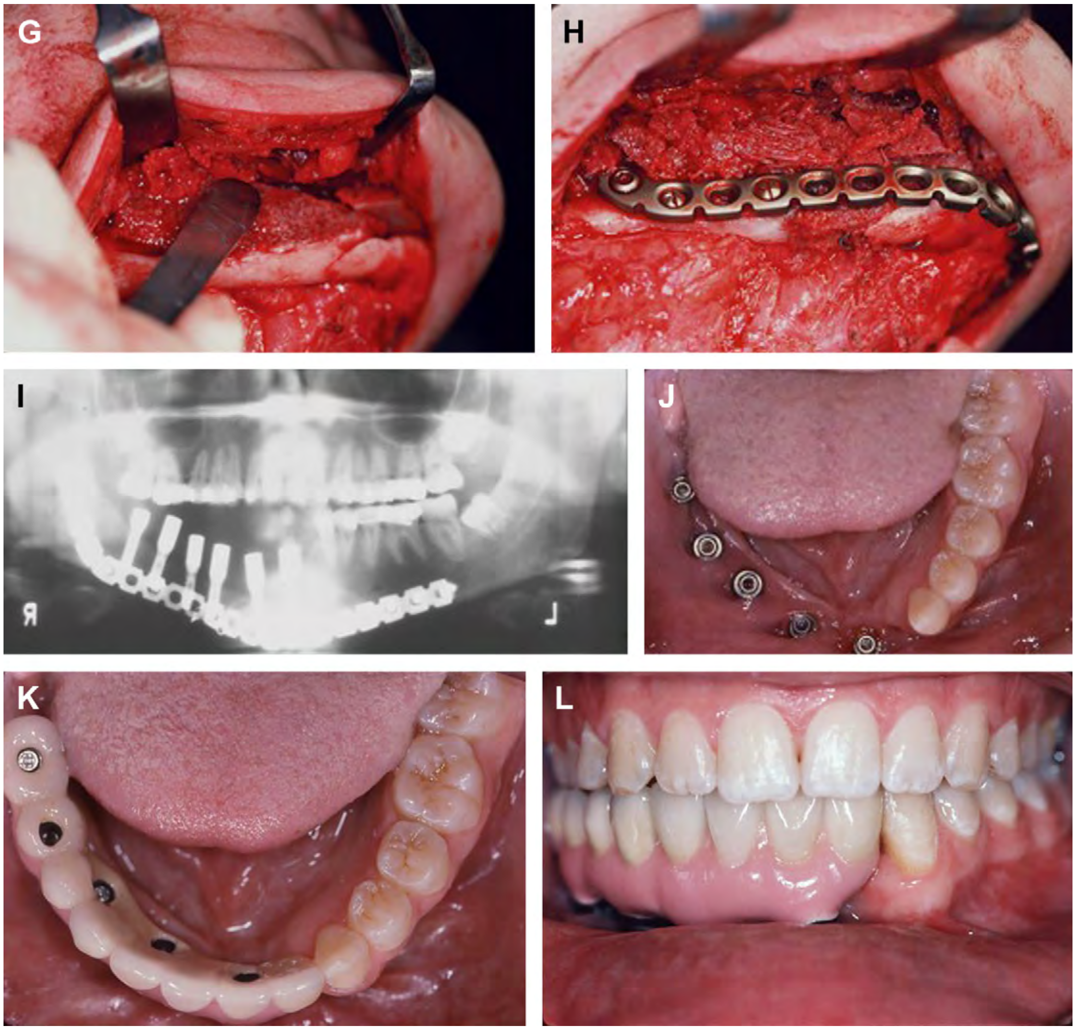


Fig. 5. (*A*) Panoramic tomograph of an extensive giant cell granuloma of the right mandibular body in a 15-year-old girl. (*B*) Occlusal radiograph of the involved right mandible. (C) Post resection panoramic tomograph of the lesion which was removed using an intraoral approach. Unfortunately, the patient had mild cerebral palsy and fell 3 weeks after the resection sustaining a pathologic fracture of the mandible. (*D*) The patient was taken to the operating room for harvesting of a posterior iliac crest bone graft. (*E*) The piece of posterior iliac crest measuring 7 × 4.5 cm in size. (*F*) A bone graft guide comprising an interocclusal wafer and a denture-like appliance derived from a diagnostic wax-up of the missing teeth and alveolar process is wired into place with the tooth-bearing left side of the mandible approaching maximal intercuspation. The buccal and lingual flanges were used to guide the buccolingual and vertical placement of the bone graft relative to the maxillary teeth. (*G*) The pathologic fracture of the mandible is manually reduced and the bone graft is placed from an extraoral approach. (*H*) Definitive reduction was achieved with the reconstruction plate. The corticocancellous bone graft is in position, restoring the continuity of the right mandible. (*I*) Dental implants were placed at the age of 16 years, 6 months following the nonvascularized bone graft. The implants were placed as a one-staged insertion with long healing caps. (*J*) Intraoral view of the healed implant sites. (*K*) Occlusal view of the prosthesis at insertion. (*L*) Labial view of the completed prosthesis in situ.



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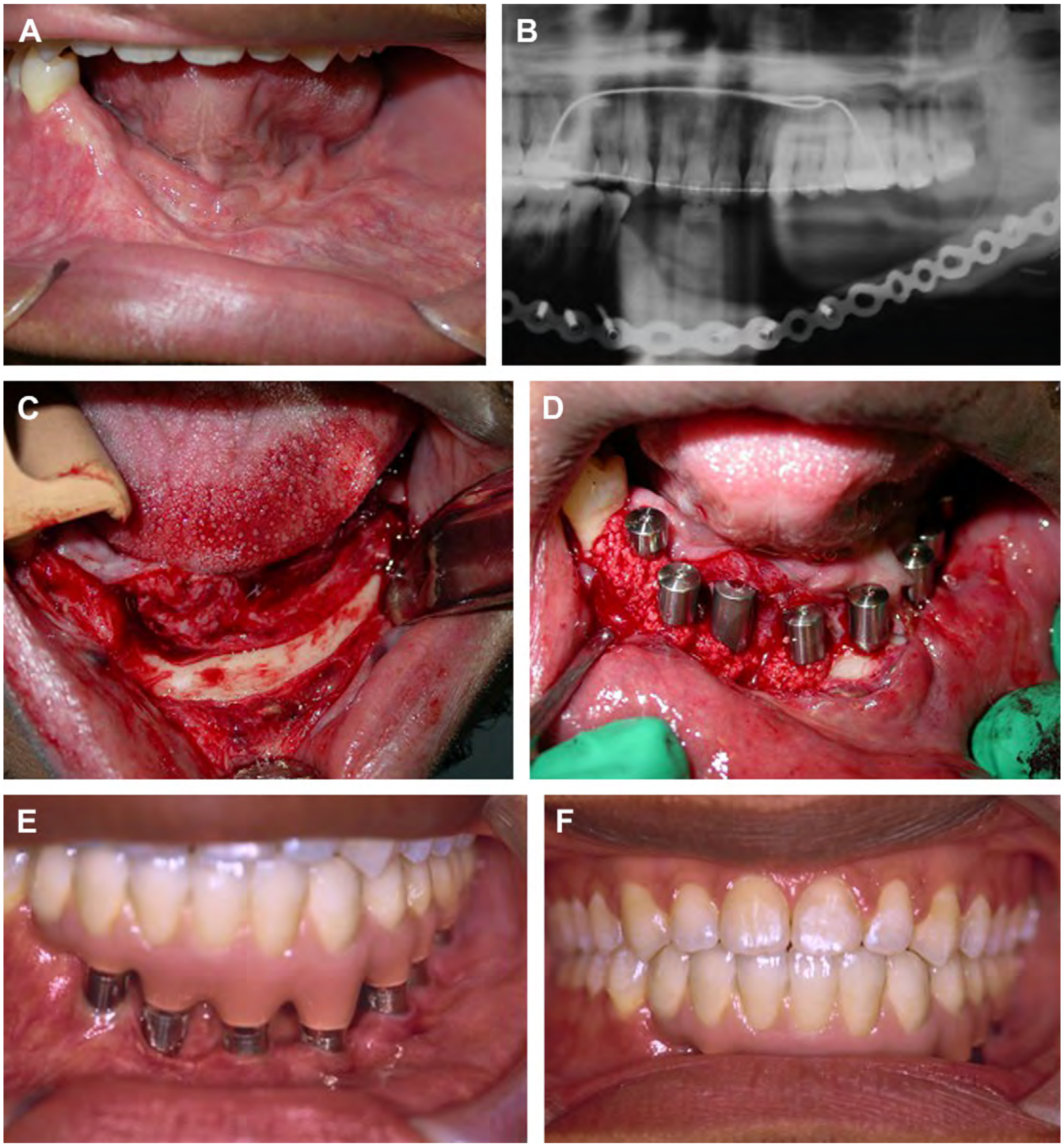


Fig. 6. (*A*) Ablative defect of the mandible after the resection of an ameloblastoma in an 18-year-old male. (*B*) Panoramic tomograph shows a reconstruction plate and vascularized fibular graft that span the defect extending from the right permanent canine to the left retromolar area. (*C*) An incision is made over the graft for implant placement. Note the discrepancy in alveolar height at the junction of the original mandible and the vascularized fibula graft. This height discrepancy is one of the disadvantages of using the fibula as a donor bone. The vertical height of the fibula does not match that of the mandible. (*D*) Eight implants were placed, and bony deficiencies were grafted with particulate bone harvested from intraoral sources. (*E*) Labial view of the completed prosthesis. (*F*) Teeth in occlusion showing the functional position of the implant-borne prosthesis.

## Aggressive fibromatosis

Juvenile aggressive fibromatosis may present as a rapidly growing intraoral mass resembling a sarcoma. In the past, some investigators have labeled these tumors as fibrosarcomas and desmoid tumors. The experience of the authors suggests that these lesions respond to local wide resection (Figs. 7A–7F). The ablative defects can then be treated by reconstruction, dental implant placement, and restoration.

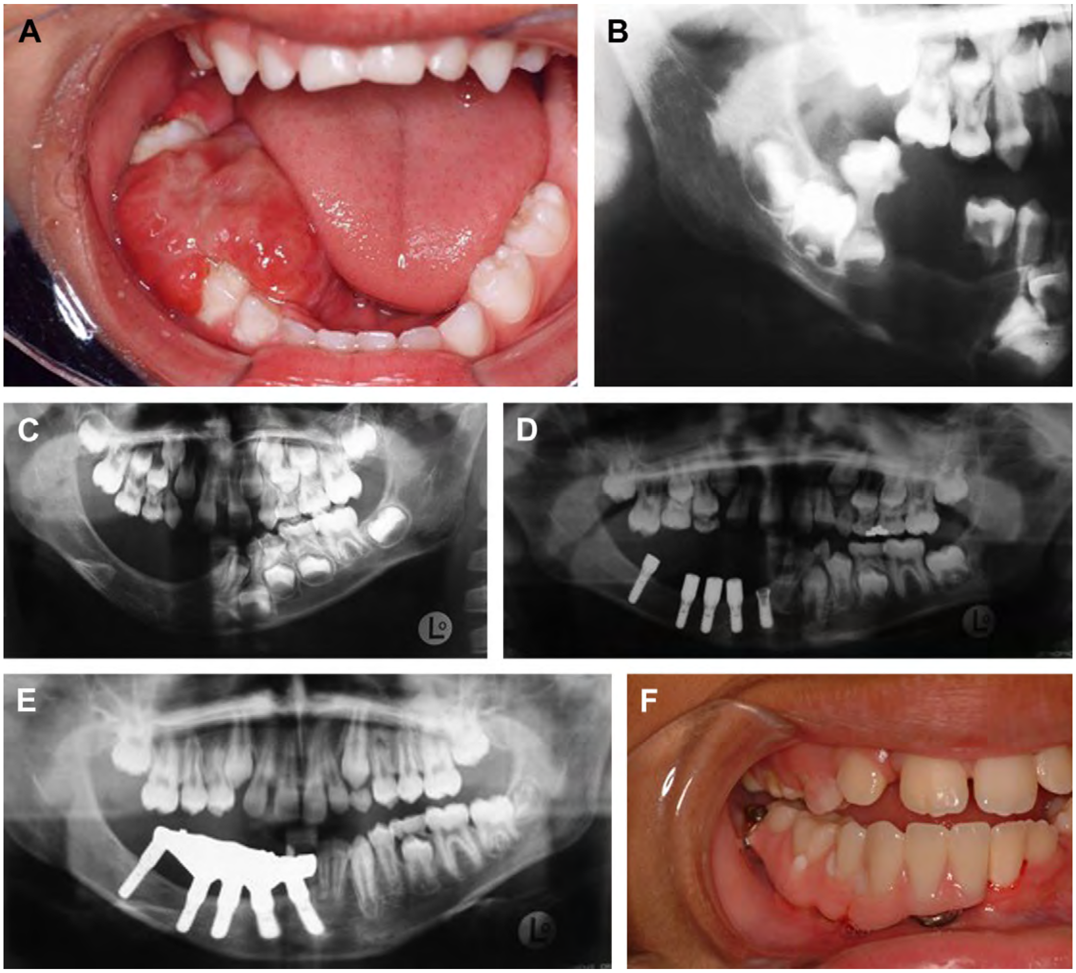


Fig. 7. (*A*) Intraoral occlusal view of rapidly growing right mandibular tumor in a 4-year-old boy. (*B*) Radiograph showing a lateral view of the aggressive and destructive lesion of the right mandible. (*C*) Panoramic tomograph taken 18 months following the resection of tumor that was found on histologic examination to be an aggressive fibromatosis. The mandible has regenerated a great deal of bone, and there is no evidence of recurrence. (*D*) The child complained of difficulty chewing, was unable to wear a removable appliance because of contiguity of the floor of the mouth and the buccal vestibule, and the opposing dentition was overerupting. Five dental implants were placed at the age of 6 years. (*E*) Panoramic tomograph of the inserted prosthesis. (*F*) Labial view of the inserted prosthesis. Periodic revisions to the bridge accommodate growth of the jaws.

