Seventh Edition

ORTHODONTICS

Current Principles and Techniques


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Robert L. Vanarsdall, Jr., DDS

It Is Never Too Late to Remember and Give Thanks

This 7th edition of *Orthodontics: Current Principles and Techniques* is dedicated to its long-time co-editor, Robert L. Vanarsdall, better known by his colleagues as "Slick." Slick passed away shortly after the publication of the 6th edition of this textbook, but his influence on the scope of this edition and indeed the specialty of orthodontics remains current today. For those who did not know Dr. Vanarsdall and even those who were privileged to know or even work with him, we want to share a picture of who Slick was and his manifold contributions.

Robert Lee Vanarsdall was born in 1930 in Crewe, a small town in south-central Virginia. Named after his father and carrying the historic name of a southerner, as a child and teen he demonstrated an outgoing nature and an affinity for being well dressed and polite. "Slick" was the name he reportedly was given by a local clothing store where he bought his clothes, always looking to be neat and stylish and becoming a trend setter with his peers. The name stuck, as did an expanded scope of leadership.

Slick graduated from the College of William and Mary and in 1962 married his college sweetheart, Sandra Hoffman. Slick's love for international travel developed after joining the United States Navy (1962), in which he served as a lieutenant, returning for his dental education and graduating from the Medical College of Virginia in 1970 with a DDS, but knowing he wanted to specialize. Dr. Vanarsdall often spoke of how "lucky" he was to be the first student at the University of Pennsylvania School of Dental Medicine to graduate with a combined orthodontic and periodontal specialty education in a then unique program developed by innovative dental educator and school dean, Dr. Walter Cohen. Slick subsequently was board certified in both Periodontics and Orthodontics, becoming an examiner for the American Board of Orthodontics.

On completion of his dual dental specialty education, Slick joined the Penn faculty initially as a teaching fellow and rose through the professorial ranks while further developing the postgraduate individual and combined orthodontic and periodontic specialty programs. He became chair of the Department of Periodontics and, later, the Department of Pediatric Dentistry. Slick directed the Department of Orthodontics for almost 30 years, serving as department chair until 2011. He continued to actively teach, practice, and lecture internationally until his passing.

During an academic career that spanned 44 years, Dr. Vanarsdall was a prolific writer with more than 100 papers and 12 book chapters. He served on multiple editorial boards and was editor-in-chief for the *International Journal of Adult Orthodontics and Orthognathic Surgery* for 17 years. In 1994, Slick joined Tom Graber as co-editor and a chapter author in the 2nd edition of this textbook published by Mosby-Elsevier. He continued in that role until the 6th edition published in 2017 (the initial text was published in 1969 by W.B. Saunders). Dr. Vanarsdall also was a co-editor and author in a comprehensive textbook on the use of implants for orthodontic anchorage, titled *Applications of Orthodontic Mini Implants,* with co-authors J. S. Lee, J. K. Kim, and Y. C. Park, all of whom remain recognized chapter authors in this 7th edition as well.

Dr. Vanarsdall was active in professional associations as a participant speaker and organizer. He lectured all over the world and was awarded every major honorary lecture. He chaired multiple local, national, and international professional meetings, including the 1994 and 2002 American Association of Orthodontists (AAO) Annual Sessions. He was a member of numerous committees and boards, including the AAO's Council on Scientific Affairs, for which he served as chair. An active contributor and member of the Eastern Component of the Edward H. Angle Society of Orthodontists, he served as its president from 2004 to 2005. Slick was the recipient of numerous national and international awards for his academic work, topped by the American Association of Orthodontists Foundation highest academic award, the Jarabak Memorial International Teachers and Research Award (2017).

Although Dr. Vanarsdall was an outstanding mentor to his students, he was even a better friend to them and his colleagues. Dr. David Musich, a longtime chapter author in this book, tells the story of receiving a patient transfer of a 16-year-old with an ankylosed/impacted canine and getting an offer of help from Slick. "This was her 4th surgery on that tooth. She was anxious—so was her mom. After 10 minutes of explanation and 35 minutes of gentle luxation, the tooth moved, and it was free to be moved into the arch. It was Slick's genuine compassion and caring spirit that allowed this young lady to finally have her canine positioned. As a clinician, he was a true artist and unique as a colleague." Important to note is that Dr. Vanarsdall flew halfway across the country just to help with this one patient and colleague. It was not unusual for Dr. Vanarsdall to share his expertise with colleagues and students, distant from the site and approbation of others.

What is extraordinary about the contributions of this dedicated teacher and clinical research scientist? Dr. Vanarsdall had the ability to come to clinical issues with an open mind. At a time when specialty orthodontics was directed at adolescents, he looked to how adult dental care could be enhanced, even in the face of periodontal concerns. In a specialty then focused on anteroposterior discrepancies, with diagnosis and treatment often driven by lateral cephalometric measures, he looked to enhanced diagnosis and therapeutics by way of the transverse dimension. He was one of the first to present patients treated with surgical arch expansion and many other clinical approaches we now use routinely. Lest we forget, he changed the way that the specialty of orthodontics is practiced today.

Author, clinician, teacher, scientist, innovator, researcher, lecturer, administrator, world traveler, practitioner, humanitarian, mentor, husband, father, friend. We all were bettered by Slick! It is never too late to remember and give thanks.

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PREFACE

Nothing is known in our profession by guess; and I do not believe, that from the first dawn of medical science to the present moment, a single correct idea has emanated from conjecture. . . .

Sir Astley Paston Cooper

Since the publication of the previous (6th) edition of *Orthodontics: Current Principles and Techniques* our specialty and the wider world have witnessed dramatic change, disruption, adaptation, and renewal. The 7th edition reflects this period of rich ingenuity and continues to be a valuable, comprehensive resource for the contemporary orthodontic specialty student and practitioner.

As in our previous editions, the goal is to target a readership of Orthodontic Residents and Specialist Orthodontic Practitioners. Excellent textbooks already exist to educate dental students in the fundamental knowledge and basic concepts and principles of orthodontics, which every dentist should have assimilated in dental school. Orthodontics, after all, is an integral part of dentistry that should be considered by generalists and other specialists in a team approach to oral health care.

We are delighted that the 7th edition continues to be used in Graduate Orthodontic programs throughout the world. This has been further facilitated by translation into multiple languages, permitting global distribution in educational settings and beyond. For graduate orthodontic programs and orthodontic specialist education, the 7th edition is available in an "eBook" format. Availability through a website and as a searchable reference text allows rapid access to clinical topics and access to fresh information in a fast-paced and rapidly changing technological world.

In this edition, we acknowledge the increasing focus on the expanding armamentarium at our disposal, including fixed sagittal correctors, bone-borne expanders, in-house aligners, autotransplantation, and computer-assisted diagnosis and treatment. Our aim has been to update the content to reflect contemporary orthodontic specialty practice, while retaining a strong theoretical and evidence-based underpinning. The opportunity to move some sections to an online format has allowed us to address more topics without substantially increasing the physical size of the book.

Given our expressed aim of providing a holistic review of our specialty from both clinical and theoretical perspectives, an overview of the history of orthodontics has been introduced. Classic chapters and case reports have been moved online, which allows us to more fully provide a historical perspective while focusing on current principles and techniques.

The pandemic-related shutdown in dental practices early in 2020 spawned creative new technology, including programs that allow us to virtually meet with patients and monitor their progress. The reintroduction of chairside practice in the summer of 2020 was accompanied with a keen focus on the generation, behavior, and mitigation of aerosols. A new chapter provides valuable insights into the topic of aerosols in orthodontic practice.

The accelerated development of new techniques and materials places ever-greater onus on the conduct and appreciation of high-quality, independent clinical trials. Moreover, the wider availability of information and ever-increasing pool of journal articles places a premium on the ability of both residents and seasoned practitioners to digest research findings and ascertain whether and when to implement new or revised treatment approaches. A new chapter dedicated to evidence-based orthodontics is a valuable resource for all. Likewise, Machine Learning and Artificial Intelligence are rapidly being integrated into orthodontics, enhancing our ability to predict, plan, and analyze tooth movement and soft tissue response. Increased use of computers for diagnosis, treatment planning, and robotics are certainly part of our future, and this is embraced in a new chapter on Artificial Intelligence and Big Data as applied to Orthodontics, as well as an updated chapter on Computer-Assisted Orthodontics.

We think that this 7th edition continues to recognize the global nature of the orthodontics specialty, which is reflected in a larger pool of international authors. Some of the topics covered by our international colleagues include autotransplantation, orthodontic-periodontic relationships, orthognathic surgery, interdisciplinary adult treatment, fixed functional appliances, biomaterials, and temporary anchorage devices.

The chapter on craniofacial dysmorphology and cleft lip and palate has been completely revised and updated with the inclusion of advanced methods of neonatal maxillary orthopedics for hospital-based orthodontists and residents enrolled in craniofacial fellowship programs. An aspect of interest for the orthodontist is the inclusion of a speech and language pathologist, describing the effects of adolescent growth and surgical maxillary advancement on velopharyngeal mechanisms. Likewise, the chapter on airway considerations in orthodontics has been revised to reflect advances in knowledge over the past 5 years.

In this new edition of the textbook we are delighted to welcome a new, talented editor and author, Padhraig Fleming. Padhraig is our first Europe-based co-editor. He has been Professor and Postgraduate Training Lead in Orthodontics at the Institute of Dentistry, Queen Mary University of London and in the summer of 2022 was appointed to a new position as Professor and Chair of Orthodontics, Dublin Dental University Hospital, Trinity College Dublin, Dublin, Ireland. He is also an Associate Editor of the *American Journal of Orthodontics and Dentofacial Orthopedics,* the *British Dental Journal,* and the *Journal of Dentistry and Progress in Orthodontics* and is on the editorial board of numerous other journals.

We are greatly indebted to each of our chapter contributors for their invaluable input. We sincerely hope that we have succeeded in doing full justice to the meteoric change that our specialty has witnessed over the past years while helping to perpetuate the fundamental principles and knowledge that we are certain will never lose relevance or import.

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CONTENTS

1

The History of Orthodontics… From an Idea to a Profession

David L. Turpin and Norman Wahl

Today, the specialty of orthodontics is looked upon by the public with respect and even admiration. There are at least 30 English-language journals whose primary focus is orthodontics. Most orthodontists, though, know little about the struggles that took place when the profession was in its infancy. In the last half of the 19th century, orthodontics was not viewed as a specialty of dentistry, and Angle even speculated that it was destined to become a specialty of medicine. At that time the mechanisms of tooth movement were a complete mystery. We have certainly come a long way.

Some of the developments in our specialty are particularly impressive. For example, the perfection of fixed appliances was far ahead of the many contributions made in later years to assist with diagnosis and treatment planning. The use of enamel bonding has almost eliminated the need for metal bands, the application of orthognathic surgery has widened the envelope of correction, and a better understanding of the biology of tooth movement and growth have all had a profound impact on our work. One has to believe that the publication of scientific journals for the past 100 years has also played a major role in disseminating ideas and knowledge and in helping to bring many of these ideas to fruition.

In recognition of the rich history and ongoing improvements in our specialty, Norm Wahl and I were asked by the editors of this 7th edition to compile a history of orthodontics, starting from the middle of the 19th century. To tell this story, we highlight many of the careers of prominent educators and clinicians who have contributed to the development of orthodontia, or *orthodontics* as we now know it. We hope that the inclusion of this chapter will not only shed light on our profession's development but also serve as a pleasurable "read."