## Growth retardation due to pediatric radiotherapy

Certain pediatric malignant lesions of the head and neck are more amenable to treatment with primary radiotherapy instead of surgical resection. Rhabdomyosarcoma is one such lesion. This malignant tumor often involves oral or perioral tissues, necessitating treatment with a surgical biopsy, clinical and radiographic staging, and chemotherapy and radiotherapy.

Patients with rhabdomyosarcoma are often infants or toddlers and are exposed to the deleterious effects of radiation at a very young age (Figs. 8A–8J). Although xerostomia may be an initial problem, by the time these patients present for reconstructive treatment, this no longer seems to be an issue; rather, there is a lack of growth of the roots of the teeth and the irradiated jaws and sometimes the facial bones. The teeth are usually amazingly stable despite the lack of root development (see Fig. 8J); however, they are prone to sudden, often unpredictable, exfoliation.

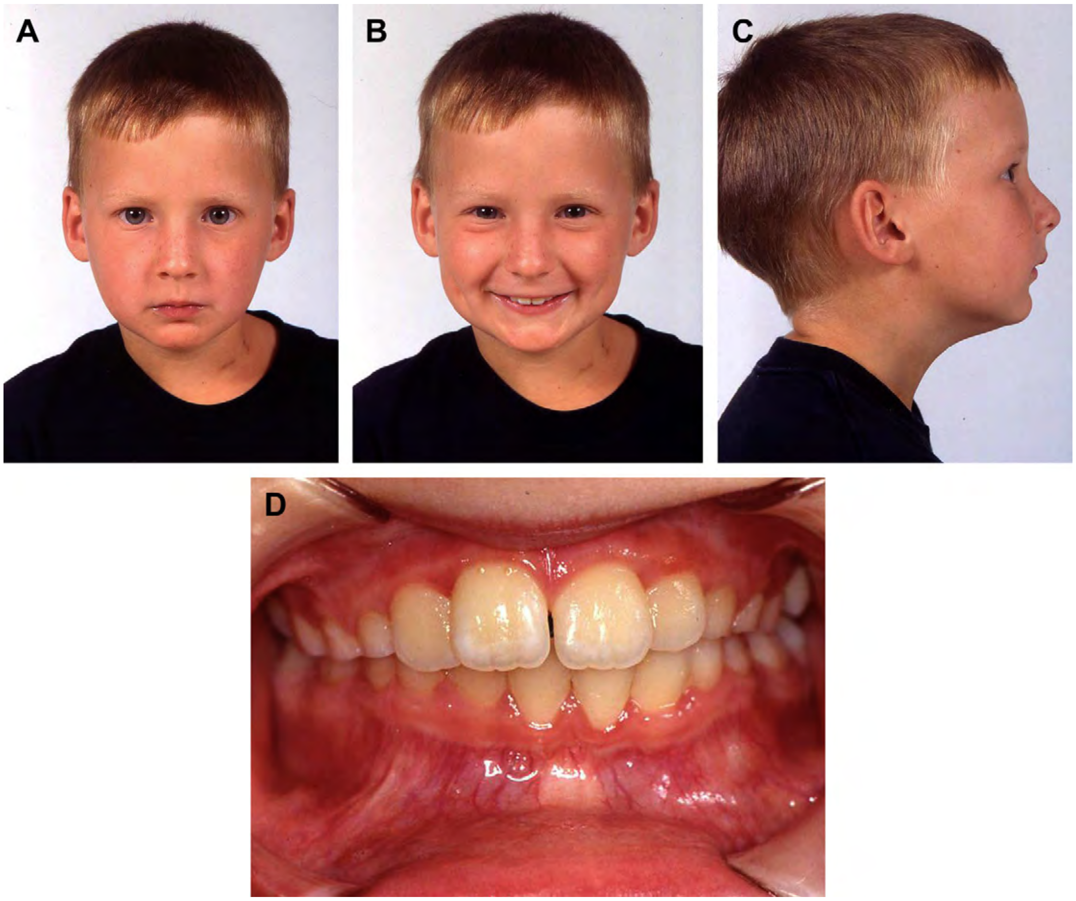
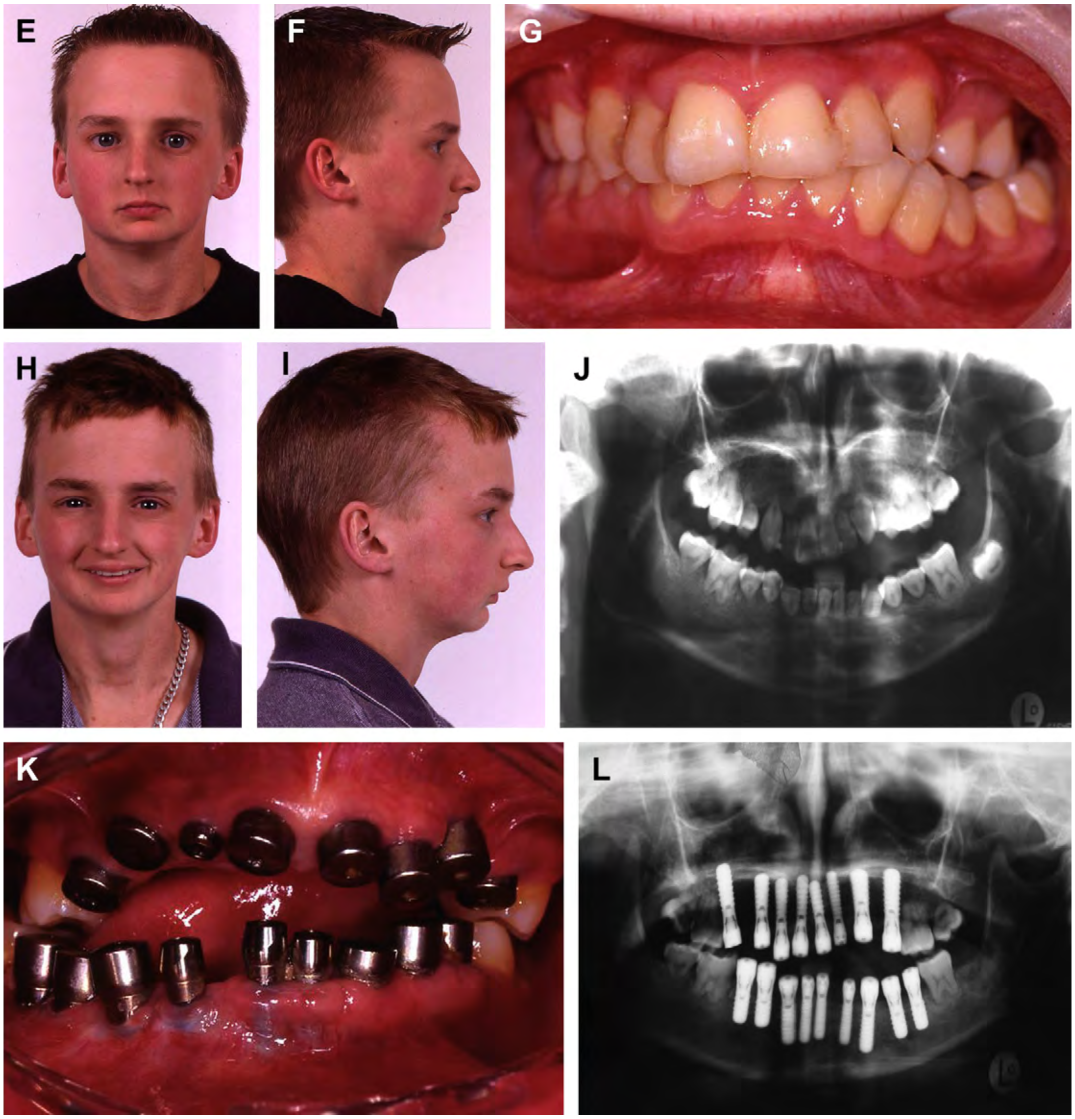


Fig. 8. (*A*) Frontal photograph of an 8-year-old child treated with radiotherapy for a rhabdomyosarcoma of the floor of the mouth at the age of 4 years showing no apparent effects at this age. (*B*) Patient smiling. (*C*) Right profile. (*D*) Frontal view of dentition. (*E*) Frontal photograph of child in Figs. 8A–8C at the age of 14 years. (*F*) Right profile. (*G*) Frontal view of dentition at age 14. (*H*) Patient smiling. (*I*) Right profile at 14 years. (*J*) Panoramic tomograph showing marked global hypodevelopment of the teeth. (*K*) Frontal view of jaws after all of the teeth except the permanent molars were extracted and 16 dental implants placed. In retrospect, implants placed at sites of maxillary lateral incisors and all four mandibular incisors were superfluous. (*L*) Panoramic tomograph following placement of implants. Molars were kept in order to provide bilateral occlusal stops as a means to protect the healing implants from occlusal trauma, and to provide for some chewing function. (*M*) Lateral cephalogram of the patient before orthognathic surgery. (*N*) Maxillary cast with transitional acrylic/cast metal implant-supported bridge. (*O*) Mandibular cast with transitional bridge. Occlusal scheme of tranitional bridges designed to coordinate postsurgically. (*P*) Left lateral view of casts mounted on a semi-adjustable articulator before model surgery. (*Q*) Left lateral view of maxillary cast advanced by 12 mm. (*R*) Frontal view of mounted casts prior to model surgery. (*S*) Frontal view of temporary acrylic/metal implant-supported maxillary and mandibular prostheses inserted into mouth of patient before orthognathic surgery. (*T*) Lateral view of the temporary ported bridges showing the extreme preoperative overjet. (*U*) Exposure for bilateral sagittal split osteotomy to advance the mandible. Note thickness of mandibular ramus despite the apparent hypodevelopment induced by early childhood radiotherapy. (*V*) Anterior view of maxilla down-fractured at the Le Fort I level. (*W*) Mandible advanced 12 mm relative to already advanced and fixated maxilla. Note elimination of severe positive overjet. (*X*) Panoramic tomograph taken post maxillary and mandibular advancement surgery showing the implants and fixation hardware at the osteotomy sites. (*Y*) Lateral cephalogram taken following orthognathic surgery. (*Z*) Anteroposterior cephalogram taken following the maxillary and mandibular advancement surgery. (*AA*) New position of the maxillary and mandibular temporary implant-supported bridges viewed from the anterior labial aspect. Note the elimination of the severe positive overjet and the gains in vertical dimension of the lower face. (*BB*) Frontal view with patient smiling 8 months following orthognathic surgery. Note improved lip and chin positions with increased lower vertical face height. (*CC*) (*1*) Presurgical lateral view of patient showing extreme mandibular retrognathia and lack of maxillary and mandibular vertical development. (*2*) Postsurgical lateral view of patient showing corrected maxillo-mandibular retrognathia and corrected maxillary and mandibular vertical development. (*3*) Five-year postoperative view following maxillo-mandibular advancement.



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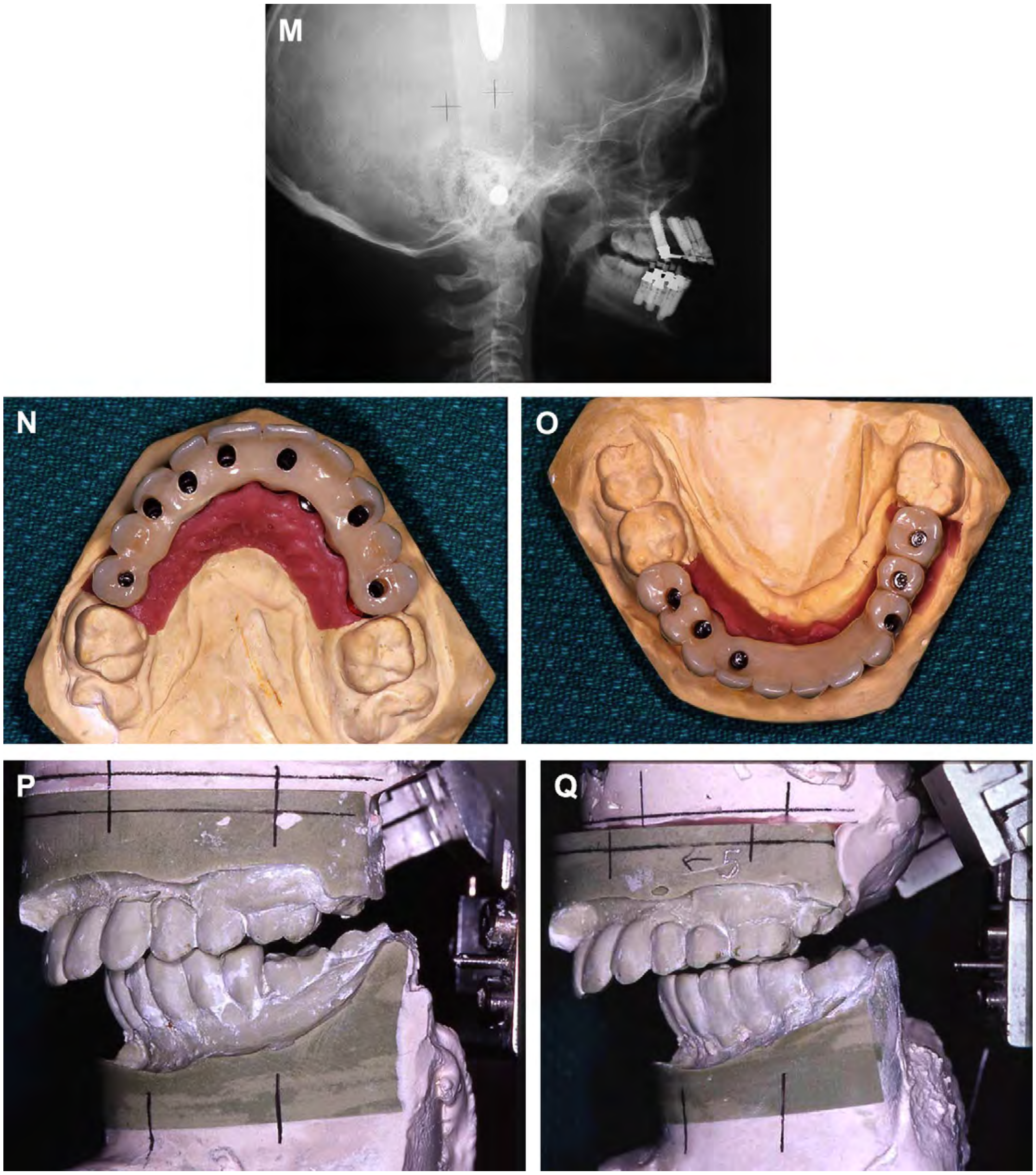