PRE-1900 DEVELOPMENT OF THE ORTHODONTIC SPECIALTY

At this time in history, many questioned whether teeth could be moved safely to new positions. Would the pulps remain vital? Would the uncompleted roots of growing teeth be bent? Would tooth longevity be affected? It would take pioneering dentists, working without the benefit of graduate training, to build the body of orthodontic knowledge brick by brick. Kingsley pioneered cleft-palate treatment. Case showed us the importance of facial esthetics. Dewey and Ketcham created the American Board of Orthodontics (ABO), the first certifying board in dentistry. But it was Edward H. Angle, the Father of Modern Orthodontics, who gave us our first school, journal, society, and practical classification of malocclusion.

THE PROFESSIONALIZATION OF ORTHODONTICS

Dentistry's first specialty organization, the Society of Orthodontists, was formed in 1900, and the first specialty journals began to appear. In the 1930s, creative thinkers in orthodontics began to more openly question the status quo. Apprenticeships had given way to formal instruction, and proprietary schools bowed to graduate university programs, including some taught or headed by women. Edward Angle was elected president of the society in 1900, and the first annual meeting was to be in St. Louis the following June. During its first year, the fledgling society claimed only 13 members.

THE AMERICAN BOARD OF ORTHODONTICS, ALBERT KETCHAM, AND EARLY 20TH-CENTURY APPLIANCES

Early in the past century, three events put Colorado in the orthodontic spotlight: the discovery—by an orthodontist—of the caries-preventive powers of fluoridated water, the formation of dentistry's first specialty board, and the founding of a supply company by and for orthodontists. Meanwhile, inventive practitioners were giving the profession more options for treatment modalities, and stainless steel was making its feeble debut. Angle led the way, designing the expansion (E) arch around 1900, which was the precursor to our modern brackets.

MORE EARLY 20TH-CENTURY APPLIANCES AND THE EXTRACTION CONTROVERSY

The trying conditions of the Great Depression and World War II did not deter innovative orthodontists from adding new appliances to our armamentarium. Clinicians became fragmented into various "camps." Silas Kloehn's neck gear became a more patient-friendly version of extraoral anchorage, but it still had drawbacks. Angle's stranglehold on the specialty was finally broken when four of his disciples advocated extractions as a reasonable option to be considered in patients with crowding and/or protrusion.

THE CEPHALOMETER TAKES ITS PLACE IN THE ORTHODONTIC ARMAMENTARIUM

After World War II, cephalometric radiography came into widespread use, enabling orthodontists to measure changes in tooth and jaw positions produced by growth and treatment. Cephalometrics revealed that many malocclusions resulted from faulty jaw relationships, not just malposed teeth, and made orthodontists wonder if it was possible for jaw growth to be altered by orthodontic treatment.

FUNCTIONAL APPLIANCES TO MIDCENTURY

The history of functional appliances can be traced back to 1879, when Norman Kingsley introduced the "bite-jumping" appliance. In the early 1900s, parallel development began in the United States and Europe in fixed and functional techniques, respectively, but the Atlantic Ocean was a geographic barrier that restricted the early sharing of knowledge and experience in these philosophies.

THE GOLDEN AGE OF ORTHODONTICS

For orthodontists, the post–World War II era was characterized by the introduction of fluoridation, sit-down dentistry, and an increase in extractions. Postwar prosperity, the baby boom, and increased enlightenment of parents contributed to what was later called the "golden age of orthodontics." The subsequent clamor for more orthodontists led to a proliferation of graduate departments and inauguration of the American Association of Orthodontists (AAO) Preceptorship Program. There was also an increase in mixed-dentition treatment, requiring improved methods of analyzing arch lengths.

TWO CONTROVERSIES: EARLY TREATMENT AND OCCLUSION

From the beginning, orthodontists have been faced with the decision of when to start treatment. Until the late 20th century, this decision was based on clinical observation, the influence of strong leaders, and (after midcentury) the results obtained by what Europeans called "functional jaw orthopedics." Recent findings questioning the efficacy of early treatment have forced orthodontists to ask themselves whether their decision to "start early" is being influenced too heavily by practice-management considerations.

THE TEMPOROMANDIBULAR JOINT AND ORTHOGNATHIC SURGERY

The temporomandibular joint (TMJ) has always been the practitioner's no-man's land. Who's in charge here? The general dentist, the prosthodontist, the oral surgeon, the otolaryngologist, the psychiatrist, or the orthodontist? Theories about the cause of problems are as varied as the specialties involved.

SURGICAL ADJUNCTS TO ORTHODONTICS

Around 1970, after overcoming obstacles related to anesthesia, infection, and blood supply, orthognathic surgeons came into their own. The history of cleft lip and palate treatment has a much earlier beginning, because a deformed infant evokes a strong desire to intervene. Angle's belief that orthodontists can grow bone finally came to fruition with the advent of distraction osteogenesis, which developed from the limb-lengthening procedures of Gavriil Ilizarov in Russia.

SKELETAL ANCHORAGE

For many years, orthodontists have searched for a form of anchorage that does not rely on patient cooperation, although the answer already lay in the implants that dentists used to replace missing teeth and that oral surgeons used to hold bone segments together. Now these divergent lines have come together with titanium as the most biocompatible material in the form of stationary anchorage. State-of-the-art miniplate and microscrews—temporary anchorage devices (TADs)—now permit movements previously thought difficult or impossible.

LATE 20TH-CENTURY

Orthodontics continues to evolve. It has taken half a century for orthodontic bonding procedures to evolve from chemically cured acrylic to light-cured acrylic, and even having precisely placed adhesive when brackets are shipped from the manufacturer. The device that threatens to replace conventional brackets altogether—the aligner—also relies on bonded buttons, so it appears that some form of bonding will be with us for a while. The digital revolution has been occurring over the past 20 years, with the advent of digital photographs, two-dimensional (2D) and 3D imaging, intraoral scanning, and 3D printing.

As mentioned earlier, these advances have all been aided by our scientific journals. The current era of evidence-based research strives to make the orthodontic literature more accessible, useful, valid, and generalizable. Please visit the complete online chapter titled The History of Orthodontics in this 7th Edition of *Orthodontics: Current Principles and Techniques* to learn more about our profession's interesting journey over the past 150 years.

2

Craniofacial Growth and Development

Developing a Perspective

David S. Carlson and Peter H. Buschang

OUTLINE

This chapter is enhanced with the following electronic assets at www.expertconsult.com: Two tables.

An appreciation of the biological principles associated with growth and development, especially of the structures composing the craniofacial complex, is essential for attaining competency within the field of orthodontics. Particular emphasis for the advanced practice of orthodontics is placed on the hard tissues comprising the craniofacial regions, that is, the skeletal structures and the teeth, because these are the primary components of the craniofacial complex that the orthodontist addresses during treatment. Development, growth, and function of other craniofacial structures and tissues, such as muscles, neural tissues, and pharyngeal structures, as well as spaces such as the airway, are also of major interest to orthodontists. However, those elements are important primarily in terms of their influence—structurally, functionally, and developmentally—on the growth, size, and form of the skeletal elements of the face and jaws.

This chapter emphasizes postnatal growth, principally of the skeletal structures of the craniofacial complex, because of its importance in orthodontic treatment. Considerable attention is also given to prenatal development of craniofacial tissues and structures because it is critical for understanding postnatal growth. The reader is referred to a number of excellent references on developmental biology and human embryology for comprehensive reviews of early craniofacial development.[1,2]

SOMATIC GROWTH

The size and form of the craniofacial complex are major components of an individual's overall body structure. Moreover, the growth and maturation of the body as a whole, referred to generally as *somatic growth,* are highly correlated with those of the craniofacial complex. Therefore clinical evaluation of the status and potential for craniofacial growth, and thus of treatment planning in orthodontic patients, is highly dependent on an understanding of the somatic growth process.[3]

Differential Development and Maturation

In his classic work during the 1930s, Scammon[4] drew attention to the fact that the rate and timing of postnatal maturation, measured as a proportion of total adult size, vary widely among major systems of the human body (Fig. 2.1). In what has become known as "Scammon's curves," for example, maturation of the central nervous system (CNS) is shown to be completed primarily during the last trimester of gestation through age 3 to 6 years. As a result, the cranial vault, which houses the precociously developing and enlarging brain, is disproportionately large in the infant relative to the rest of the craniofacial region (Fig. 2.2). In contrast, the reproductive organs become mature a decade later, during adolescence.

The rate of general somatic growth and development, which includes the skeletal and muscular systems, is characterized by an S-shaped curve. The relative rate of growth is very high prenatally but then decreases during infancy and becomes even slower during childhood. The rate then accelerates greatly with the initiation of adolescence through the point of peak growth velocity, after which it slows once again and effectively stops altogether in adulthood. Development and growth of the craniofacial complex is intergraded between neural and somatic maturity patterns. The gradient moves from the cranium, which is the most mature, through the anterior cranial base, posterior cranial base and maxillary length, upper face height, corpus length, to

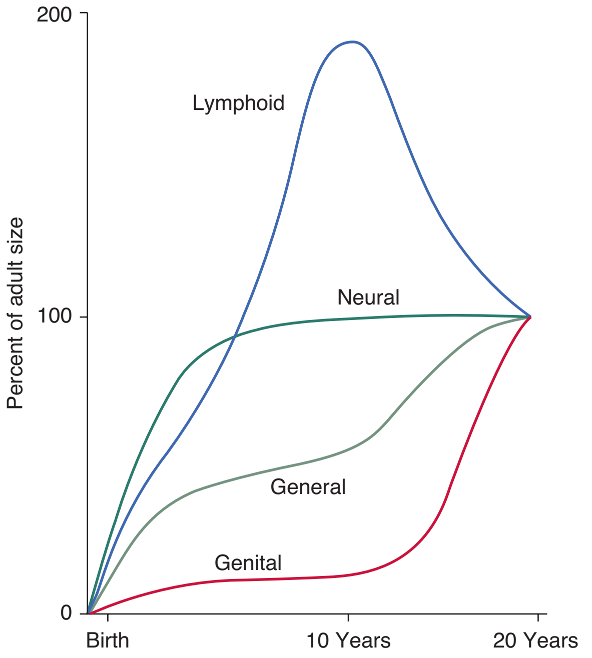

Fig. 2.1 Scammon's curves illustrating the fact that different systems of the body have different rates of development and come to maturity at different ages. (Adapted from Lowry GH. *Growth and Development of Children*. ed 6. Chicago: Year Book Medical Publishers; 1973.)

ramus height, which is the least mature and most closely approximates the general S-shaped pattern of general somatic maturation.[5]

Overall somatic growth, including the onset and end of puberty, is coordinated throughout the body by sex hormones and growth factors that are expressed differentially during the first two decades of postnatal life. However, the timing, rate, and amount of secretion of endocrine factors vary significantly between males and females and within each sex relative to chronologic age.

Variation in Rates of Growth during Maturation

Three episodes of relatively rapid growth have been documented for both general somatic and craniofacial growth. The greatest rates of growth occur prenatally and during infancy. The mid-childhood spurt takes place in approximately 50% of children between 6.5 and 8.5 years of age. The mid-growth spurt tends to occur more frequently and approximately 1 year later for boys than girls.[6] The more prominent adolescent growth spurt begins with the onset of puberty, at approximately 9 to 10 years of age in females and 11 to 12 years in males (Fig. 2.3). Female and male peak height velocities (PHV) are attained on average at 12 and 14 years of age, respectively, for North Americans and Europeans.[7] Females complete adolescence approximately 2 or more years ahead of males. The extra years of childhood growth before adolescence in males, as well as the slightly greater rates of adolescent growth and the slightly lengthier adolescent period, explain most of the sex differences in overall body size and craniofacial dimensions.