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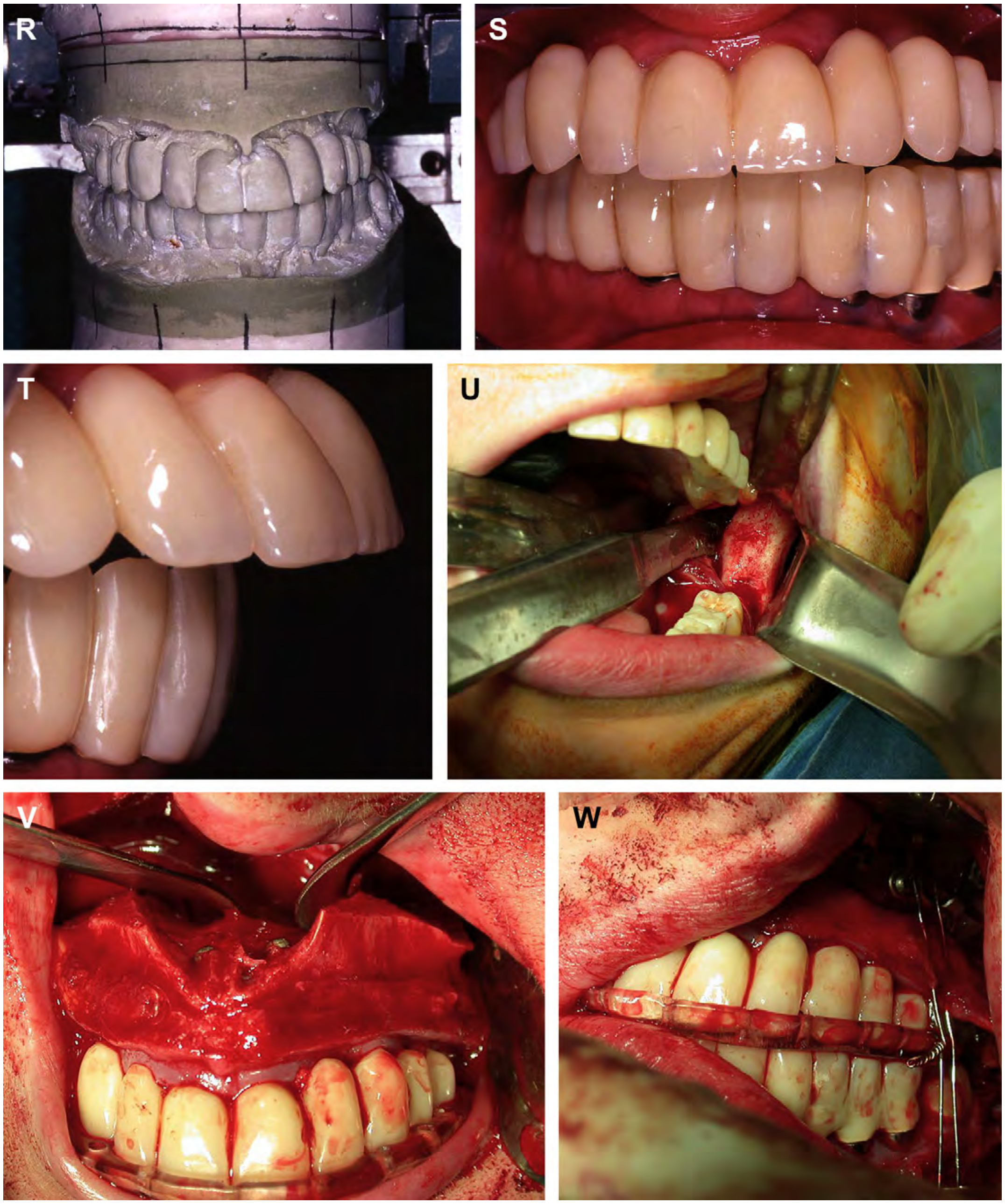

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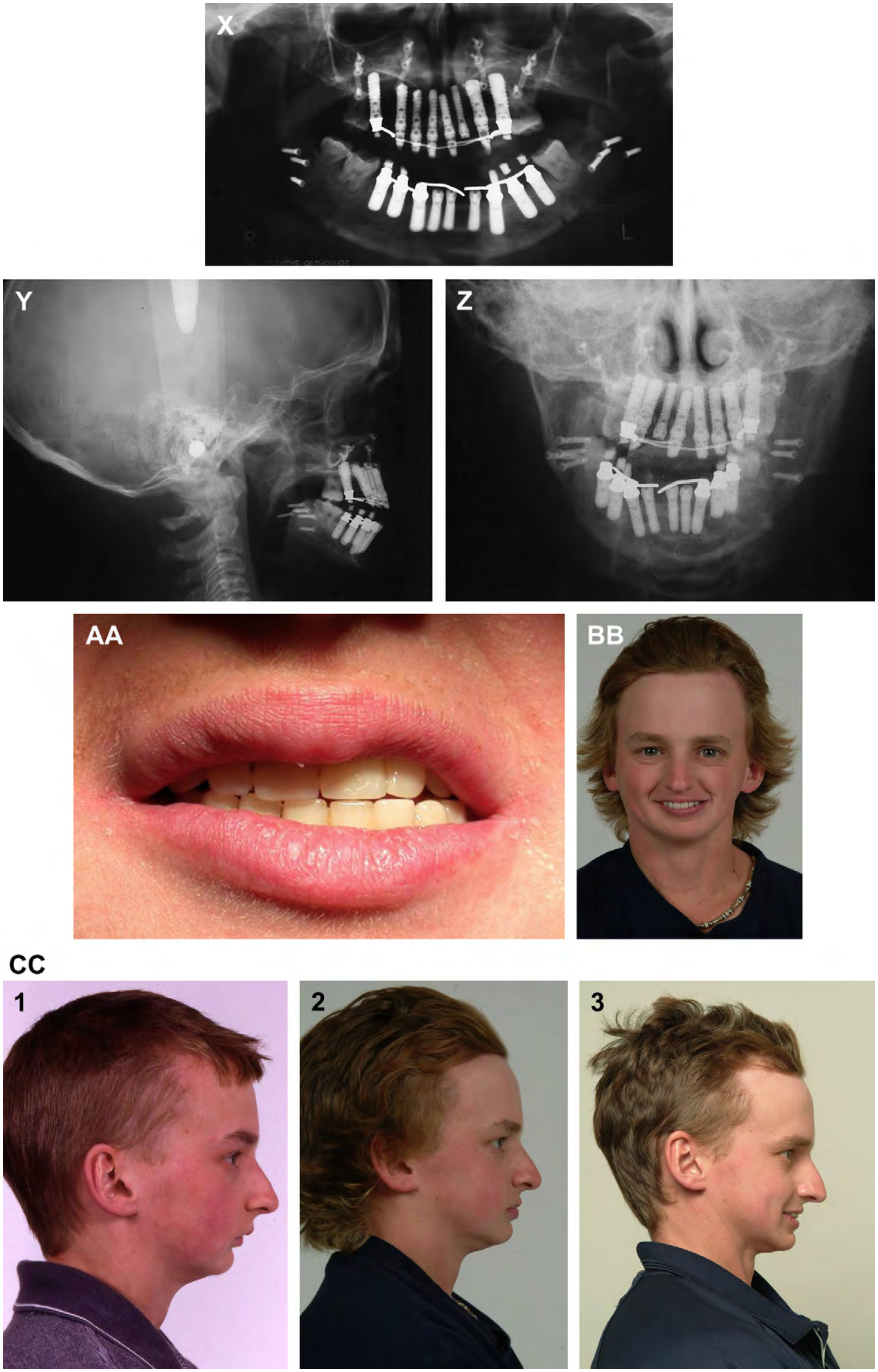

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The facial deformities secondary to radiation therapy administered in early childhood may be characterized by a lack of development of lower vertical face height (see Fig. 8I). There may be tremendous retrognathia in one or both jaws (see Figs. 8C, 8F, and 8I) and degrees of facial bone asymmetry.

Implant survival appears to be within the range of normal in young adults who have been irradiated in early childhood if more than 10 years have elapsed between the radiation treatment and the time of implant surgery. This observation contrasts with the observation that implant survival is poor in patients with a history of radiation therapy delivered during adulthood. Clinicians contemplating provision of implant treatment in irradiated patients must be meticulous about obtaining radiation histories, records of fractionation, and details of masking and portals. The case pictured in Figs. 8A–8CC documents a complex reconstruction in a child irradiated for a rhabdomyosarcoma of the floor of the mouth in early childhood.

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# Facilitation of Orthodontics and Orthognathic Surgery Using Dental Implants

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Conditions requiring orthodontic treatment and replacement of missing teeth in young patients are by their very nature complex. The treatment approach must be multidisciplinary, requiring the close cooperation of a triad of prosthodontist, orthodontist, and oral and maxillofacial surgeon.

The advantage of absolute anchorage provided by an ankylosed dental implant was recognized by orthodontists early in the years following the advent of osseointegration. In more recent years, microimplants have enjoyed a certain level of popularity due to their novelty and ease of placement, however, their acceptance is waning somewhat with the realization by practitioners that they have a high failure rate. Intraosseous screws and bone plates offer the opportunity for secure orthodontic anchorage, although they are obviously more invasive. Dental implants used to obtain orthodontic anchorage have the advantage of being useable as part of the final prosthodontic restoration if the treatment has been properly planned and executed.

Dental implants intended to provide orthodontic anchorage can be placed either in an extra-alveolar location, outside of the tooth-bearing parts of the jaws, or in an intra-alveolar location within. This distinction is an important one as it pertains to growth of the young patient.

Extra-alveolar fixtures can be placed in the palate (Fig. 1), the tuberosities of the maxilla, the zygomatic arches, or the retromolar areas of the mandible (Fig. 2). These fixtures can be placed in growing children because they are temporary and may be removed after the conclusion of the orthodontic treatment. Such implants are particularly useful in patients with oligodontia who have significantly reduced dental anchorage options due to their missing teeth.

Intra-alveolar implant fixtures require careful planning. They are generally placed after skeletal maturity because they would otherwise interfere with alveolar development. Once placed, the position of these implants is final, and the orthodontist and prosthodontist must prescribe their locations with adequate forethought.

The normal treatment sequence in patients requiring multidisciplinary therapy begins with orthodontic idealization of the alignment of the teeth, implant placement, and, finally, prosthodontic treatment. When implants are needed to provide anchorage consideration must be given to the length of time required to achieve osseointegration so as not to interupt timely delivery of orthodontic treatment. The issue of wait time for osseointegration to take place is,

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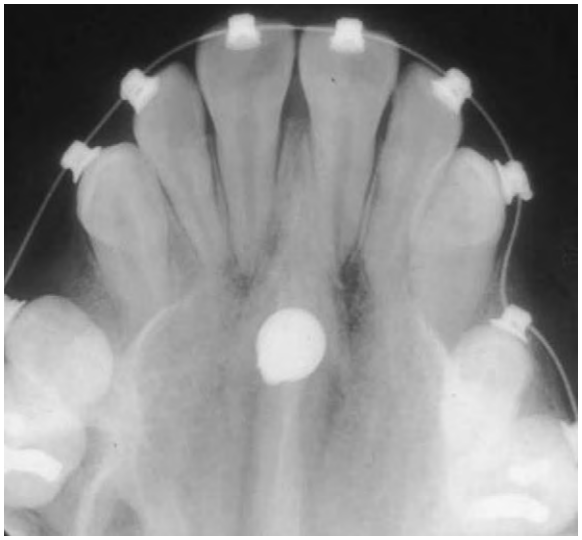

Fig. 1. Midpalatal implant in an extra-alveolar location.

however, becoming less important with the commercial availability of biologically active, more rapidly integrating implant surfaces.

## Midpalatal anchorage

Midpalatal fixtures can provide absolute anchorage, and are particularly useful in patients who have deficient anchorage secondary to oligodontia (Fig. 3), or as a means to facilitate distalization of posterior teeth as an alternative to conventional head gear therapy. These screws can be inserted easily under local anesthesia or with sedation. In growing children whose midpalatal sutures have not yet fused, the midpalatal sutures can be placed in a paramedian rather than a midline position.

The midpalatal implant insertion begins with the removal of a mucosal plug using a punch mounted on a hand piece. The midline nasal crest of the maxilla is then drilled to the precise implant diameter (Fig. 4A). An implant (Fig. 4B) and a separate healing screw are then placed. Once osseointegration is complete, impressions are taken using a transfer coping, and a transpalatal bar is constructed in the laboratory that connects the implant fixture to the palatal surface of the teeth in the anchorage segment (Fig. 4C). Teeth can now be moved sequentially (Fig. 4D & E) or en masse. Once the orthodontic treatment is completed, the midpalatal implant can be removed.

Fig. 2. Implants placed bilaterally in the maxillary tuberosity and retromolar regions are extra-alveolar and can be used as anchorage to mesialize the existing dentition.

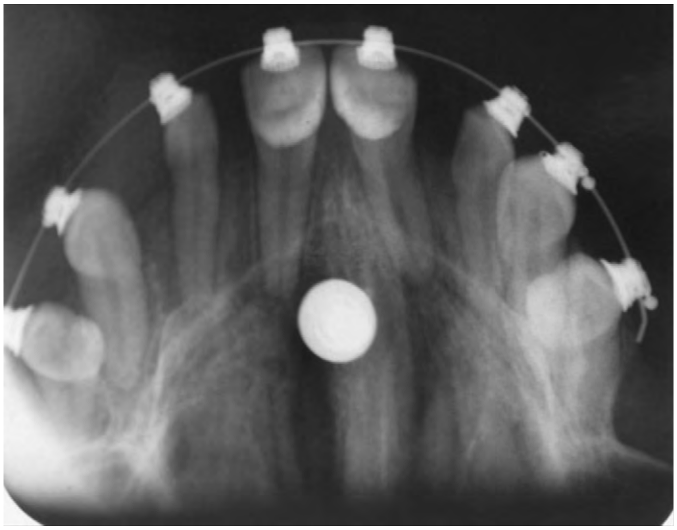

Fig. 3. Midpalatal implants are particularly useful in patients with severe oligodontia who have extremely compromised anchorage.

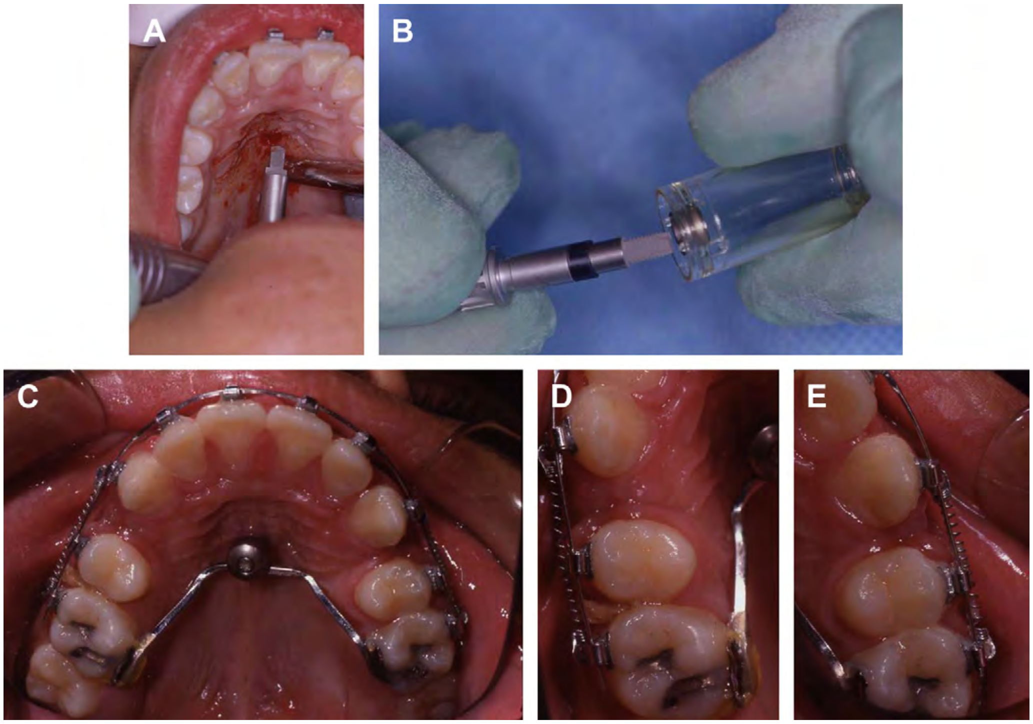

Fig. 4. (*A*) The implant site is prepared with drills. (*B*) The specifically designed midpalatal implant (Straumann AG, Basel, Switzerland). (*C*) The transpalatal bar is inserted and connected to the palatal surfaces of the two first permanent molars. (*D,E*) Progressive distalization of the molars and then the bicuspids in sequence.

## Retromolar and tuberosity sites

Implants can be placed in the maxillary tuberosity or mandibular retromolar regions to obtain additional anchorage to help mesialize teeth or upright tipped mandibular molars. Once again, this technique may be particularly helpful in patients with oligodontia who have reduced

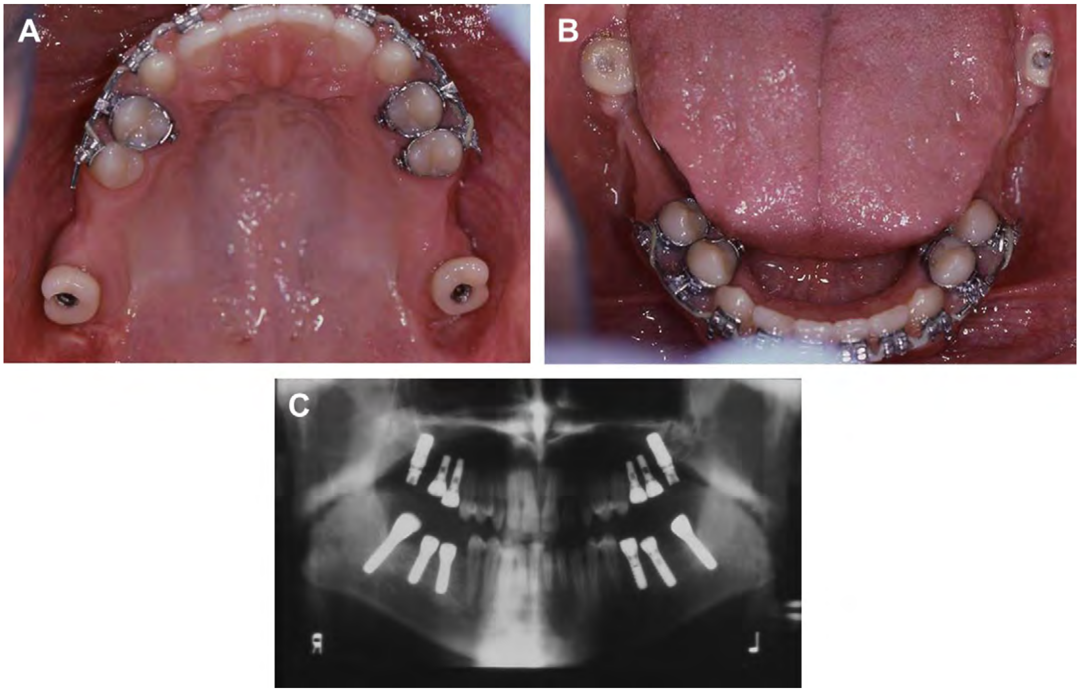

Fig. 5. (*A*) Implants placed in the maxillary tuberosity in an extra-alveolar location. (*B*) Implants placed in the mandible in the retromolar region are also in an extra-alveolar location. The implants have been restored with temporary acrylic crowns which can facilitate the attachment of brackets and open the bite to disengage the anterior dentition thus facilitating orthodontic tooth movement. Using the implant supported crowns to prosthetically open the bite permits eruption of the natural dentition to effect a definitive increase in vertical dimension of occlusion. (*C*) Once the teeth are properly aligned, the remaining implants are placed more mesially. The tuberosity and retromolar implants may now be removed or restored depending on the requirements of the case.

anchorage. Placement of implants in these locations can be difficult: bone in the tuberosity may not be dense; and in the retromolar areas the rami may flare laterally dictating placement of the implant in a more buccal position than planned. Once healed, the implants can be temporarily restored with provisional crowns to facilitate bracket attachment and to open the bite if necessary (Figs. 5A–5B). Use of implant supported crowns in the posterior regions of the jaws to open the bite permits forced orthodontic eruption of the anterior dentition in order to achieve a definitive increase in the vertical dimension of occlusion. This increase can be particularly helpful in oligodontia where the vertical dimension of occlusion may be deficient to begin with. Once the planned tooth positions have been achieved (Fig. 2), the remaining posterior dentition can be restored with dental implants\placed in ideal positions in the tooth-bearing portions of the alveolar processes (Fig. 5C).

## Intra-alveolar implants for tooth movement

Implants placed into tooth-bearing portions of the dental arches can be used to support prosthetic reconstructions subsequent to their use as orthodontic anchors (Figs. 6A–6J). Abutments may be roughened with a diamond drill (Fig. 6C) and etched to allow the attachment of an orthodontic bracket (Fig. 6D). Some manufacturers make special abutments to which the orthodontist can bond directly. This approach facilitates orthodontic movement of the teeth (Fig. 6E). Once the planned alignment of the teeth is achieved (Fig. 6F), the implant is restored (Figs. 6G–6J), thus the anchorage implant becomes the restored prosthesis-bearing fixture.

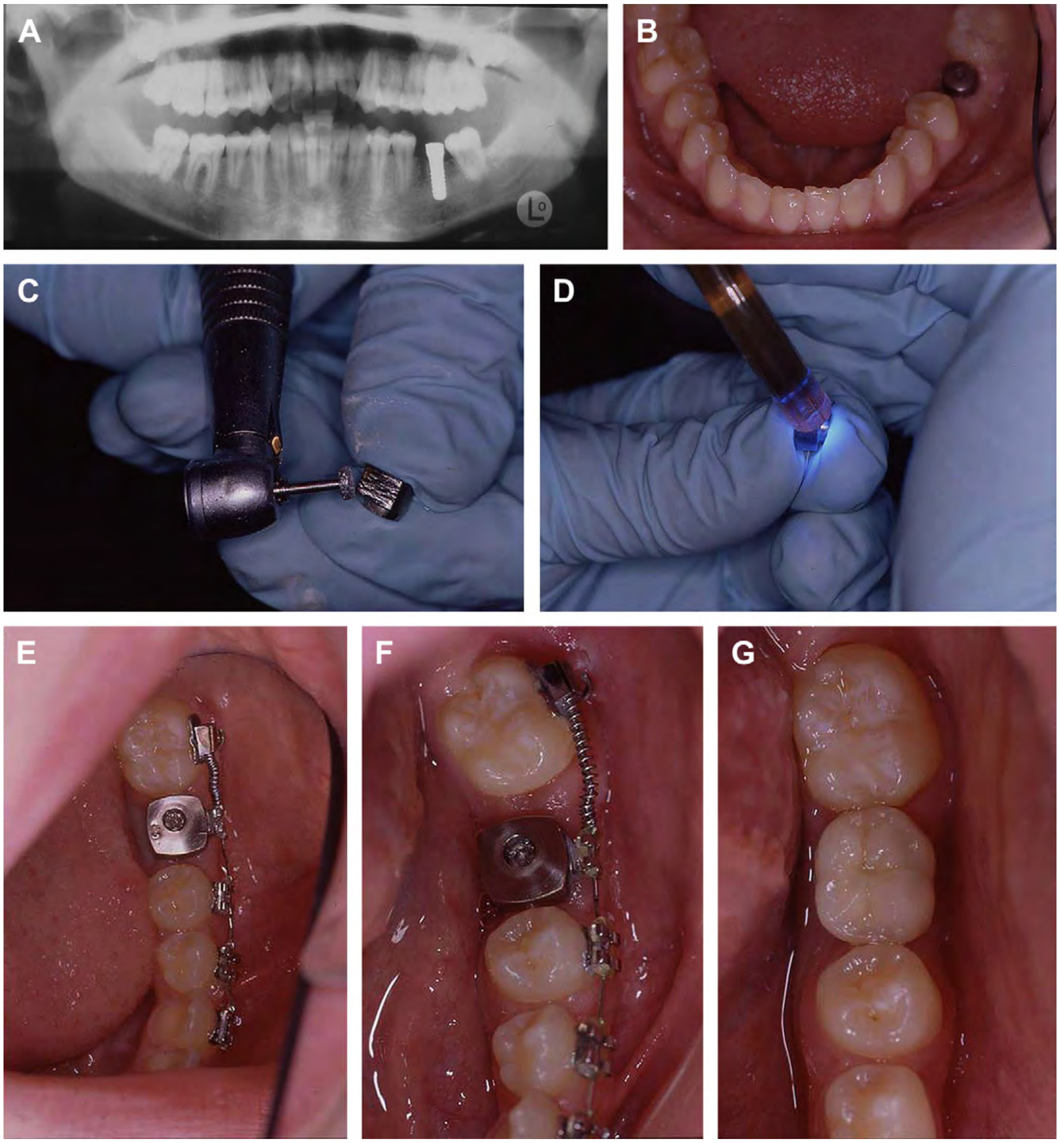

Fig. 6. (*A*) An implant has been placed to replace the left permanent first molar mesial to a mesially inclined second molar. (*B*) The clinical appearance of the position of the implant at the permanent first molar site. This implant will be used for anchorage but because it will be used following orthodontic treatment to support the final crown, it must be positioned in such a way as to facilitate crown fabrication. (*C*) The implant abutment is roughened with a diamond bur. (*D*) The bracket is bonded to the abutment. (*E*) The abutment is installed on the tooth and the orthodontic hardware attached. (*F*) The second molar has been successfully distalized. (*G*) Occlusal view of the restored first permanent molar crown. (*H*) Buccal view of the restored mandibular first permanent molar implant site. (*I*) Panoramic tomograph showing the restored implant and correctly positioned second permanent molar. (*J*) Occlusal radiograph showing excellent positioning of the restored tooth and the orthodontically repositioned second molar tooth.