Because growth of craniofacial structures is correlated with general somatic growth, the timing of peak height velocity (PHV), which occurs at the pinnacle of the adolescent growth spurt, is especially useful for estimating peak maxillary and mandibular growth velocity. It has been shown that maxillary growth attains its maximum rate slightly before PHV, whereas the maximum rate of mandibular growth occurs just after PHV.[8,9]

The timing, rate, and amount of somatic growth are best determined by changes in overall height. Thus, height provides an important adjunct for cephalometric evaluations, especially during periods of rapid growth. Population-specific height percentiles make it possible to individualize craniofacial assessments. For example, if an individual's rate of somatic growth is particularly high or low, it is likely that his or her rate of craniofacial growth will be similarly high or low. Knowing a patient's height percentile also makes it possible to adjust measures of craniofacial size for the patient's body size. For example, if an individual is at the 90th percentile for body size, you would also expect his or her mandible to be larger than average. Height measurements are recommended because they are noninvasive, highly accurate, and simple to obtain at multiple occasions. Reference data for height are also typically based on larger samples of defined populations than are craniofacial reference data, which makes them more precise at the extreme percentiles.[10]

Assessments of maturation also provide critical information about the likelihood that the growth of craniofacial structures will continue and for how long or that growth has been completed. This is important because patients' maturational and chronologic ages should be expected to differ, often by more than 1 to 2 years, which confounds growth assessments necessary for orthodontic diagnosis and treatment planning. For this reason, it is always better to use the patient's skeletal age based on radiologic assessments of hand/wrist ossification to determine skeletal maturity, especially for determining whether the patient has entered adolescence, attained peak velocity, is past peak

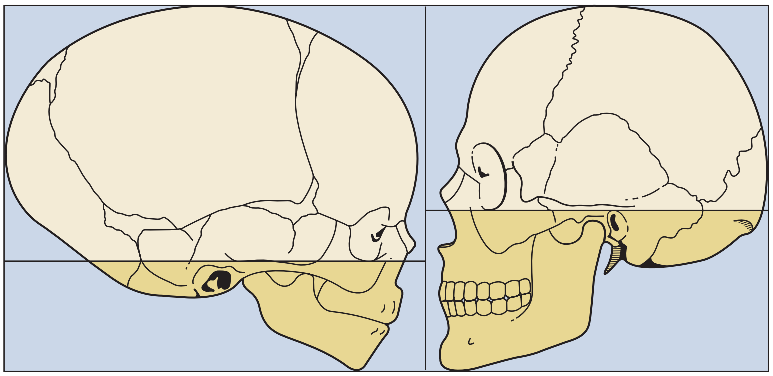

Fig. 2.2 Disproportions of the Head and Face in Infant and Adult. The neurocranium, which houses the brain and eyes is precocious in its development and growth and therefore is proportionately larger than the face during infancy and early childhood. (Adapted from Lowry GH. *Growth and Development of Children.* 6th ed. Chicago: Year Book Medical Publishers; 1973.)

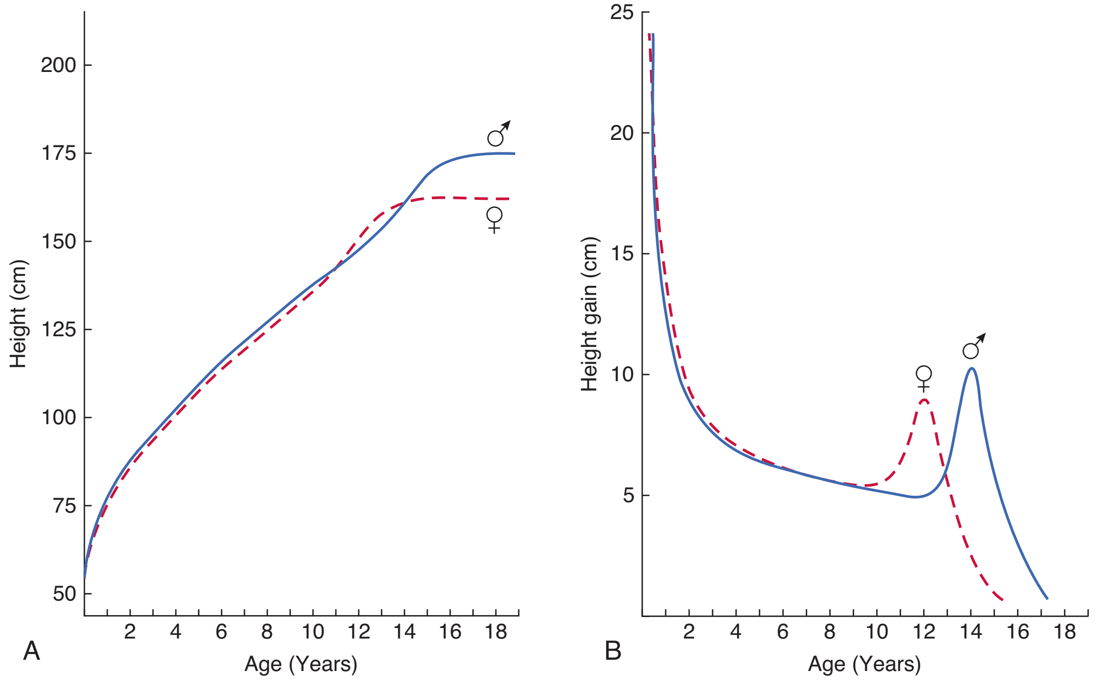

Fig. 2.3 **Growth Velocity Curve (Growth per Unit of Time) for Skeletal Growth as General Measure of Human Ontogeny.** Velocity of growth is characterized by decrease in growth rate beginning in the last trimester of prenatal development through maturation in the adult. During adolescence, hormonally mediated growth typically occurs to bring about a spurt in skeletal growth (peak height velocity). Pubertal growth spurt is characterized by considerable variability in onset and duration among individuals and according to sex. Onset of the pubertal growth spurt typically begins about age 10 in girls and lasts approximately 2 years. Boys have later onset (12 years); the entire pubertal period can last 4 to 6 years. (Adapted from Tanner JM, Whitehouse RH, Takaishi M. Standards from birth to maturity for height, weight, height velocity and weight velocity: British children, 1965. *Arch Dis Childh.* 41:454-471, 1966.)

growth, or is near the end of clinically meaningful growth.[11,12] Cervical vertebrae maturation provides another, albeit less precise, method to determine skeletal maturity.[13] Molecular assays are now being developed to provide more sensitive assessments to determine maturational status of skeletal growth.[14]

CRANIOFACIAL COMPLEX

The craniofacial complex comprises 22 separate bones that can be organized for heuristic purposes into relatively discrete anatomic and functional regions. Each of these regions has distinct mechanisms of development and growth, as well as different capacities for adaptation during growth (Fig. 2.4).

Structural Units

Desmocranium

The term *desmocranium* refers to the portion of the craniofacial skeleton that arises from a membrane of ectodermal, mesodermal, and neural crest origin that surrounds the proximal end of the notochord very early in development. As the brain develops and expands in utero, the desmocranium develops initially as a fibrous membrane covering of the brain that eventually will give rise to the bones of the cranial vault and fibrous joints, or sutures, as well as the dura mater over the brain and the periosteum overlying the bones of the cranial vault. In fact, in the absence of a brain, as with anencephaly, the desmocranial bones will fail to develop at all. Because the skeletal derivatives of the desmocranium have exclusively a membranous precursor, initial

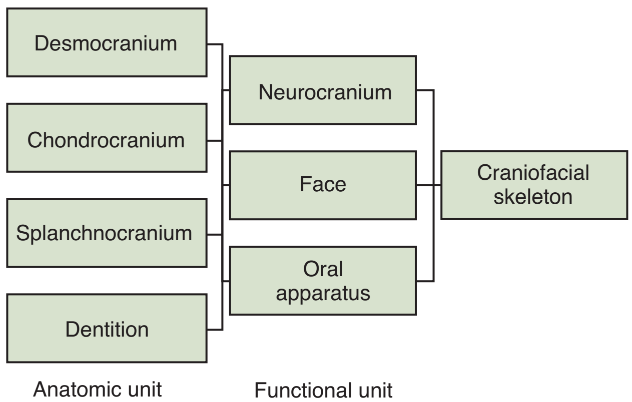

Fig. 2.4 Schematic of Organization of the Craniofacial Skeleton into Anatomic Regions and Overlapping Functional Regions.

morphogenesis and subsequent bone growth take place completely by intramembranous ossification.

Chondrocranium

The *chondrocranium* forms initially as part of the embryonic anlagen of primary cartilage that will become the cranial base, nasal septum, and nasal capsule. Like the desmocranium, the chondrocranium is also a derivative of the embryonic membrane surrounding the developing central nervous structures. However, the chondrocranium is significantly less dependent on the presence of the brain for its initial formation and subsequent development. Growth associated with the derivative bones of the cranial base occurs by means of endochondral ossification.

Viscerocraniu

The *viscerocranium,* also referred to as the *splanchnocranium,* is composed of all those elements of the craniofacial complex that are derived from the first branchial arch and thus is of neural crest origin. These elements primarily include the bones of the midfacial complex and the mandible. Because the skeletal elements of the viscerocranium have no primary cartilaginous precursors, development and growth of its skeletal derivatives take place by intramembranous ossification that is also characterized by the presence of sutures and a specialized form of membrane-derived (secondary) cartilage at the mandibular condyles.

Dentition

The deciduous and permanent teeth are specialized anatomic components of the craniofacial complex that are composed of unique tissues and undergo a unique mechanism of development characterized by the interaction between ectodermal and mesenchymal tissues.

Functional Units

These four anatomic components can be combined organizationally into three overlapping and very broad functional units composing the craniofacial complex (Fig. 2.5).

Neurocranium

The *neurocranium* houses the brain and other elements of the CNS, such as the olfactory apparatus and auditory apparatus. As the brain rests on the cranial base and is covered by the cranial vault, development and growth of the neurocranium are characterized by a combination of membranous (desmocranium) and cartilaginous (chondrocranium) bone growth.

Face

The upper face may be defined as the region of the orbits of the eye. The midface, comprising primarily of the maxillae and zygomatic bones, is the region between the orbits and the upper dentition. Ectocranially, the bones of the face are composed externally of the intramembranously formed bones of the viscerocranium. However, the face also receives contributions from the chondrocranium as the cartilaginous nasal capsule and nasal septum. The lower face, comprising the mandible, develops entirely from the first branchial arch and thus is derived entirely as part of the viscerocranium. The mandible develops and grows by a specialized form of intramembranous formation of both bone and secondary cartilage.

Oral Apparatus

The oral apparatus is composed of the dentition and supporting structures within the upper and lower jaws. Thus the oral apparatus also is characterized by a unique morphogenesis of the teeth and a specialized form of intramembranous bone growth of the alveolar processes of the maxilla and mandible (viscerocranium). Development and growth of the skeletal structures comprising the oral apparatus are greatly influenced by the muscles of mastication and other soft tissues associated with mastication.

MOLECULAR BASIS OF CRANIOFACIAL DEVELOPMENT AND GROWTH

Patterning and subsequent formation of craniofacial tissues and structures have a complex, polygenic basis. For example, it has been shown that there are over 90 specific genes in which mutations will result in major disruptions of development, leading to severe craniofacial malformations.[15] Moreover, variations in craniofacial development and growth, from dysmorphologies to malocclusions, are multifactorial as a result of epigenetic mechanisms.[16,17] No genes are unique to the craniofacial complex. However, certain genes, especially those associated with developmental patterning of the head region and growth of cartilage, bone, and teeth, are of particular relevance for craniofacial development and growth and thus are of special importance for orthodontics. In addition, a number of genes of interest include those responsible for specific craniofacial deformities, such as craniosynostosis and facial clefts. The reader is referred to Hartsfield and Morford (see Chapter 3) for a comprehensive review of genetic mechanisms in the craniofacial region that are most important to orthodontics. A summary of the key genes associated with the patterning, development, and growth of the craniofacial region can be found in E-Table 2.1.