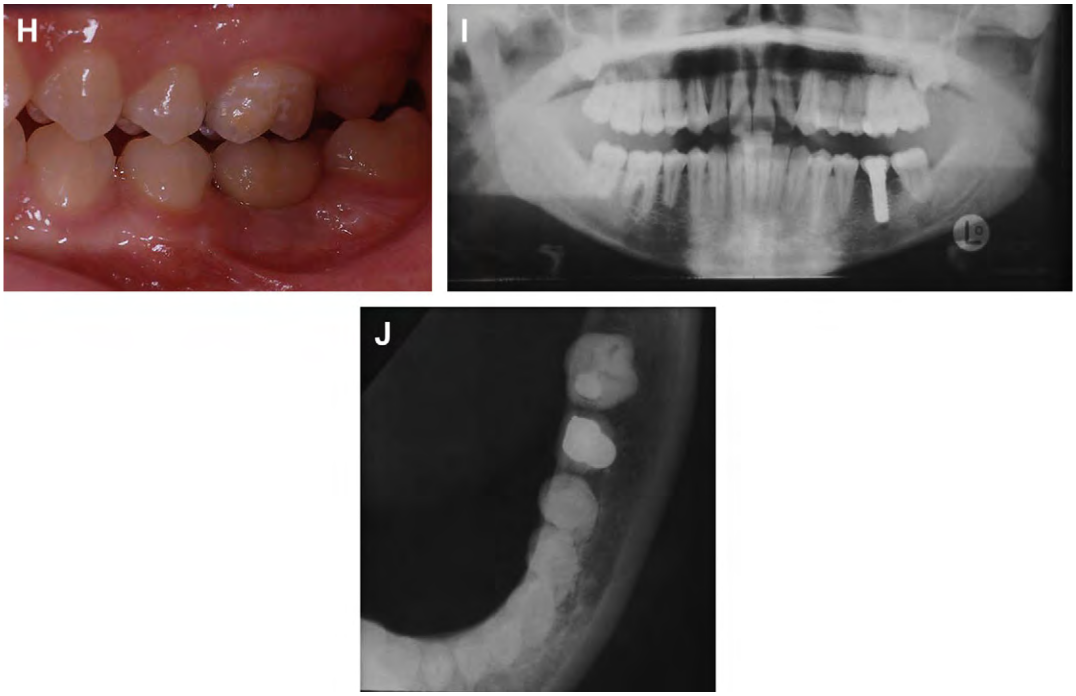

Fig. 6 (*continued*)

## Implants to facilitate orthognathic surgery

In partially edentulous patients requiring orthognathic surgery, it is generally recommended to place dental implants as the final step in the reconstruction process following repositioning of the jaw(s). However, some patients require additional occlusal stops to stabilize the repositioned osteotomy segments. In these cases, implants may be placed and temporarily restored before orthognathic surgery is performed (Figs. 7A–7L). Definitive restoration of the implants is carried out subsequent to healing and remodelling of the osteotomy sites.

In patients who have maxillomandibular disharmony requiring orthognathic surgery, and who have extremely severe oligodontia (Figs. 8A–8E) implant supported bridges can be designed and constructed to anticipate the final jaw relationship, used to guide the model surgery (Figs. 8F, 8G, and 8H), inserted in the patient's mouth right before surgery (Fig. 8I), and used to guide the surgery and fixate the jaws (Figs. 8J–8M). In essence, temporary implant supported

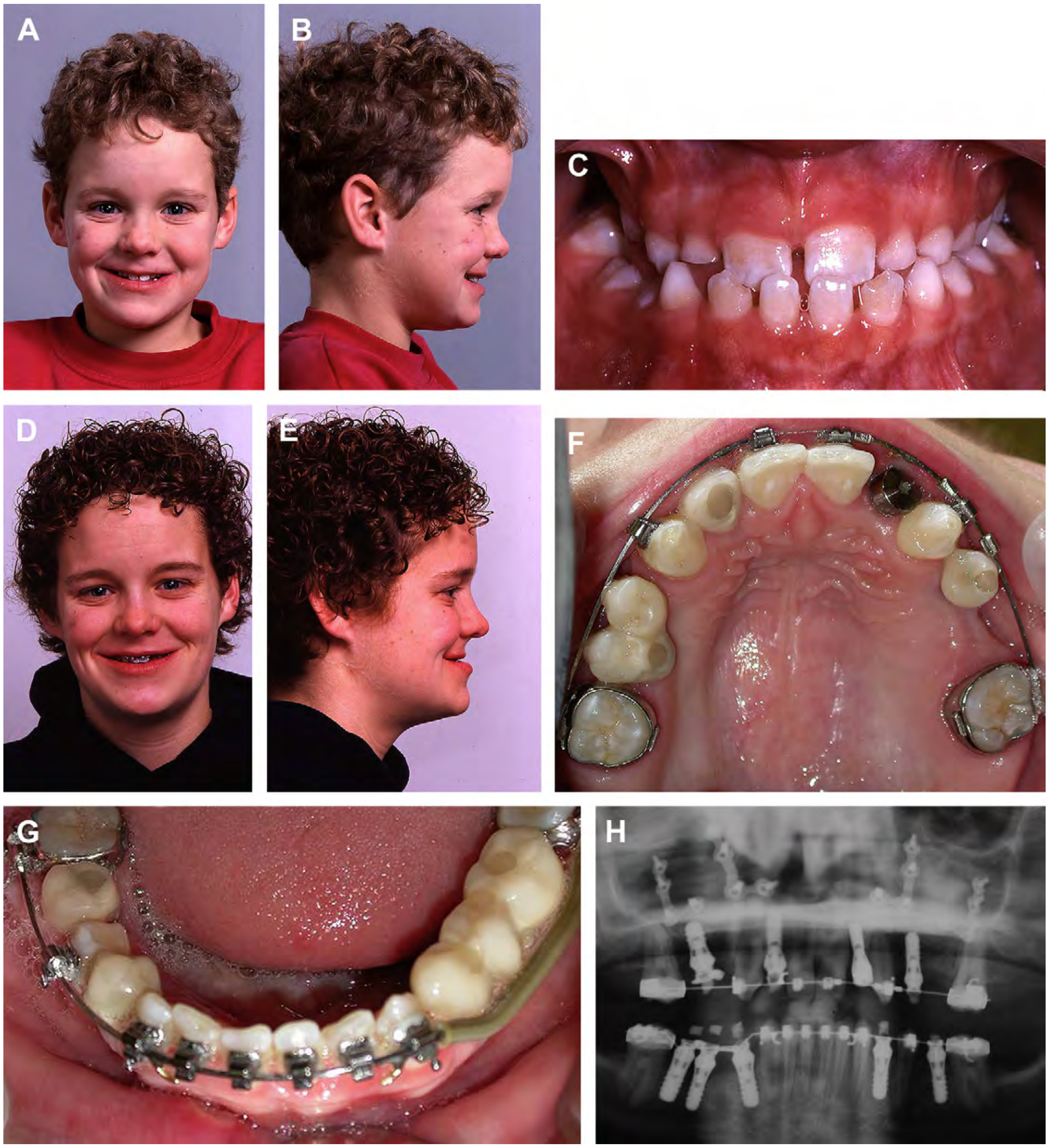

Fig. 7. (*A,B*) Frontal and profile views of 12-year-old patient with oligodontia and prognathic tendency of the mandible. (*C*) Class III malocclusion with negative overjet and transverse discrepancy of maxilla. (*D,E*) Frontal and profile views of patient at 19 years of age. (*F*) Maxillary arch partially restored with temporary acrylic implant-supported crowns on dental implants to aid in orthognathic surgery. (*G*) Mandibular arch with temporary acrylic implant-supported crowns to provide additional occlusal stops to aid with orthognathic surgical repositioning and fixation of jaws. (*H*) Panoramic tomograph demonstrates temporarily restored dental implants provided to facilitate orthognathic surgery. (*I,J*) Postoperative photographs following maxillary Le Fort I advancement to correct class III occlusal relationship. (*K*) Occlusion following jaw surgery and prior to commencement of post surgical orthodontics. Note the corrected ovejet and posterior open bites requiring vertical elastic traction to erupt the natural posterior molars. (*L*) Postoperative lateral cephalogram. (*M*) Smiling full-face debonding photograph. (*N*) Right profile photograph. (*O*) Close-up smile photograph. (*P*) Anterior view of teeth in occlusion, including nine restored dental implants. (*Q*) Occlusal view of maxillary reconstruction. (*R*) Occlusal view of mandibular reconstruction.

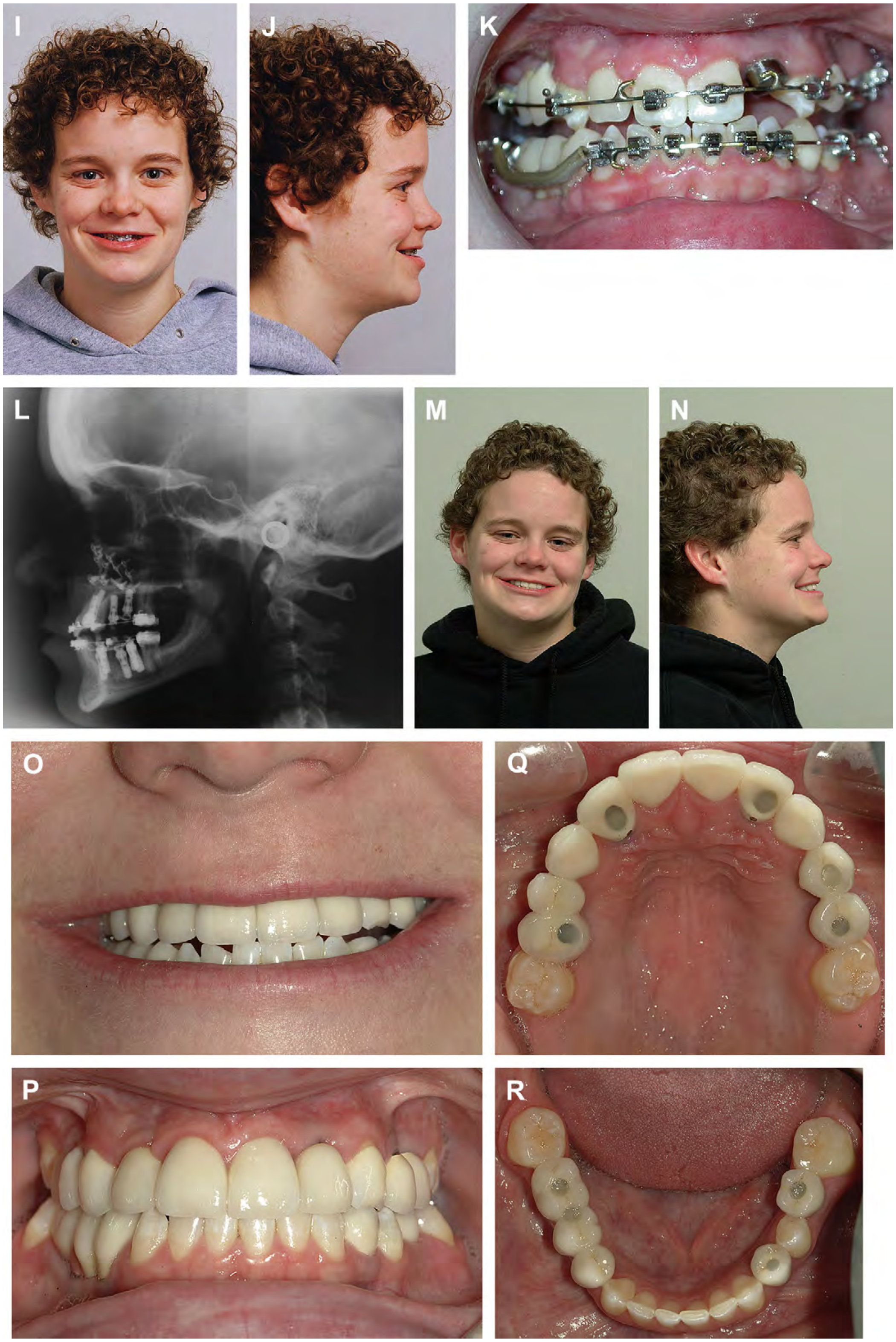

Fig. 7 (*continued*)

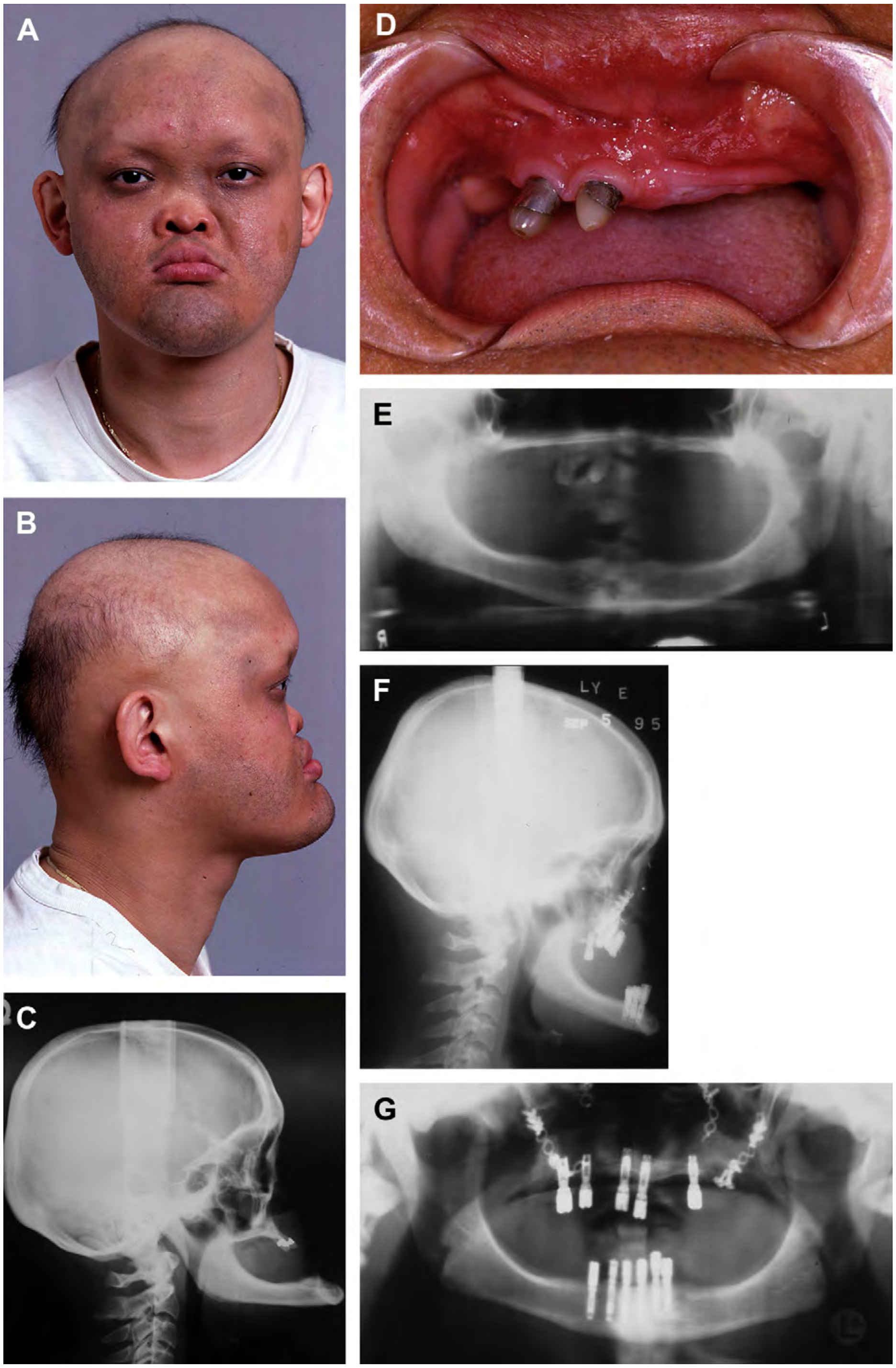

Fig. 8. (*A*) Anterior view of patient with ectodermal dysplasia, severe mandibular prognathism, and subtotal anodontia. (*B*) Right profile view. (*C*) Patient with hypohidrotic ectodermal dysplasia, severe oligodontia, and severely prognathic mandible. (*D*) Frontal view of dentition. (*E*) Presurgical panoramic tomogram. (*F*) Lateral cephalogram after implant placement and before orthognathic surgery. (*G*) Panoramic tomogram showing implant locations prior to orthognathic surgery. (*H*) Model surgery predicting the mandibular set-back is facilitated by presurgical fabrication of implant-supported prostheses. The occlusal surfaces of the prostheses guide intraoperative placement of the mandible into the correct final occlusion. The prostheses also facilitate intermaxillary fixation. The operative plan called for a mandibular set-back of 30 mm. The patient had a Le Fort 1 advancement performed previously at another center. (*I*) The temporary implant-supported maxillary and mandibular prostheses are inserted preoperatively. The occlusion of the prostheses has been designed to accommodate the set back mandible. (*J*) Postoperative panoramic tomogram. (*K*) Postoperative lateral cephalogram following a 3-cm posterior repositioning of the mandible. (*L*) Postoperative frontal photograph. (*M*) Post-operative right profile photograph.

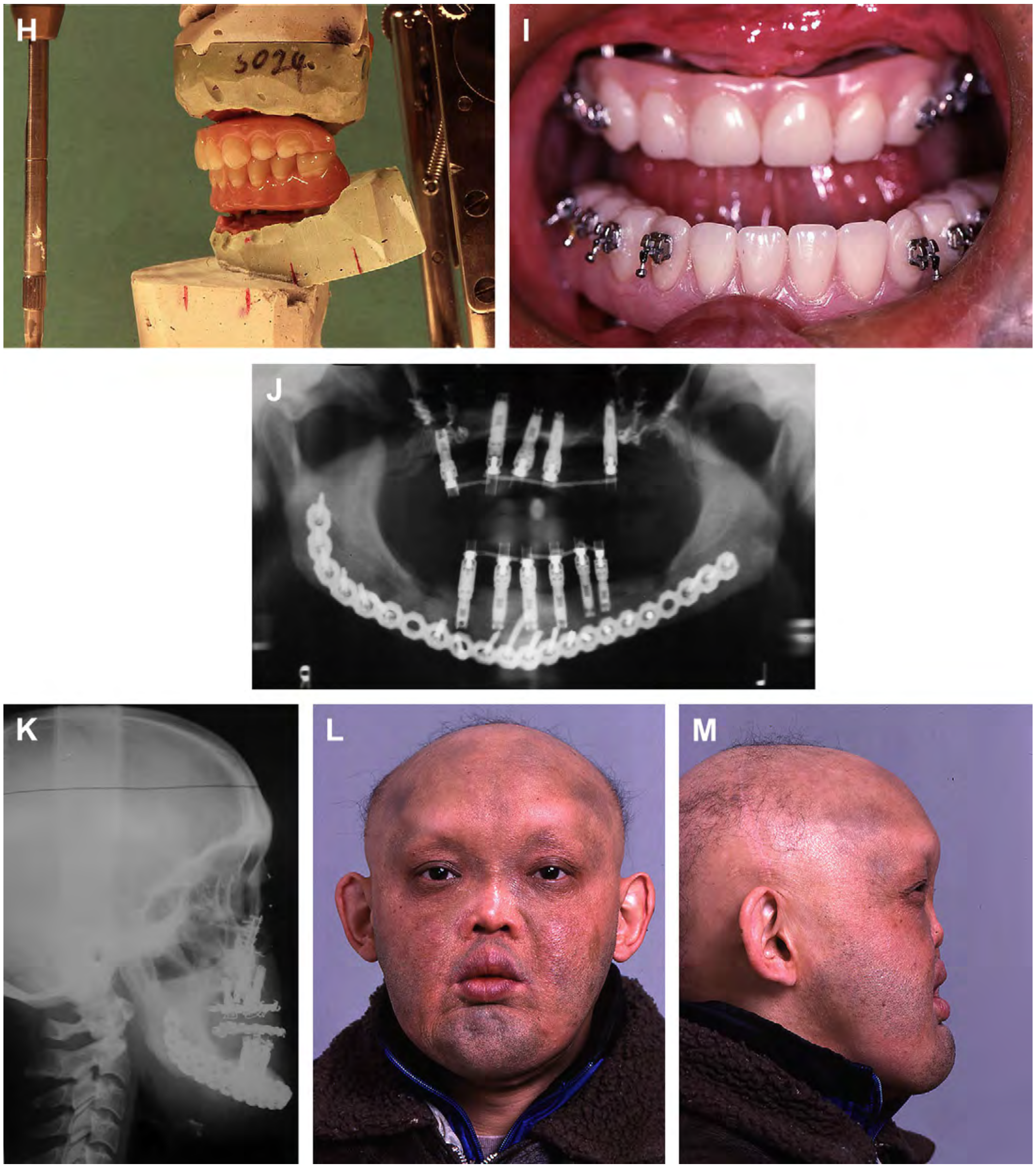

Fig. 8 (*continued*)

bridges designed to occlude postoperatively, are made to act as their own surgical splints and used to guide the surgeon in positioning the jaws and aid in stabilizing the postoperative result.

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# Distraction Osteogenesis Using Dental Implants

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Congenital absence of teeth, such as in oligodontia and alveolar clefting, is usually accompanied by bony defects of the maxillary alveolus. Acquired bony defects of the maxillary alveolus result following tooth extraction, periodontal disease, maxillofacial trauma, and tumor ablation. The configuration of alveolar defects can be primarily horizontal or vertical in nature, or a combination of each, and can limit the restoration of missing natural teeth with dental implants.

The treatment of alveolar defects includes guided bone regeneration using a variety of membranes, onlay grafting of autogenous bone, connective tissue grafting, and alloplastic augmentation. Vertical alveolar defects are difficult to overcome in a predictable manner using autogenous bone grafts and often lead to esthetic shortcomings. Distraction osteogenesis of the maxillary alveolus permits correction of alveolar defects, often without the use of a bone graft.

Alveolar distraction osteogenesis (ADO) may offer several advantages over bone grafting alone in the treatment of vertical alveolar defects. No donor site is required; distraction of bone and surrounding soft tissue occurs simultaneously; and the transport segment is a form of pedicled graft that is never separated from its blood supply, maximizing vitality and minimizing resorption. ADO has the potential for better control of vertical height, esthetics, and biomechanical loading.

The following alveolar defect classification has been proposed by Jensen et al:

**Class I:** A vertical defect exists that is up to 5 mm in which there is sufficient bone to distract without bone grafting.

**Class II:** Alveolar defects are present with up to 10 mm of vertical loss in which there is usually significant horizontal loss. Such defects require bone grafting for width before or after distraction.

**Class III:** The defects have more than 10 mm of vertical loss and significant horizontal loss. Bone graft reconstruction of the basal bone is required before a delayed distraction procedure can be performed.

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Alveolar distraction devices have three basic components: an upper member, a distraction rod, and a lower member/base plate supporting the vertical force of distraction. These devices can be classified as intraosseous or extraosseous; uni-, bi- or multidirectional; nonresorbable or resorbable (not requiring a second surgery to remove distracter components); and prosthetic (can remain in place to be used to support the dental prosthesis) or nonprosthetic (must be removed following distraction and replaced with a dental implant).

ADO is indicated for the treatment of defects where the alveolar processes are atrophic and deficient. ADO can also be used to correct vertical defects caused by ankylosis and submergence of primary teeth retained in the absence of succedaneous teeth (Fig. 1). ADO is contraindicated in severe atrophy where there is insufficient bone to allow safe hardware placement between tooth roots and the floor of the nose, the maxillary sinus, or the inferior alveolar nerve. It may also be contraindicated in cases of severe osteoporosis where bone quality is poor, or in patients who are unlikely to demonstrate compliance with the rigors of the distraction process. This latter requirement in an adolescent patient may be the most important. ADO is a labor intensive technique with a significant transitional morbidity. Bone grafts may greatly simplify treatment and should always be considered as an alternative in young patients.

The first step in ADO is to plan the vector of distraction. A distractor is chosen that is capable of delivering a force in the direction of the chosen vector. If teeth are available to anchor a distraction device, an external tooth-borne device can be chosen (Fig. 2A, B); otherwise, an internal bone-borne device must be selected. The effect of the rigid palatal tissues and the lingual tissues on the vector of distraction should be kept in mind when distracting the maxilla or mandible. Palatal tissues tend to exert pull on the distracting segment, causing it to tilt lingually away from the desired vector.

An incision is made in the vestibule or at the crest of the alveolar process, and a mucoperiosteal flap is elevated. Vertical and horizontal osteotomies are performed through the labial or buccal cortical bone of the alveolus using a saw or a fine fissure bur (Fig. 3A). The device is then attached to the teeth flanking the partially osteotomized segment (Fig. 3B). The osteotomies are then completed by extending the cuts through the palatal cortical bone using osteotomes, and the segment is mobilized (Fig. 4A, B) to ensure that there are no bony or dental interferences to unrestricted transport along the selected vector of distraction. The wound is then closed.

After a 5- to 7-day latency period, the segment is distracted once or twice daily at a rate of 0.5 to 1.0 mm per day (Fig. 5A, B) until the desired bony position is attained. Overdistraction of the segment by 1 to 2 mm may minimize relapse. A consolidation phase of 6 to 12 weeks with the distractor in place allows undisturbed healing of the distracted bone. If teeth are present in a configuration which, when united by fixed orthodontic appliances, can facilitate stabilization

Fig. 1. Ankylosed deciduous teeth are useful anchorage units for the attachment of tooth-borne distraction osteogenesis devices. Note the submergence of the deciduous lateral incisors and deciduous canine teeth. The growth of the alveolar bone has been retarded locally by the ankylosed teeth, leading to a vertical discrepancy in the alveolus requiring vertical distraction osteogenesis before dental implant restoration.