The key genes associated with craniofacial development may be organized informally into two broad yet overlapping groups based on their timing and patterns of expression and also their primary target tissues. First are those highly conserved genes, such as homeobox genes and transcriptions factors, that are responsible primarily for

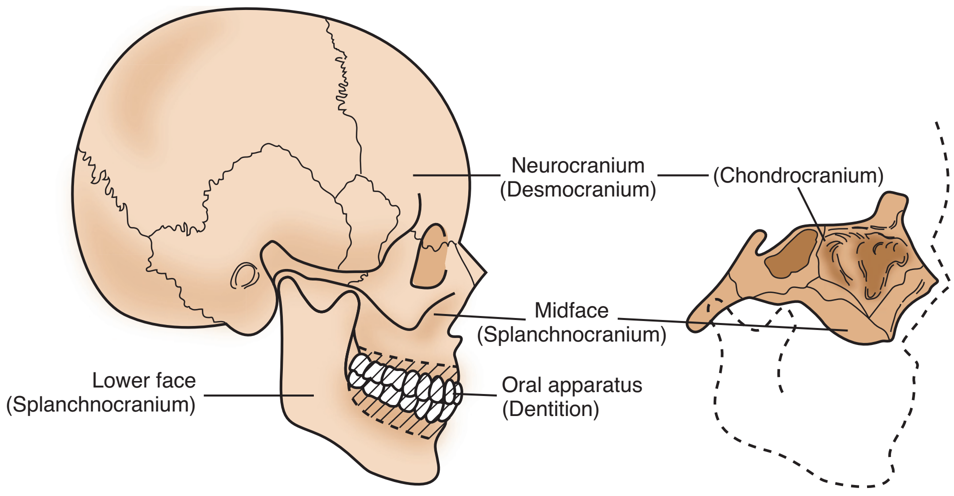

Fig. 2.5 Major Components of the Craniofacial Skeletal Complex.

TABLE 2.1 **Comprising the Craniofacial Complex**

Gene/Protein		General Role and Function	Significance for Craniofacial Development and Growth	References
Bmp-1 to *Bmp-9*	Bone morphogenetic protein 1-9	*Signaling molecule:* Skeletal differentiation, growth, repair	NCC and CF mesenchyme patterning; suture development; odontogenesis; nsCL/P	1-6
Dlx-1 to *Dlx-6*	Distal-less 1-6	*Homeobox:* Limb development; chondrogenesis; osteogenesis	Orofacial clefting	7-9
Efnb1	Ephrin B1	*Protein coding:* Cell division, adhesion	Craniofrontonasal syndrome; candidate for role in Class III malocclusion	1, 10-12
Fgf-1 to *Fgf-18*	Fibroblast growth factor 1-18	*Growth factors*: Differentiation and growth of multiple tissues and structures	CF ectoderm, NCC patterning; suture development; MCC growth; tooth induction; CL/P	1, 3, 4, 13-15
Fgfr-1 to *Fgfr-3*	Fibroblast growth factor receptor 1-3	*Transmembrane receptors*: Fgf receptor	Anterior cranial base growth; MCC growth; syndromic, nonsyndromic C-SYN; MX hypoplasia; CL/P	1, 3, 4, 15-17
GH	Growth hormone	*Peptide hormone-mitogen*: Cell growth and tissue regeneration	Growth of multiple CF tissues, structures; variations in MD growth, dentofacial treatment	13, 18
GHr	Growth hormone receptor	*Transmembrane receptor*: Receptor for GH	Polymorphisms associated with MD growth and MCC response to dentofacial treatment	19-21
Gli2 to *Gli3*	Zinc finger protein Gli2-3	*Transcription factor*: Regulates Ihh and Shh signaling	C-SYN; Greig cephalopolysyndactyly syndrome	1, 10, 22
Gsc	Goosecoid	*Transcription factor*: Dorsal–ventral patterning of NCC, head formation; rib fusion	Inner ear, cranial base, MX/MD anomalies	1, 8, 13, 23, 24
Hoxa1 to *Hoxa3*	Homeobox A1, A2, A3	*Homeobox*: Patterning of hindbrain rhombomeres and pharyngeal arches	Neural tube closure, 1st-2nd arch deformities	25, 26
Igf-1	Insulin-like growth factor 1	*Growth factor*: Mediator of GH; muscle, cartilage, and bone growth	MX/MD growth; suture development/growth; mediation of MCC to dentofacial treatment	3, 8, 13, 27-30
Ihh	Indian hedgehog	*Signaling molecule*: Endochondral and intramembranous ossification	Cranial base development; mediation of MCC growth during dentofacial treatment	31-33
L-Sox5	Long-form of Sox5	*Transcription factor*: Neurogenesis; chondrogenesis; type II collagen	Mediation of MCC growth during dentofacial treatment	34
Msx1 to *Msx2*	Muscle segment homeobox 1-2	*Homeobox*: Limb development; ectodermal organs	NCC proliferation, migration; odontogenesis; MD development; nsCL/P; Boston-type C-SYN	1, 3, 4, 8, 10, 35
Myo1H and *Myo1C*	Myosin 1H, Myosin 1C	*Protein coding*: Cell motility, phagocytosis, vesicle transport	Polymorphisms associated with MD prognathism	36, 37
Nog	Noggin	*Signaling molecule*: Patterning of the neural tube and somites	Head formation; neural tube fusion	4, 25, 26
Notch		*Transmembrane receptor*: Neuronal development; cardiac development; osteogenesis	MCC development	38
Osx	Osterix	*Transcription factor*: Osteoblast differentiation, mineralization; chondrogenesis	MCC differentiation, endochondral ossification; mediation of MCC growth during dentofacial treatment	39
Pitx1-2	Paired-like homeodomain 1-2	*Homeobox*: Left–right axis; left lateral mesoderm; skeletal development; myogenesis	MD development; role in Treacher-Collins syndrome; CL/P; odontogenesis	8, 13

Continued

TABLE 2.1 **Comprising the Craniofacial Complex—cont'd**

Gene/Protein		General Role and Function	Significance for Craniofacial Development and Growth	References
Prx-1Prx-2		*Homeobox*: Epithelial development in limbs and face	NCC patterning; malformations of 1st-2nd arch structures	8, 40, 41
PTHrP	Parathyroid-related protein	*Protein coding*: Endochondral bone formation	Development/growth of cranial base, MD, dental arches	42, 43
Runx2	Runt-related transcription factor	*Transcription factor*: Osteoblast differentiation; intramembranous and endochondral bone growth	Closure of fontanelles and sutures; ossification of cranial base, MX, and MCC; cleidocranial dysplasia	32, 43-46
Shh	Sonic hedgehog	*Transcription factor*: Development of limbs, midline brain, neural tube; osteoblastic differentiation; skeletal morphogenesis	Induction of frontonasal ectoderm; cranial base; fusion of facial processes; palatogenesis; odontogenesis; holoprosencephaly	1, 9, 33
Sho2		*Signaling molecule*: Development of digits; organization of brain, CF mesenchyme	Palatogenesis; TMJ development	6, 9, 38
Sox9		*Transcription factors*: Chondrogenesis; type II collagen; male sexual development	Cranial base; MCC growth; CL/P; Pierre-Robin sequence	38, 46-48
Spry 1-2	Sprouty	*Protein coding*: Mediates FGF signaling	MD/TMJ development	38, 48
Tcof1	Treacle	*Protein coding*: Early embryonic nucleolar-cytoplasmic transport	NCC proliferation, migration, survival; Treacher-Collins syndrome	38, 49
Tgf-β1 to *Tgf-β3*	Transforming growth factor-beta 1-3	*Growth factor*: Proliferation, differentiation, growth, function of multiple tissues	Palatogenesis; MD growth; suture development, maintenance, fusion; sCL/P	3, 24
Twist-1	Twist-related protein 1	*Transcription factor*: Skeletal development; syndactyly	MCC development; suture fusion; Saethre-Chotzen syndrome; facial asymmetry	9, 35, 38, 50, 51
Vegf	Vascular endothelial growth factor	*Growth factor*: Ingrowth of blood vessels	Chondrogenesis in cranial base, MCC	38, 45, 52
Wnt-1	Proto-oncogene protein Wnt 1	*Signaling molecule*: Cell fate, patterning during embryogenesis	MCC development/growth; MCC growth during dentofacial treatment	6, 32, 38, 53

CF, Craniofacial; *CPO,* cleft palate only; *CL/P,* cleft lip and palate; *C-SYN,* craniosynostosis; *MCC,* mandibular condylar cartilage; *MD,* mandible; *MX,* maxilla; *NCC,* neural crest cells; *nsCL/P,* nonsyndromal cleft lip and palate; *sCL/P,* syndromal cleft lip and palate; *TMJ,* temporomandibular joint.

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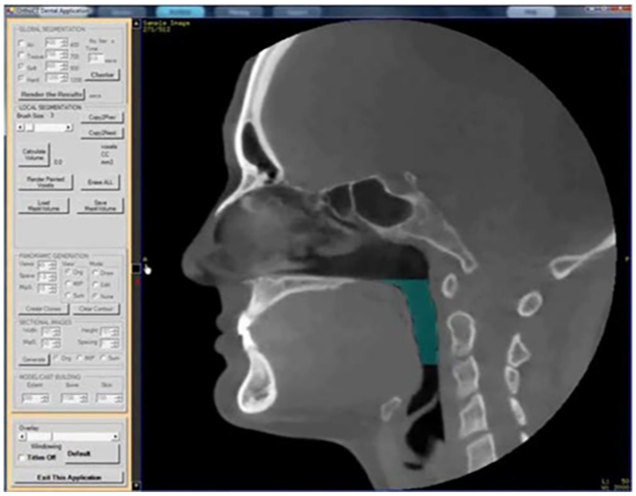
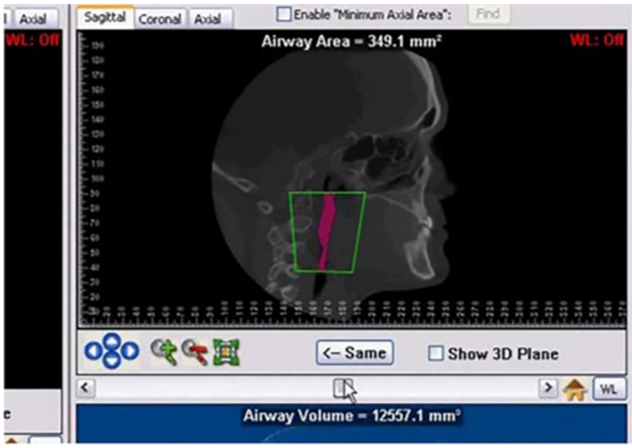
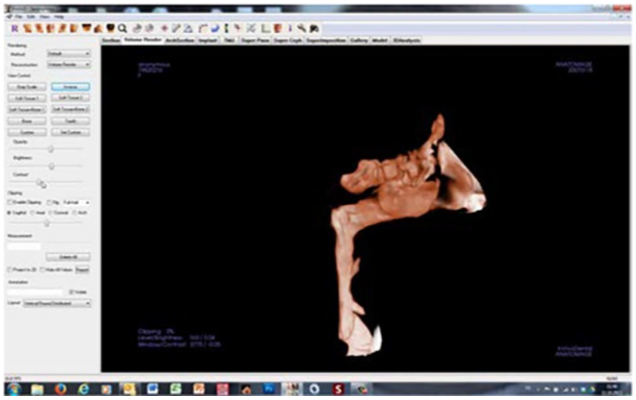


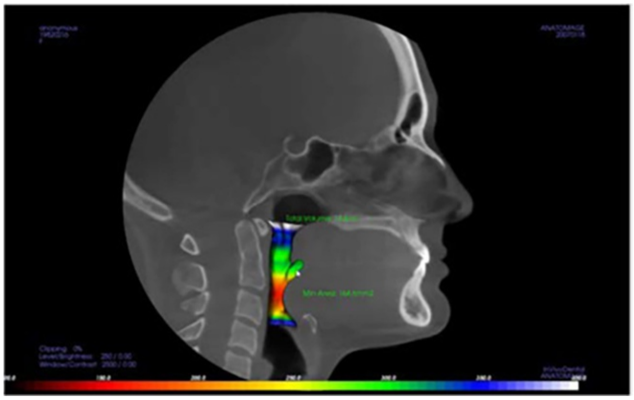
Video 13.1 Manual segmentation of the airway. When performing manual segmentation of the airway, the user identifies the airway in each slice through the length of the airway. This is a labor-intensive procedure that gives the operator total segmentation control.