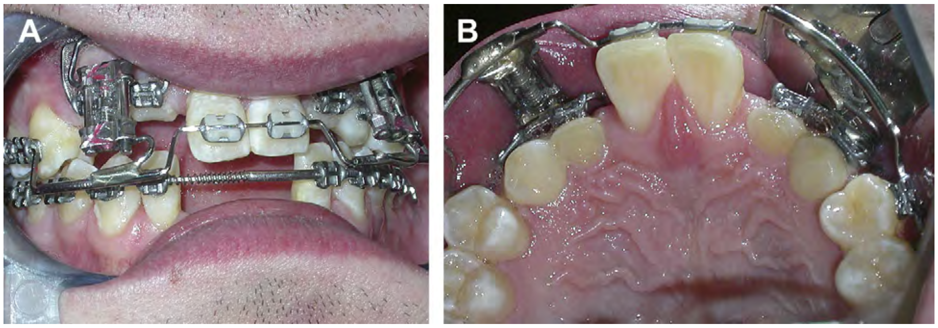

Fig. 2. (*A*) Anterior view of tooth-borne distraction apparatus to distract two maxillary alveolar segments simultaneously. (*B*) Occlusal view of tooth-borne maxillary alveolar distractor.

of the segment, the distractor can be removed. Fixed orthodontic appliances should be worn for the duration of the consolidation phase (Fig. 5C). At some point following the consolidation phase, all metal distractors must be removed unless they are resorbable. If ankylosed teeth were used for anchorage of the distraction segment, they are extracted following the removal of the distraction hardware (Fig. 5D). Dental implants can then be placed into the distracted alveolar segment and restored in their new ideal position (Fig. 6A–H).

Large alveolar cleft palatal defects can be reduced in size using distraction osteogenesis to transport bone segments across the cleft (Fig. 7A–J). Such a decrease in the size of the cleft and associated oronasal fistula may enhance the outcome and predictability of bone grafting techniques.

## The distracting dental implant

There are clear advantages to having a device that can be used to correct a vertical bony defect by distraction osteogenesis and that can also serve as the anchor for a prosthesis following the completion of distraction. Such an intraosseous, prosthetic distraction device with completely internalized components is in a preclinical stage of development (Fig. 8). The distracting implant comprising a fixture connected to a footing by means of a retaining screw is

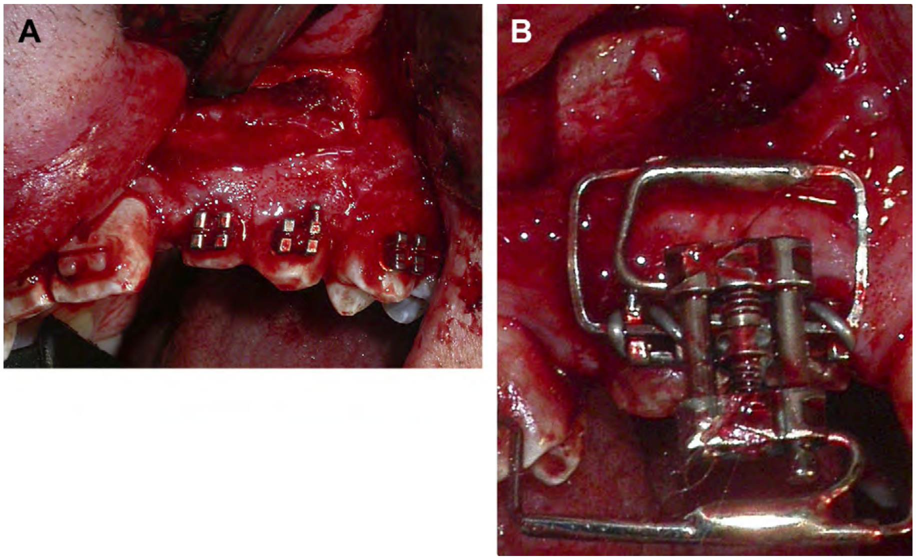

Fig. 3. (*A*) The corticotomy is completed at both sites through the labial cortex of the maxilla with the distractor removed. (*B*) The tooth-borne distractor is reapplied to the teeth, and the palatal bony cuts are completed by osteotomes inserted from the labial side.

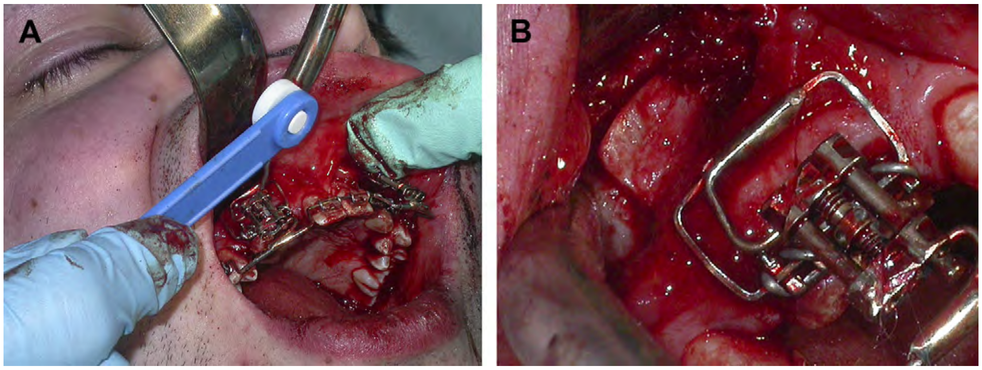

Fig. 4. (*A*) The jackscrew is activated to test the mobility of the segment and to ensure that the segment moves freely without obstructions in its pathway. (*B*) Anterior view of the right anterior maxillary segment partially distracted.

placed within the bone. When the assembly is completely installed, the proximal surface of the footing bears against the bottom of the osteotomy. Following the completion of the distraction process (Fig. 9), the distracting dental implant is used to support a dental prosthesis.

## Description of the alveolar distraction process using dental implants

The first step in ADO using a dental implant is assessment of the nature of the bony defect. The distracting dental implant should be used only in class I alveolar defects, that is, in a vertical

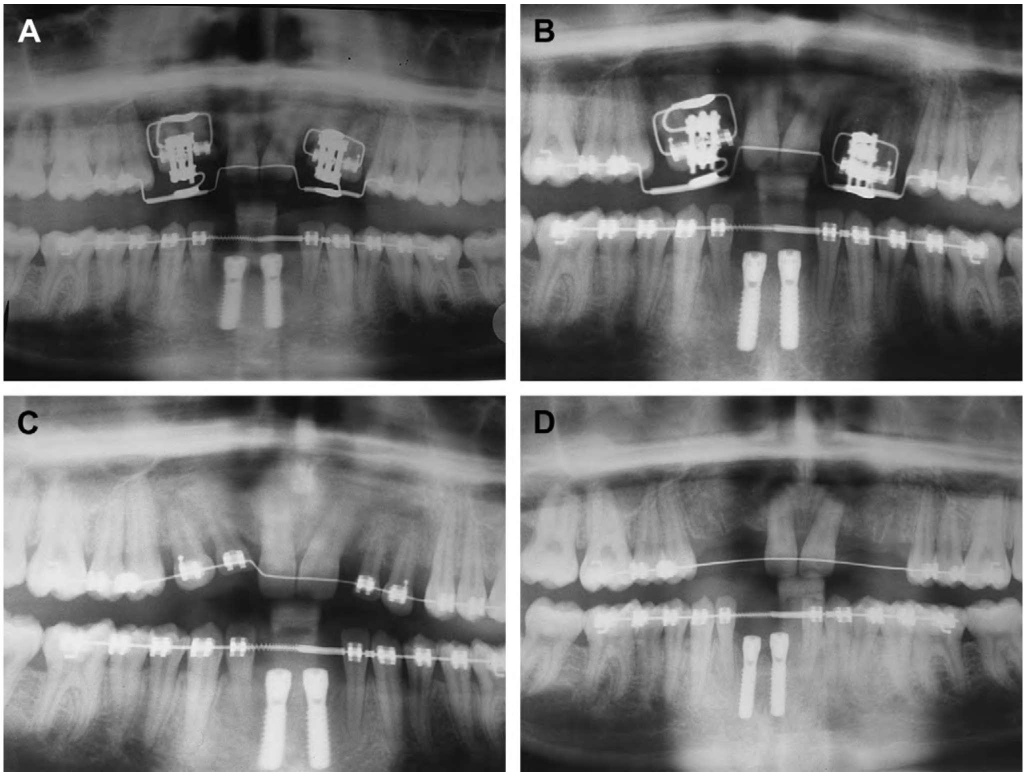

Fig. 5. (*A*) Postoperative panoramic radiograph taken immediately following surgery. (*B*) Panoramic radiograph showing that the fragments are fully distracted, except the segment on the right, which has failed to advance totally because the vector of distraction was aimed too mesially, resulting in binding of the segment and failure to fully distract. (*C*) Panoramic radiograph with distraction device removed showing an orthodontic arch wire securing the segments during the consolidation phase. (*D*) Panoramic radiograph with the deciduous teeth removed at the end of the consolidation phase in preparation for dental implant placement.

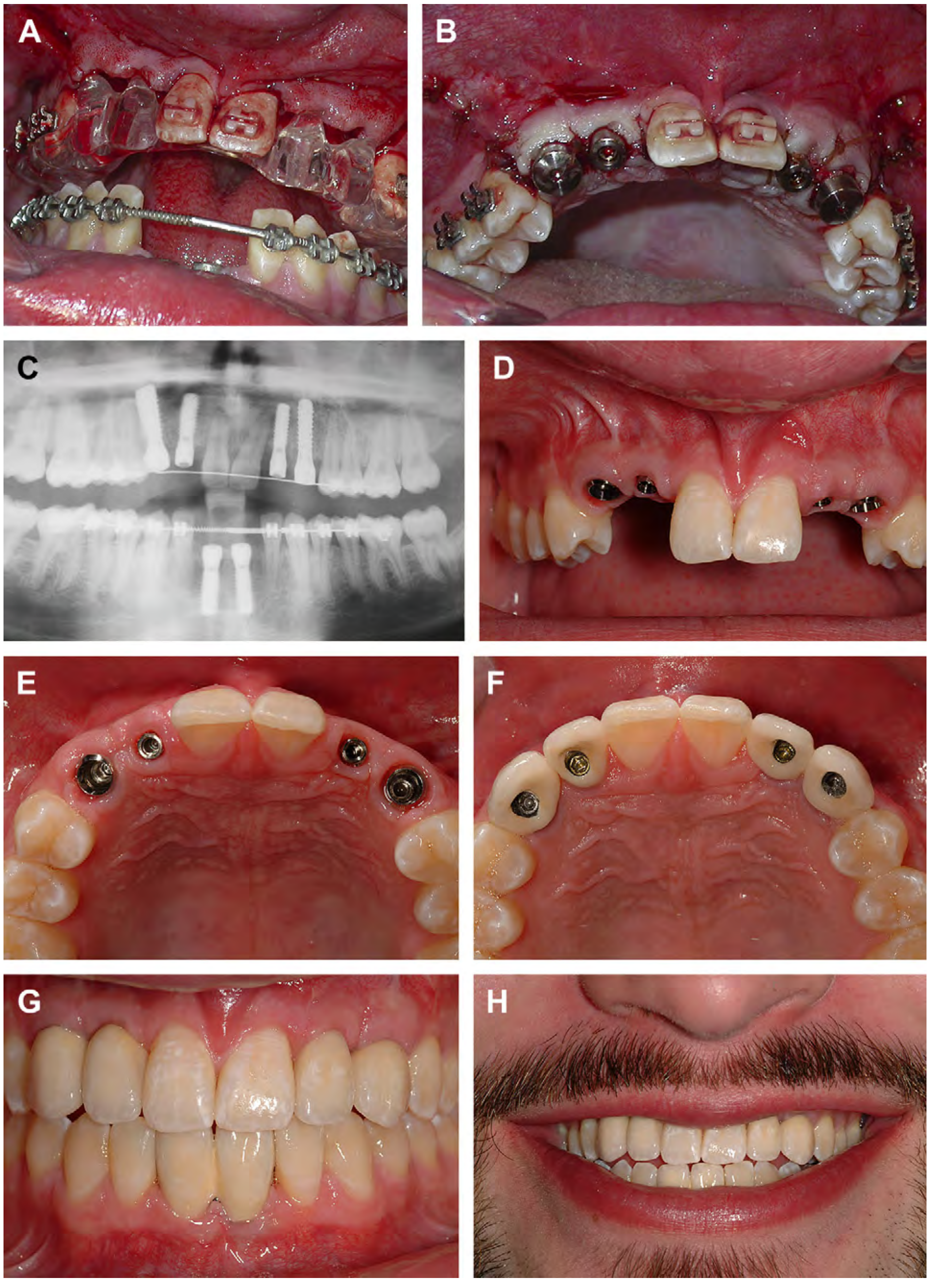

Fig. 6. (*A*) Intraoperative photograph of splint to guide precise implant placement in an esthetically sensitive zone. (*B*) Photograph showing implant placement at the correct vertical position following tooth-borne alveolar distraction osteogenesis. (*C*) Panoramic radiograph following implant fixture placement. (*D*) Photograph of labial view of implant fixtures with correct vertical height. (*E*) Photograph of palatal view of implant fixtures at correct labiolingual location. (*F*) Photograph of palatal view of restored implant fixtures. (*G*) Photograph of labial view of final implant-retained crowns. (*H*) Photograph of patient's smile with final implant-supported crowns.

defect of up to 5 mm in which there is sufficient bone to distract without bone grafting. Class II alveolar defects with up to 10 mm of vertical loss in which there is significant horizontal loss may require bone grafting for width followed by healing before distraction. The distracting dental implant should not be used in the treatment of class III alveolar defects. In addition, the proximity to the maxillary sinus, nasal floor, and the inferior alveolar nerve must be borne in mind during planning.