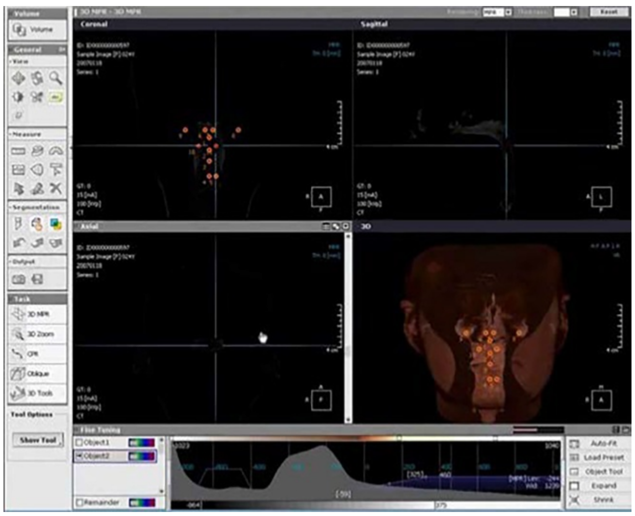
Video 13.2 Airway segmentation using Dolphin 3D v12. Semiautomatic segmentation of the airway using the color mapping feature of Dolphin 3D v12. The software was a pioneer in user-friendly and fast airway segmentation. (Used with permission from Dolphin Imaging & Management Solutions, Chatsworth, CA.)



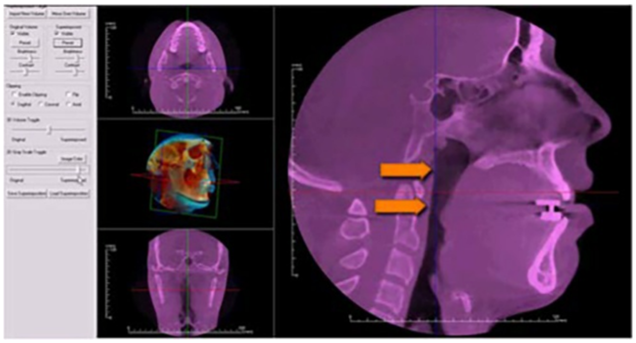
Video 13.3 Airway segmentation using InVivo Dental v4. Semiautomatic segmentation of the airway using InVivo Dental 4. In this older version, the segmentation was more manual than automatic. (Used with permission from Anatomage Inc., San Jose, CA.)



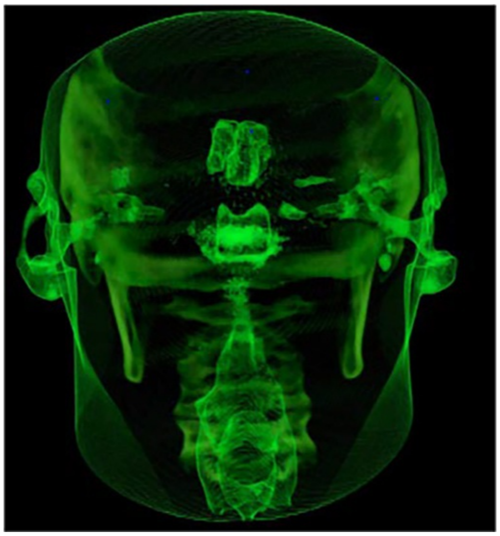
Video 13.4 Airway segmentation using InVivo Dental v5.1. Semiautomatic segmentation of the airway using InVivo Dental 5.1. Software updates made segmentation faster and more user-friendly. (Used with permission from Anatomage Inc., San Jose, CA.)



Video 13.5 Airway segmentation using OnDemand 3D v1.0. Semiautomatic segmentation of the airway using OnDemand 3D. This older version uses a combination of seed points and extensive manual sculpting. (Used with permission from Cybermed Inc., Seoul, South Korea.)

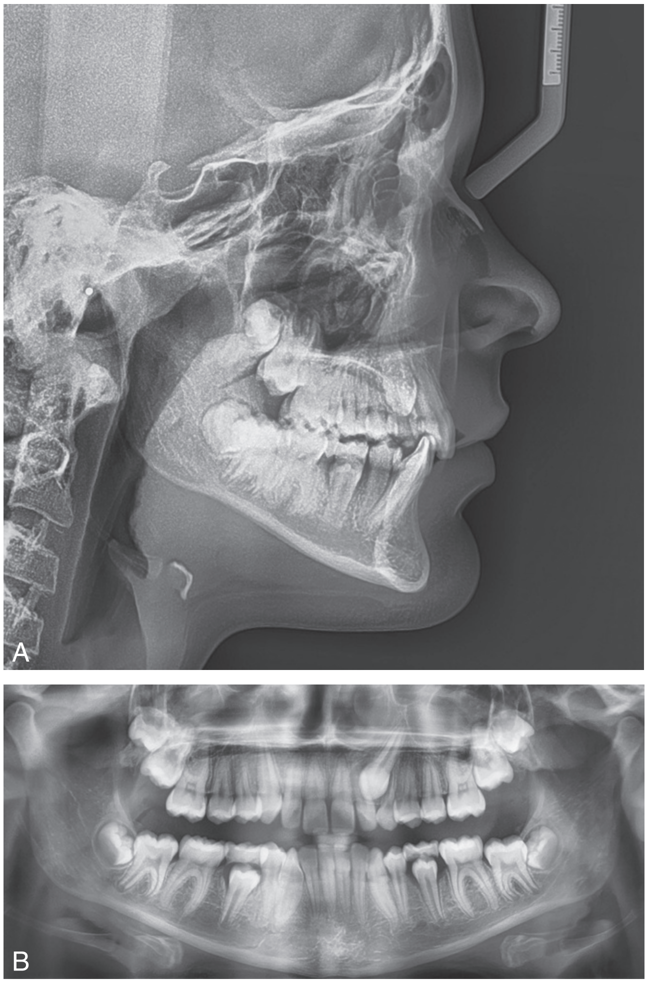


Video 13.6 **Superimposition of an OSA patient.** Superimposition of an OSA patient with *(purple)* and without *(gray)* a mandibular advancement oral appliance, in all three planes of space. (From Anatomage Inc., San Jose, CA.)



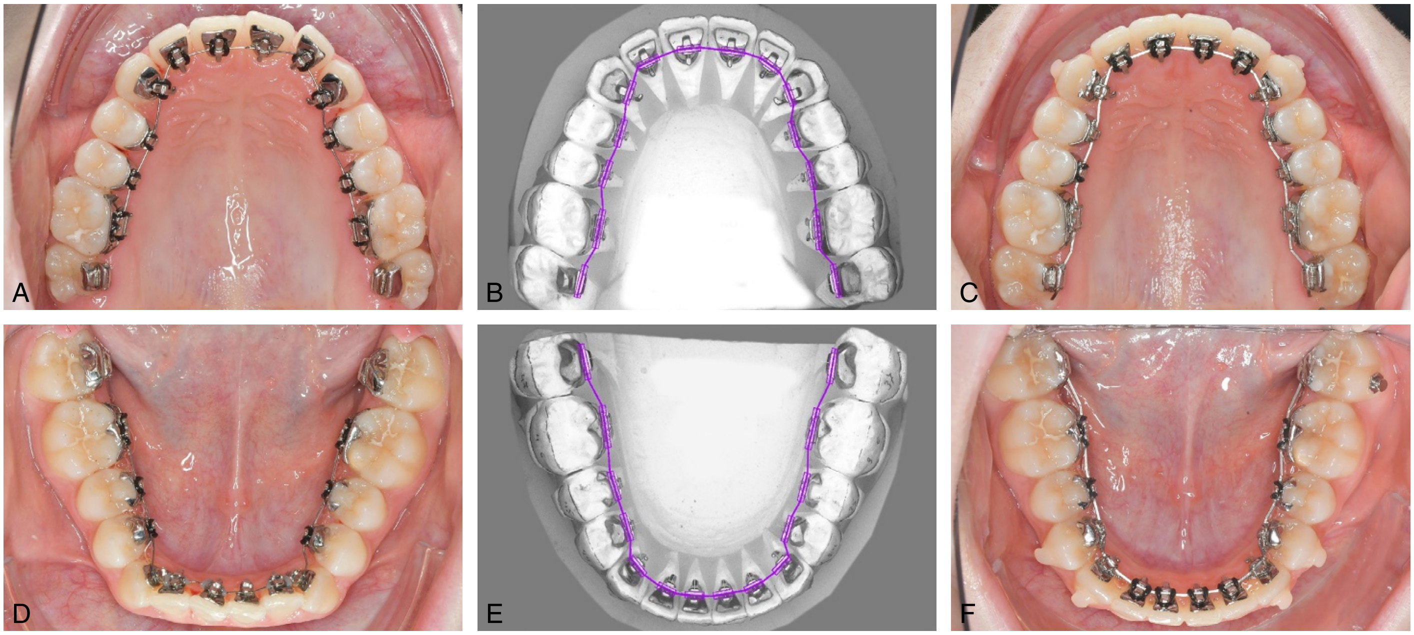
Video 13.7 **Three-dimensional superimposition of an OSA patient.** 3D superimposition of an OSA patient with *(orange)* and without *(green)* a mandibular advancement oral appliance. Notice the mediolateral change in the airway width, which would not be apparent in a lateral cephalogram.

Patient A, Page 1 Teenage female patient presented to the office to improve alignment and appearance of her smile. She displayed adequate facial esthetics and dental Class I. Crowding was mild.