The distracting dental implant is meant to be used in a two-stage surgical procedure wherein the implant is placed in a first surgery and permitted to heal for some months before the

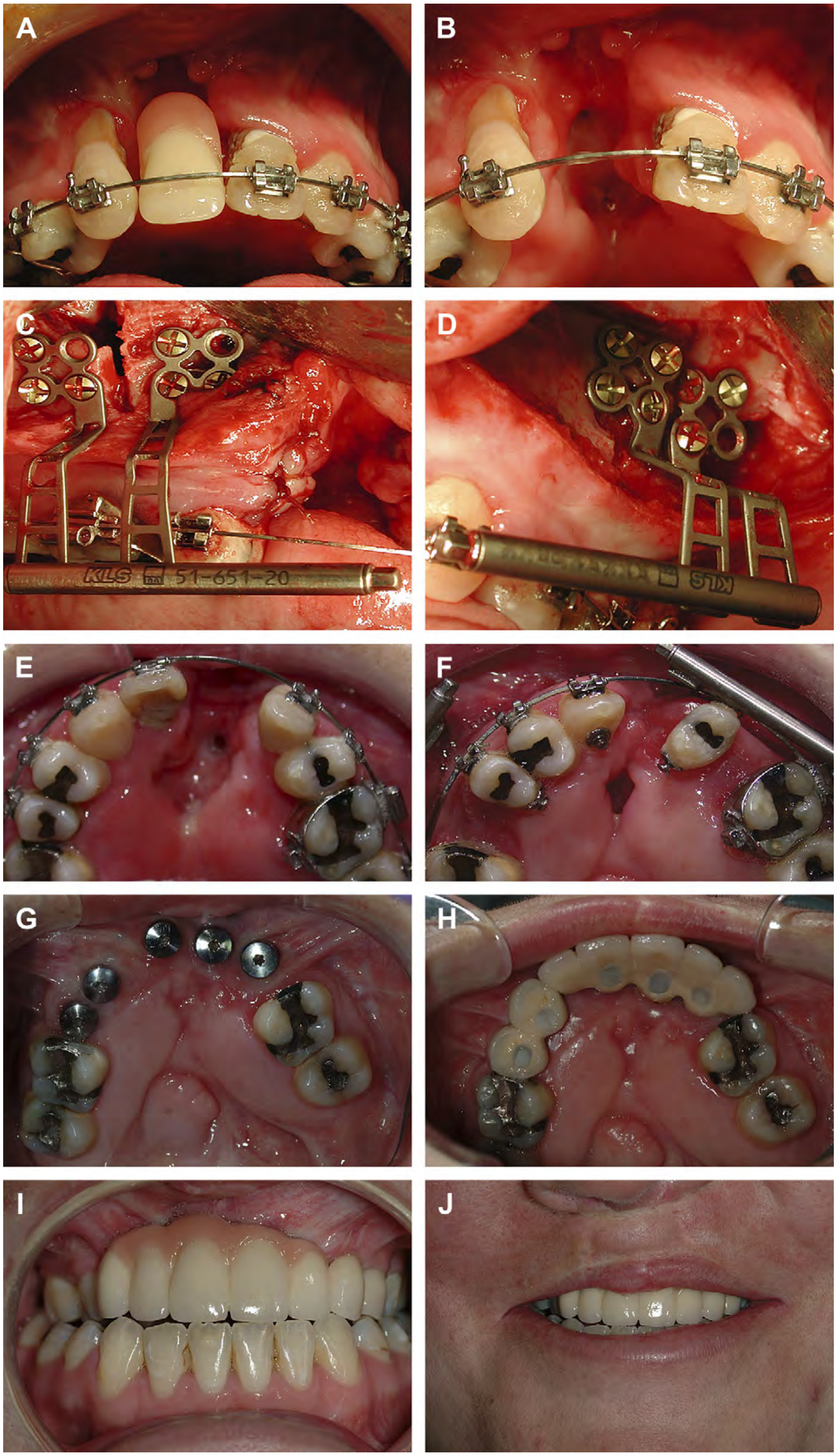
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Fig. 8. The parts of the distracting dental implant including the fixture body, distractor rod, and foot plate represented by the clear plastic disk next to the implant.

distraction procedure commences in a second surgery. With the advent of newer titanium surface geometries and the concomitant use of growth factors leading to more rapidly developing osseointegration, it may be advantageous to combine implant placement and the distraction procedure in a single surgical procedure or into tissue engineered bone.

When sufficient osseointegration of the fixture and the footing has occurred, the distraction osteogenesis process may commence. To carry out the distraction osteogenesis, the surgeon opens the original site of implantation and performs a corticotomy using an oscillating saw or bone chisels. The wound is then closed and permitted to heal.

When it is estimated that the fixture and the footing are stable and that sufficient periosteal healing and callus formation have taken place following alveolar corticotomy, the distraction osteogenesis process can commence. A latency period of 5 to 12 days is normally permitted to elapse before initiating distraction osteogenesis.

To commence the distraction procedure, the retaining screw is removed, and the distractor rod is placed within the fixture (Fig. 9). The distractor rod is advanced along the bore of the fixture until it bears against the footing. Further rotation of the distractor rod results in the fixture moving in the distal direction relative to the footing (Fig. 9). The segment of bone into which the fixture is integrated will be caused to move in the direction of distraction. To perform the distraction osteogenesis, the distractor rod is rotated so that the separation from the horizontal cut is increased at a rate of 0.5 to 1 mm daily (Fig. 10). As the fixture moves away from the footing, new bone will be generated between the footing and the fixture. Depending

Fig. 7. (*A*) Anterior view of a large alveolar cleft defect temporarily restored with a prosthodontic tooth. (*B*) Anterior view of the large alveolar cleft with an oronasal fistula. (*C*) An internal distractor is applied to the right osteotomized segment. (*D*) An internal distractor is applied to the left osteotomized segment. (*E*) Occlusal view of the alveolar defect preoperatively. Note that the two failing cleft-adjacent teeth were removed before the start of distraction. (*F*) Postoperative occlusal view of the alveolar cleft and oronasal fistula, both of which have been greatly reduced in size. More soft tissue is available for the reconstruction of the alveolar defect which will require a much smaller bone graft. (*G*) Dental implants restored with implant-retained prosthesis. (*H*) Occlusal view of maxillary reconstruction with restored dental implants in the maxillary arch. (*I*) Anterior teeth in occlusion. (*J*) Close-up full-smile photograph.

Fig. 9. The distracting dental implant is activated. These series of photographs show the potential gradual gains in vertical height of the alveolus. The advantage of this system is that the distracting hardware also serves ultimately as the prosthetic restoration.

on the length of travel along the direction of distraction, one or more distractor rods of different lengths may be used inside the implant (Fig. 10).

Final bone healing will not occur until distraction is complete and the bone is held in a stabilized position. This position may be achieved using the distractor or by external support such as orthodontic splinting. Thereafter, the distractor rod is removed, leaving a cylindrical void in the newly formed bone which will also fill in with bone.

On completion of the distraction osteogenesis procedure the fixture may remain in place, having been firmly integrated in the bone tissue, where it can be used to serve as an anchor for a prosthetic crown or bridge.

## Guidance of implant placement

Although the distracting dental implant is a unidirectional distraction device, its trajectory can be guided to a certain extent using orthodontic forces or a prosthodontic docking station. A further consequence of the unidirectional nature of the distracting dental implant is that the vector of distraction will be defined primarily by the implant's longitudinal axis. To a certain extent, the geometry of the corticotomy can be designed to counter pull from the lingual or

Fig. 10. The internal distractor rods of varying lengths are used depending on the magnitude of the planned distraction.

palatal mucoperiosteum. Because the trajectory of the distracting implant depends substantially on the vector of distraction, it is of critical importance to have control over the spatial location and axial inclination of the implant. An implant positioning device with the capability to control spatial location and axial inclination is currently under development.

## The future of alveolar and midface distraction osteogenesis

Distraction osteogenesis is a powerful technique that has revolutionized pediatric oral and maxillofacial surgery by providing a means of reliably lengthening the bones of the midface and mandible. As an alternative or an adjunct to conventional ridge augmentation procedures, ADO with a distracting dental implant offers the prospect of greater control in the correction of vertical alveolar defects and therefore better esthetic outcomes. A distracting implant would also allow for the correction of unsuccessful treatment results which might otherwise only be corrected by the use of long clinical crowns or pink porcelain, or, in the worst case, by removal of the implant, revisional ridge augmentation, and re-implantation.

Distraction osteogenesis may hasten the timing of implant placement in the pediatric population. The most appropriate earliest age for placement of implants has been widely discussed in many of the articles in this issue. Experiments designed to study the effect of dental implants on dentoalveolar growth and development in pigs have demonstrated that implants remain stationary and do not erupt together with adjacent teeth. Implants were found to inhibit local growth and development of the alveolar process, similar to the behavior of ankylosed teeth. A 3-year prospective clinical study in adolescents with congenitally missing teeth verified

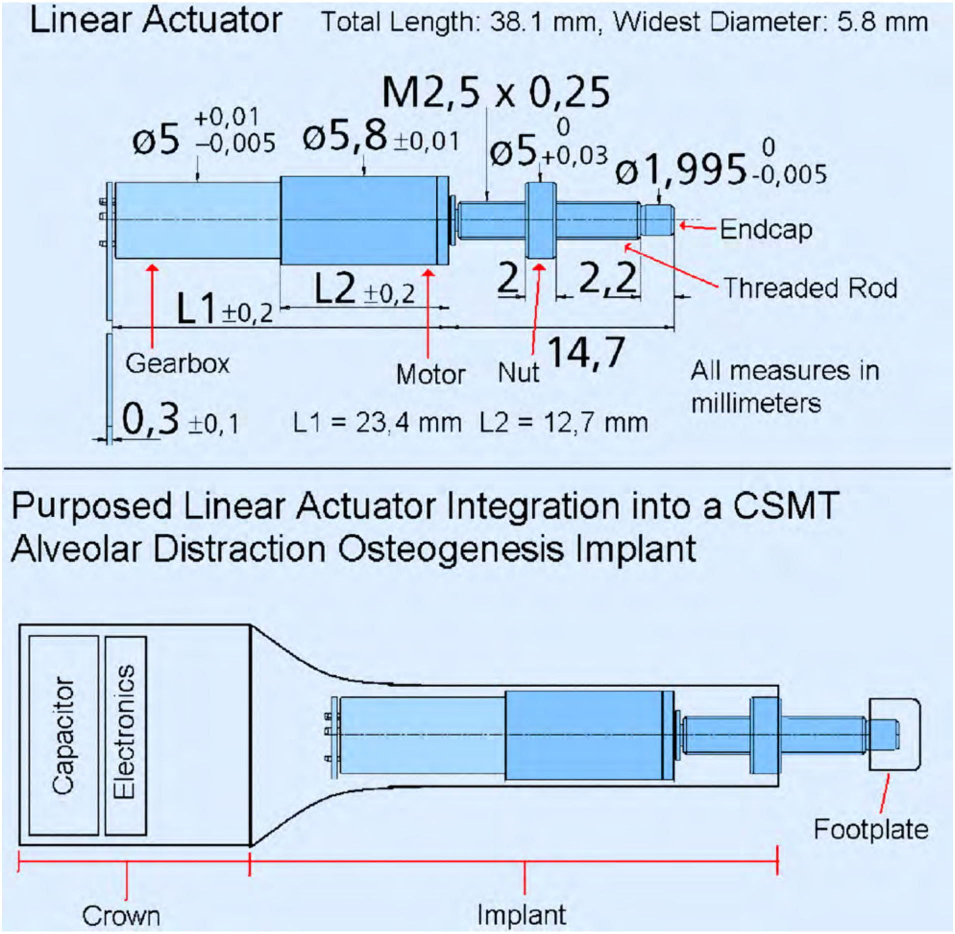

Fig. 11. Motorized distraction osteogenesis components will remove patient compliance as a factor by using built-in micromotors and microprocessors to deliver smooth uninterrupted pre-programmed distraction forces.

that implants do not move during growth of the jaws and result in the development of an infraocclusion and vertical marginal discrepancy of the prosthetic crown that is proportional to the amount of residual jaw growth following restoration of the implants. One case report documents a similar phenomenon occurring over a decade in an adult, putatively caused by continuing growth of the facial skeleton.

Standardization of implant capability to permit distraction osteogenesis would extend the ability to refine esthetics in the future following late detrimental changes related to residual alveolar growth, continued growth of the dentoalveolar process through adulthood, eruption of adjacent teeth, and recession of soft tissue levels.

In the future, all levels of distraction osteogenesis of the facial skeleton and alveolus may benefit from automation of the distraction technique by the incorporation of a micromotor controlled by a microprocessor allowing smooth and continuous distraction (Fig. 11). Automated distraction osteogenesis would liberate the patient from having to comply with protracted distraction schedules requiring multiple clinical sessions held over several weeks. Moreover, success of the distraction procedure would no longer depend on the patient to activate the distraction device.

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