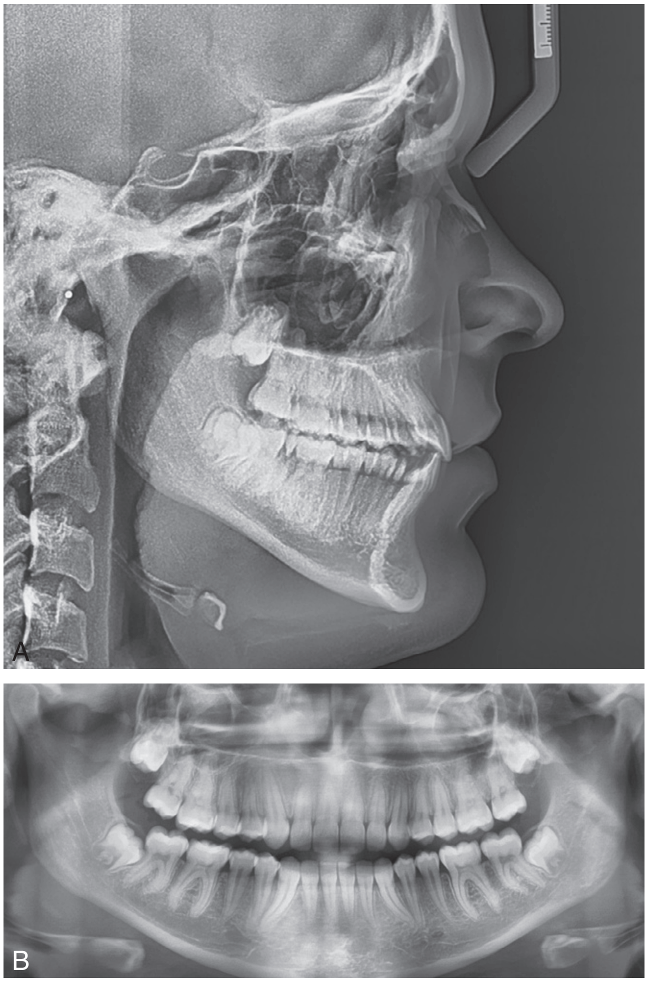


Patient A, Page 2 Radiographs were acquired before the initial photos. Normal development with slight eruption delay of upper left canine was observed.

Patient A, Page 3 Stainless steel wires of 0.024 × 0.016 inch were inserted after leveling and alignment. These wires were used for anteroposterior correction with Class II elastics attached to upper canines and lower second molars



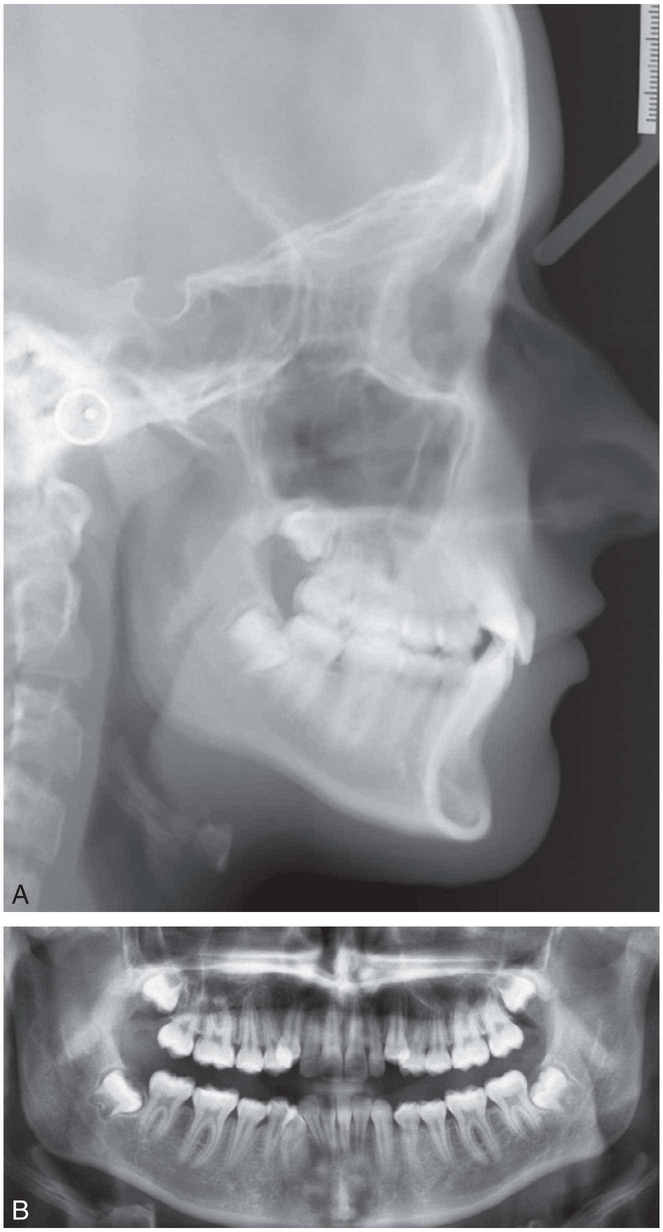
Patient A, Page 4 Completely customized lingual appliances are built on a three-dimensional simulation of the desired result. Images of the simulated outcome (B and E) can be compared with both initial bonding day (A and D), and final result before debonding (C and F). Note the maintenance of the initial dental arch form, and its implications on long-term stability. Upper and lower occlusal pads on second molars were trimmed for better interdigitation.



Patient A, Page 5 Posttreatment radiographs display adequate torque of incisors with correct interincisal angle (A). Roots are parallel; third molars might be removed in the future (B).

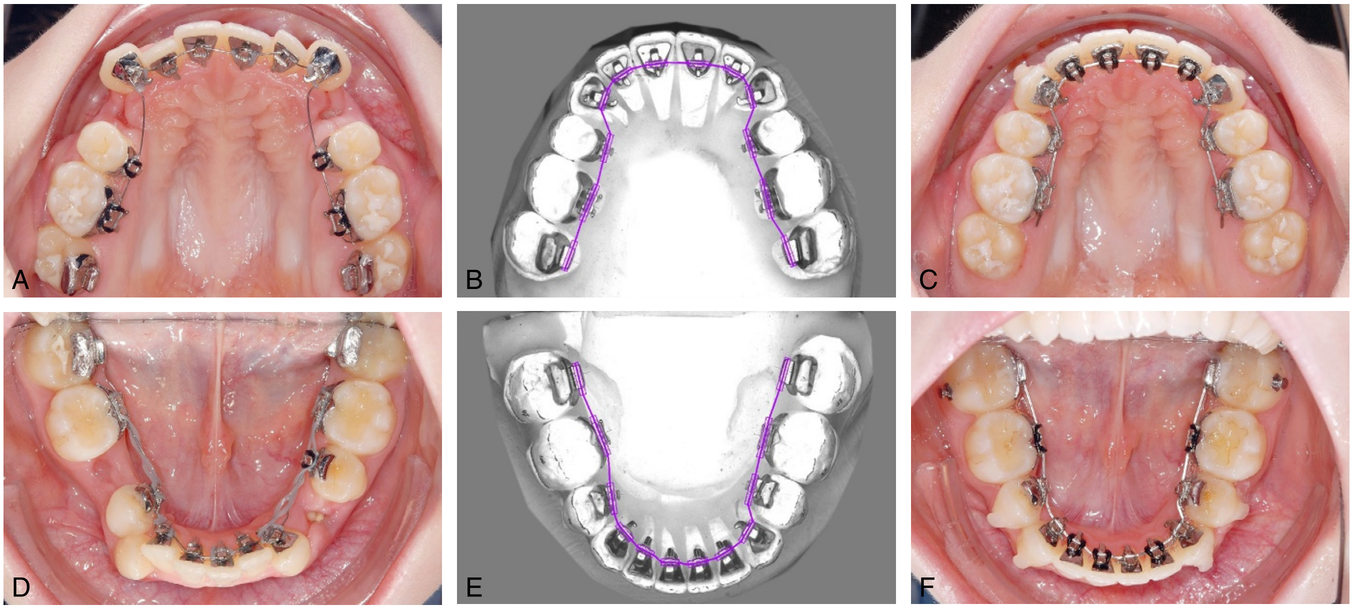
Patient A, Page 6 Patient was satisfied with her new smile. Class I dental with adequate overbite and overjet were achieved. Lower long-term retainer was bonded to incisors and canines; the upper long-term retainer was a removable retainer.

Patient B, Page 1 Teenage female patient presented to the office with chief concern of "crooked teeth." Crowding was moderate to severe, and because of the amount of crowding, the thin periodontal biotype, and the angulation of the canines, it was decided that removal of premolars was necessary to achieve alignment, adequate occlusion, and improved smile esthetics.



Patient B, Page 2 Interincisal angle and incisors' inclination (torque) was adequate at the initial radiographs, and these were maintained during treatment. Skeletal and dental Class I in a normal vertical relationship were present.

Patient B, Page 3 After leveling and alignment stainless steel wires of 0.024 × 0.016 inch were inserted. Upper wire had extra torque from canine to canine to prevent loss of inclination during en-masse retraction. Lateral segments of the wires are straight (distal to canines) to allow sliding of the wires during space closure.



Patient B, Page 4 Comparison of the initial malocclusion, the target setup and the final outcome before debonding. Note that the upper second molar brackets and lower occlusal pads on lower second molars were removed for better interdigitation.

Patient B, Page 5 Posttreatment radiographs display adequate torque of incisors with correct interincisal angle. This was only possible thanks to bodily tooth movement achieved with accurate customized lingual appliances. Note the enlargement of the periodontal ligament on the labial side of the upper central incisors representing palatal-root torque movement (A). Roots are parallel; third molars might be removed in the future (B).

Patient B, Page 6 Patient was happy with her smile. Class I dental with adequate incisor inclination, overbite, and overjet were achieved. Lower long-term bonded retainers were used in the lower dental arch, upper long-term retainer was a removable one.

Patient C, Page 1 Adult female patient presented to the office with dental Class II, retroclined upper anterior teeth, deep bite, and moderate crowding. Because of the angulation and inclination of the upper central incisors a "black triangle" was present with incomplete fill of the interincisal papilla embrasure.

Patient C, Page 6 Interincisal black triangle was corrected with the correction of the upper central incisors' angulation and inclination. Deep bite was corrected with intrusion of lower incisors and change in inclination upper incisors. Class I dental with adequate overbite and overjet were achieved. Lower long-term retainer was bonded to upper and lower anterior teeth.

Patient D, Page 1 Complex adult orthodontic patient presented to the office with dental Class II, deep-bite, moderate upper crowding, and mild lower crowding. Upper incisors were severely retroclined. Chief concern was appearance of her smile.

Patient D, Page 6 Full anteroposterior correction into Class I occlusion was possible thanks to en-masse maxillary distalization using interradicular miniscrews, Class II intermaxillary elastics, and completely customized lingual appliances. Smile esthetics, including vertical position of upper incisors, were greatly improved. Long-term retainers were bonded to upper and lower anterior teeth.

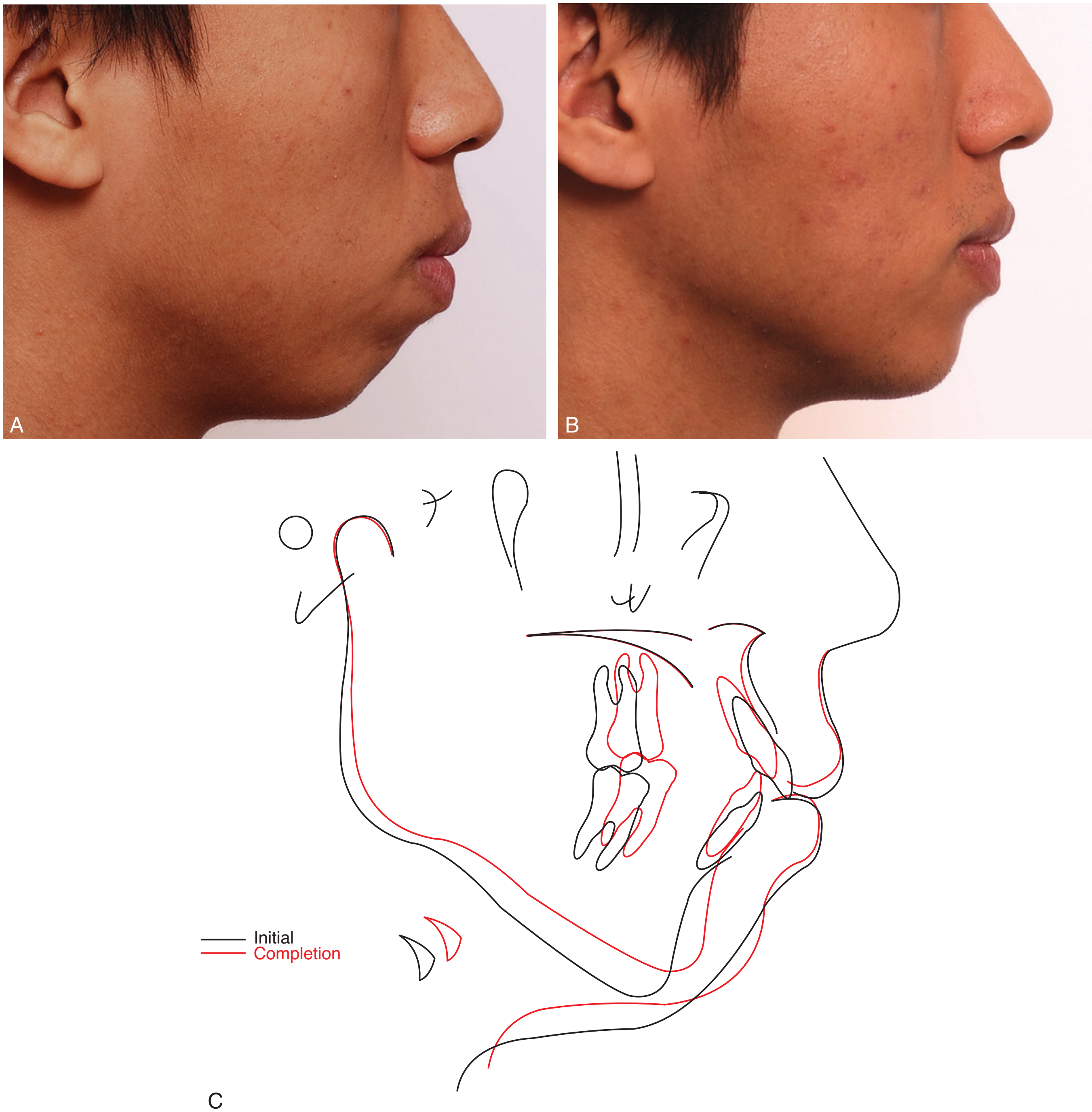


Fig. 24.4 A 22-year-old male patient's chief complaints were protrusive lips and a retrusive chin. After premolar extractions, anteroposterior and vertical disharmonies were improved by anterior retraction and molar intrusion. The chin position was also altered through molar intrusion and subsequent autorotation of the mandible. The duration of active treatment was 31 months. **A,** Lateral facial view before treatment. **B,** Lateral facial view after treatment. **C,** Superimposition of pretreatment and posttreatment cephalometric radiographs. (Refer to online version for more details.)

Shifting from a Mechanics-Centered Approach

Although anchorage preparation has become easier and simpler with TADs and the range of orthodontic and orthopedic treatment has broadened (see Case Studies 24.1 through 24.4 for more details), the need to consider additional factors has resulted. To put it more simply, the decision between extraction and nonextraction treatment was a key factor with conventional mechanics in the past. However, further considerations, such as whether to intrude teeth, have become necessary with TAD mechanics. The *mechanics* portion of biomechanics used to be the main limiting factor in anchorage control in conventional treatment, whereas the *bio*, or biological, aspect has become the main limiting factor in treatment using TAD mechanics. For the proper use of effective and powerful mechanics, a comprehensive understanding and active adjustment of the "bio" aspect is necessary.[68-76]

Fig. 24.4 A 22-year-old male patient's chief complaints were protrusive lips and a retrusive chin. After premolar extractions, anteroposterior and vertical disharmonies were improved by anterior retraction and molar intrusion. The chin position was also altered through molar intrusion and subsequent autorotation of the mandible (Figs. 24.24 and 24.27). Furthermore, the frontal occlusal plane was monitored during space closure. The duration of active treatment was 31 months. Although the upper incisors protruded slightly and the labial bow of the upper removable retainer was broken because of suspected bruxism, the patient's chin position and vertical dimension were well maintained 4.5 years after completion of treatment. **A, B,** Facial views prior to treatment. **C, D,** Intraoral views prior to treatment.

Continued

Fig. 24.4, cont'd E–G, Intraoral views at the start of active treatment. H, I, Facial views at the completion of treatment. J, K, Intraoral views at the completion of treatment. L, M, Intraoral view at 4.5-year posttreatment follow-up.

Continued

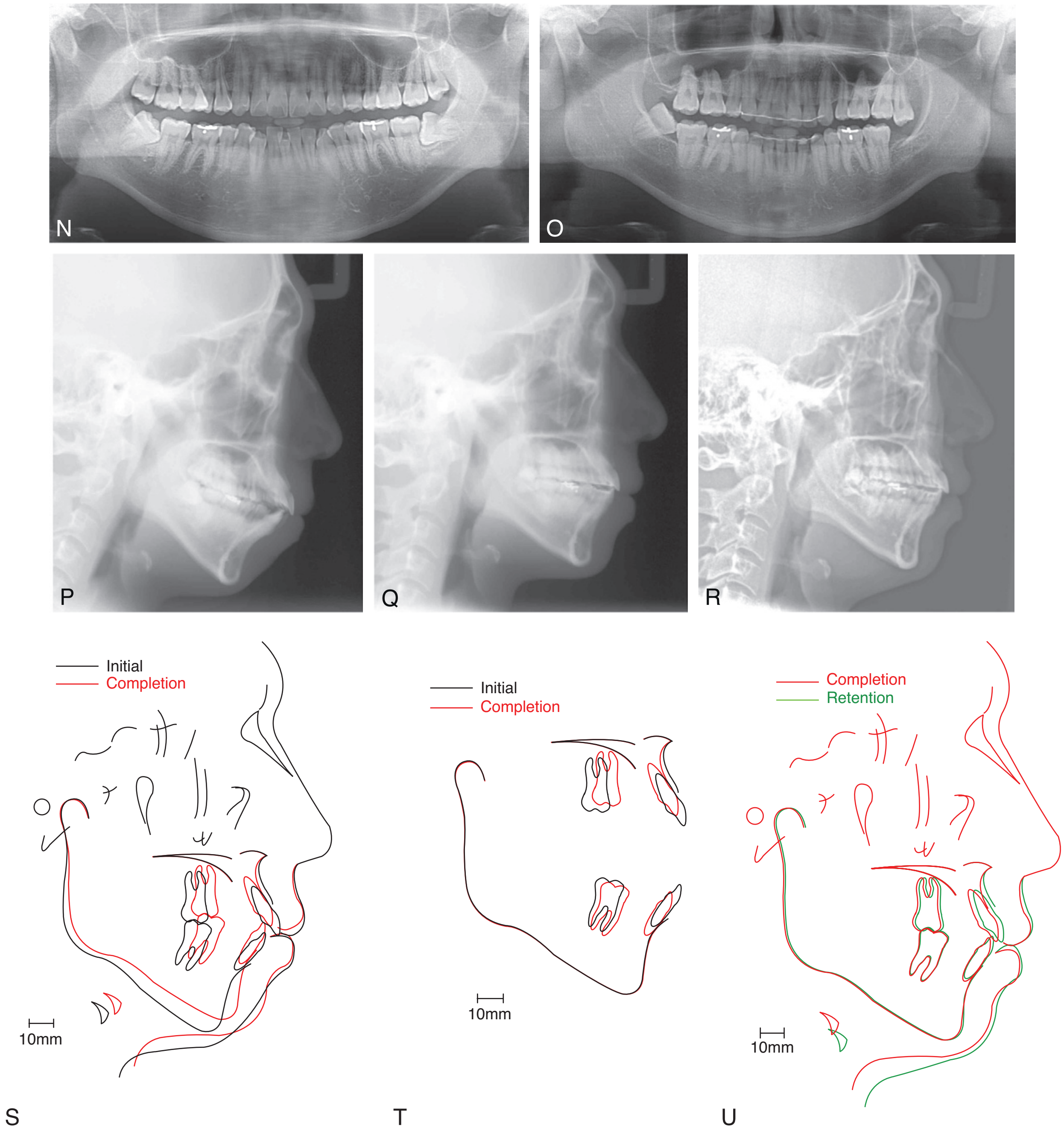


Fig. 24.4, cont'd N, Panoramic radiograph prior to treatment. O, Panoramic radiograph view at the 4.5-year posttreatment follow-up. P, Cephalometric radiograph prior to treatment. Q, Cephalometric radiograph at the completion of treatment. R, Cephalometric radiograph at the 4.5-year posttreatment follow-up. S, Overall superimposition of pre- and posttreatment cephalometric radiographs. T, Maxillary and mandibular superimpositions of pre- and posttreatment cephalometric radiographs. U, Overall superimposition of posttreatment and 4.5-year posttreatment follow-up cephalometric radiographs.

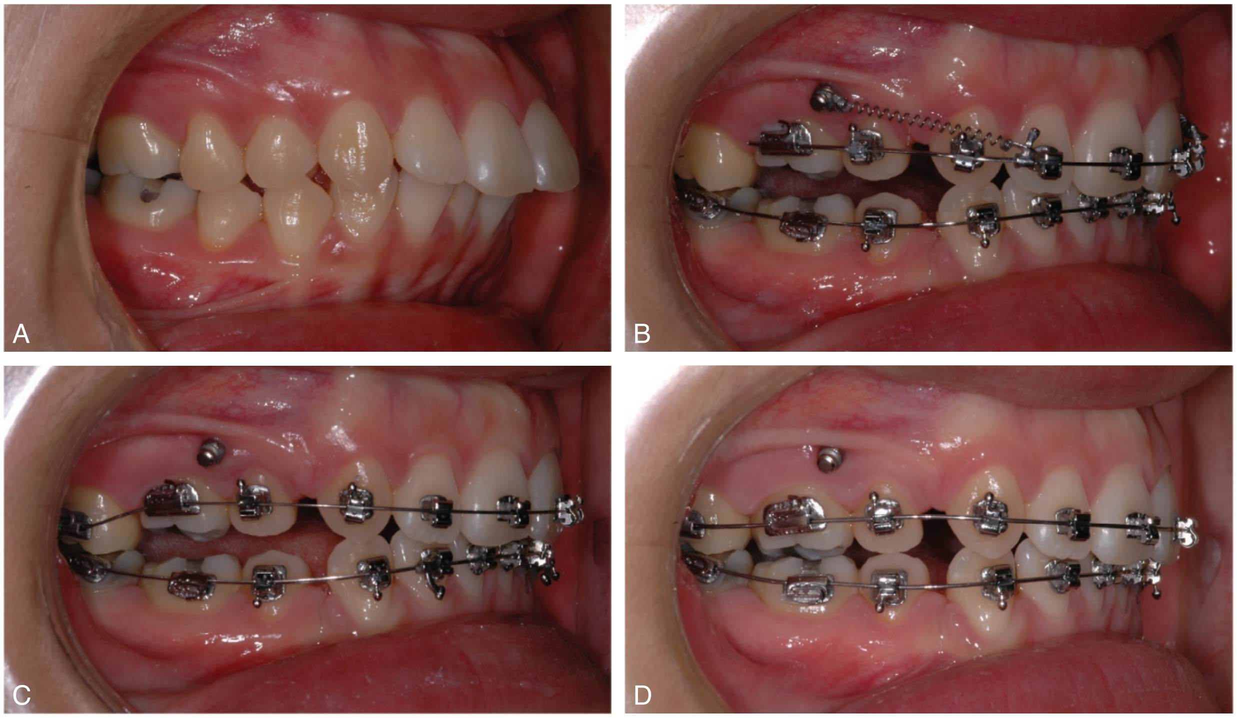


Fig. 24.51 Canine axis control and control of the intrusive force vector are important in preventing posterior bite opening. Posterior bite opening was corrected in this case using canine axis control and wire engagement into the second molar. **A,** Intraoral view before treatment. **B,** Intraoral view during anterior retraction, demonstrating posterior bite opening. **C,** An attachment was bonded to the second molar. A leveling archwire was placed, and the retraction force was removed. **D,** Intraoral view during anterior retraction, demonstrating an improvement in the posterior bite.

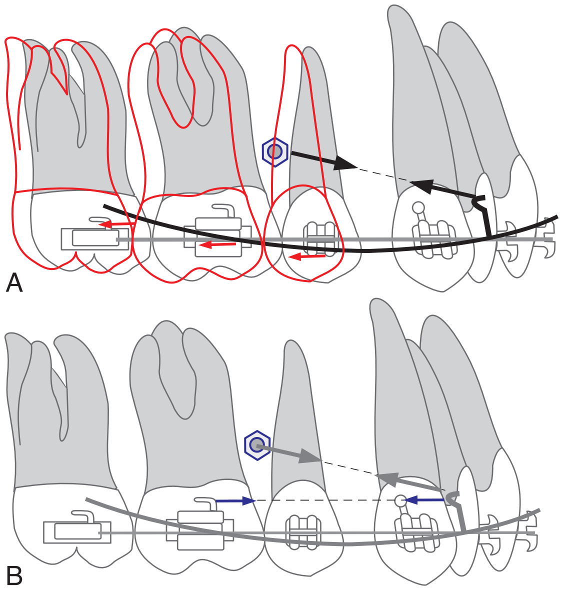


Fig. 24.52 When a TAD is used for anterior retraction, particularly with a curved main archwire, the retraction force can be delivered to the posterior teeth by friction of the archwire. As a consequence, the posterior teeth move distally (**A**). This distal movement of the posterior teeth can be monitored by checking the intermaxillary occlusal relationship. Application of a light force to the molar is useful in maintaining molar position (**B**).

monitored, side effects such as occlusal plane canting can occur. When a curved main archwire is used, the retraction force from the TADs can reach the molars and eventually the molars can be distalized in conjunction with anterior retraction. One should remember that the TAD itself is not controlling the canine axis and anterior torque.

CASE STUDIES

Four case studies, including detailed treatment records, are available in the online version of this chapter. They demonstrate practical use of the principles discussed in this segment of the chapter. Please use the Expert Consult eBook feature to access these clinical reports.

Prospective Insight

For successful treatment, designing treatment mechanics with an optimal force system based on biomechanical principles is important. However, even with the same mechanics and force systems, different outcomes can result depending on functions of the orofacial muscles. Broadly speaking, conditioning or intervention of the orofacial muscle functions should be considered in the design and application of mechanics.

Recent studies have emphasized the necessity of brain intervention, which is using central control for the periphery.[235,243,245,272,273] A biomechanical understanding based on physics is well developed, but a biomechanical understanding based on physics of the mind (i.e., neuroscience) is still in development, with a great deal of insufficiency. The next biomechanical consideration of TAD mechanics is to manage the "invisible" forces and moments stemming from the brain.

CASE STUDY 24.1 Treatment of Congenitally Missing Teeth

Molar Protraction Using Asymmetric Mechanics

The patient was a 20-year-old woman whose chief complaints were mobile primary molars, anterior crowding, and minor protrusion. The primary molars were retained at the sites of congenitally missing upper left second and lower right second premolars. Prosthodontic treatment after extraction of the primary molars was an option, but the patient desired a conservative approach and also wished to correct the anterior crowding. Therefore protraction of the maxillary left and mandibular right molars with TADs after extraction of the primary molars was planned to close the spaces left by the congenitally missing premolars and to relieve the anterior crowding. The presence of the mandibular right third molar allowed for proper occlusion with the maxillary right second molar after protraction of the mandibular right first and second molars.

For satisfactory treatment results and facial esthetics, overretraction of the anterior teeth had to be prevented, and each molar needed to be anteroposteriorly controlled using asymmetric mechanics.

In an effort to protract the molars while controlling their anteroposterior positions, continuous arch mechanics and lever-arm mechanics were used (Fig. 24.53CD). The mechanics consisted of 0.022-inch slot SPEED brackets (SPEED System Orthodontics, Ontario, Canada), buccal Orlus TADs (1.8 mm in diameter and 7.0 mm in length in the maxilla, 1.6 mm in diameter and 7.0 mm in length in the mandible) (Ortholution Co., Seoul, Korea) and 0.017- × 0.022-inch SPEED stainless-steel wires. An average compensating curve (reverse curve of Spee) was placed in the wires to prevent mesial angulation of the molars during protraction. Furthermore, constriction bends were used to prevent arch widening.

Lever arms were placed on the molars to apply protraction forces near the center of resistance to prevent mesial tilting and unwanted intrusive forces that could lead to occlusal canting.

The second molars were included during full bonding, initially to aid first-order rotation control of the first molars and then to maintain arch form.

The mechanical design is important, but the three-dimensional monitoring of the factors that contribute to the design is more critical. For example, if first-order rotation and arch form control are insufficient, the mandibular second molar will tilt buccally and the buccal overjet will become shallow or a crossbite may develop. If a shallow overjet or crossbite results after the protraction force is reduced and the arch form is adjusted, components that control first-order rotation and arch form, such as lingual attachments and lingual force vectors, can be added to the design of the mechanics.

Active treatment to achieve the desired results was completed after 24 months. Radiographic examination showed that all of the molars were vertically and anteroposteriorly well controlled (see Fig. 24.53M–R). Furthermore, although pneumatization of the maxillary sinuses was present, this did not present an obstacle in the protraction of the maxillary left molars.

Fixed retainers extending from first premolar to first premolar were used in the maxilla and mandible. In addition, a maxillary circumferential retainer was worn at night. The results were well maintained 1 year after treatment.

Dr. Jung Kook Kim

Continued

CASE STUDY 24.1 **Treatment of Congenitally Missing Teeth —cont'd**

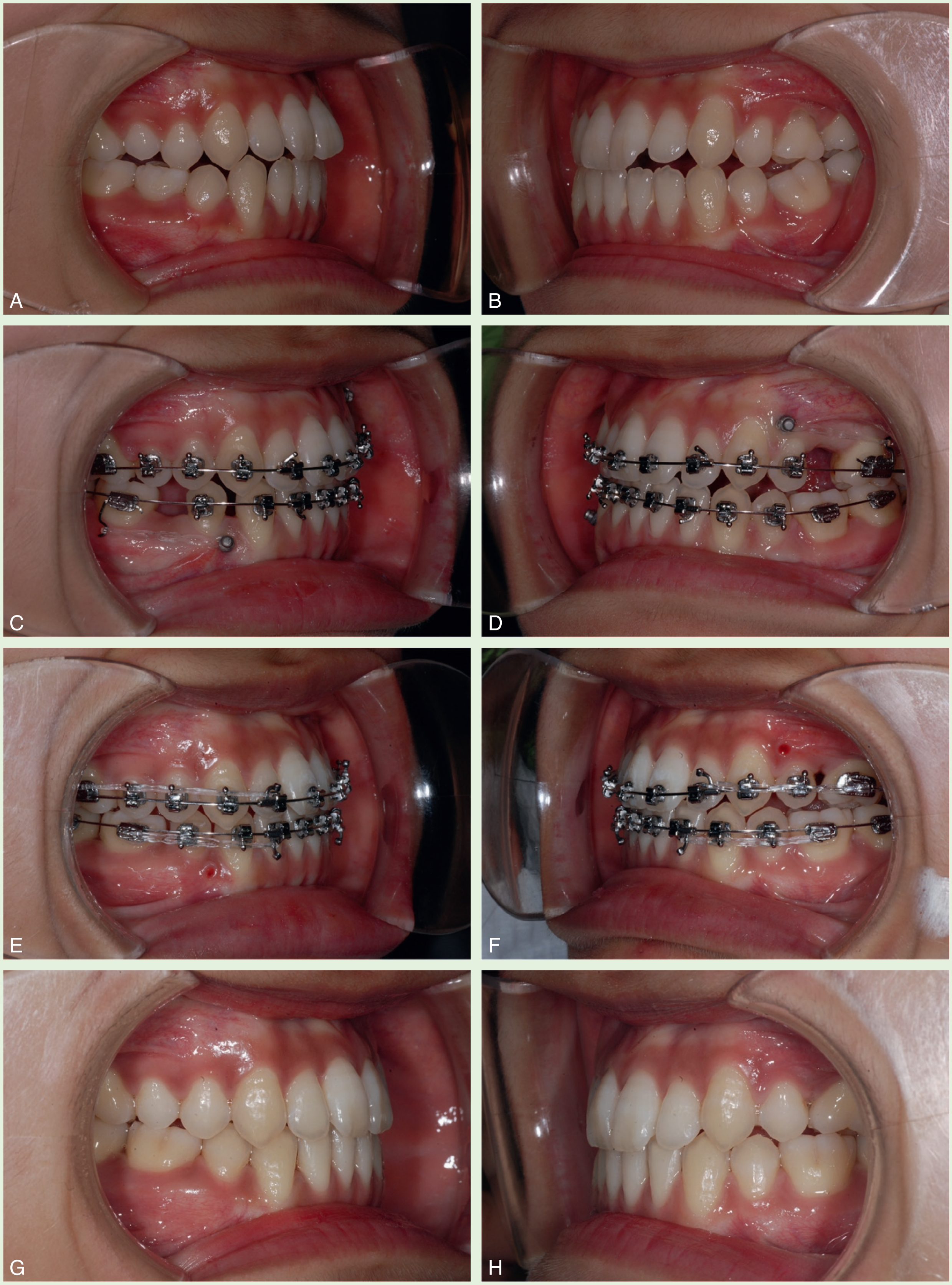


Fig. 24.53 A, B, Intraoral views before treatment. C, D, Intraoral views during treatment. E, F, Intraoral views after molar protraction. G, H, Intraoral views at the completion of active treatment.

CASE STUDY 24.1 **Treatment of Congenitally Missing Teeth —cont'd**

M N

Fig. 24.53, cont'd **I, J,** Intraoral views 10 months after the completion of active treatment. **K,** Profile view before treatment. **L,** Profile view at the completion of active treatment. **M,** Panoramic radiograph before treatment. **N,** Panoramic radiograph at the completion of active treatment.

Continued

CASE STUDY 24.3 Nonsurgical Correction of Vertical Excess—cont'd

Active treatment to the desired position was completed after 20 months. The entire dentition was distalized and intruded with only the use of buccal TADs. The cephalometric superimposition showed that the upper and lower anteriors were retracted and that the chin point had moved upward and forward (see Fig. 24.55W).

Fixed retainers extending from first premolar to first premolar were used in the maxilla and mandible. A maxillary circumferential retainer was also worn at night. At 18 months' posttreatment follow-up, the results were well maintained (see Fig. 24.55P–R).

Fig. 24.55, cont'd G–I, Intraoral views during treatment. J–L, Facial views at the completion of active treatment.

CASE STUDY 24.4 Correction of Occlusal Cant and Midline—cont'd

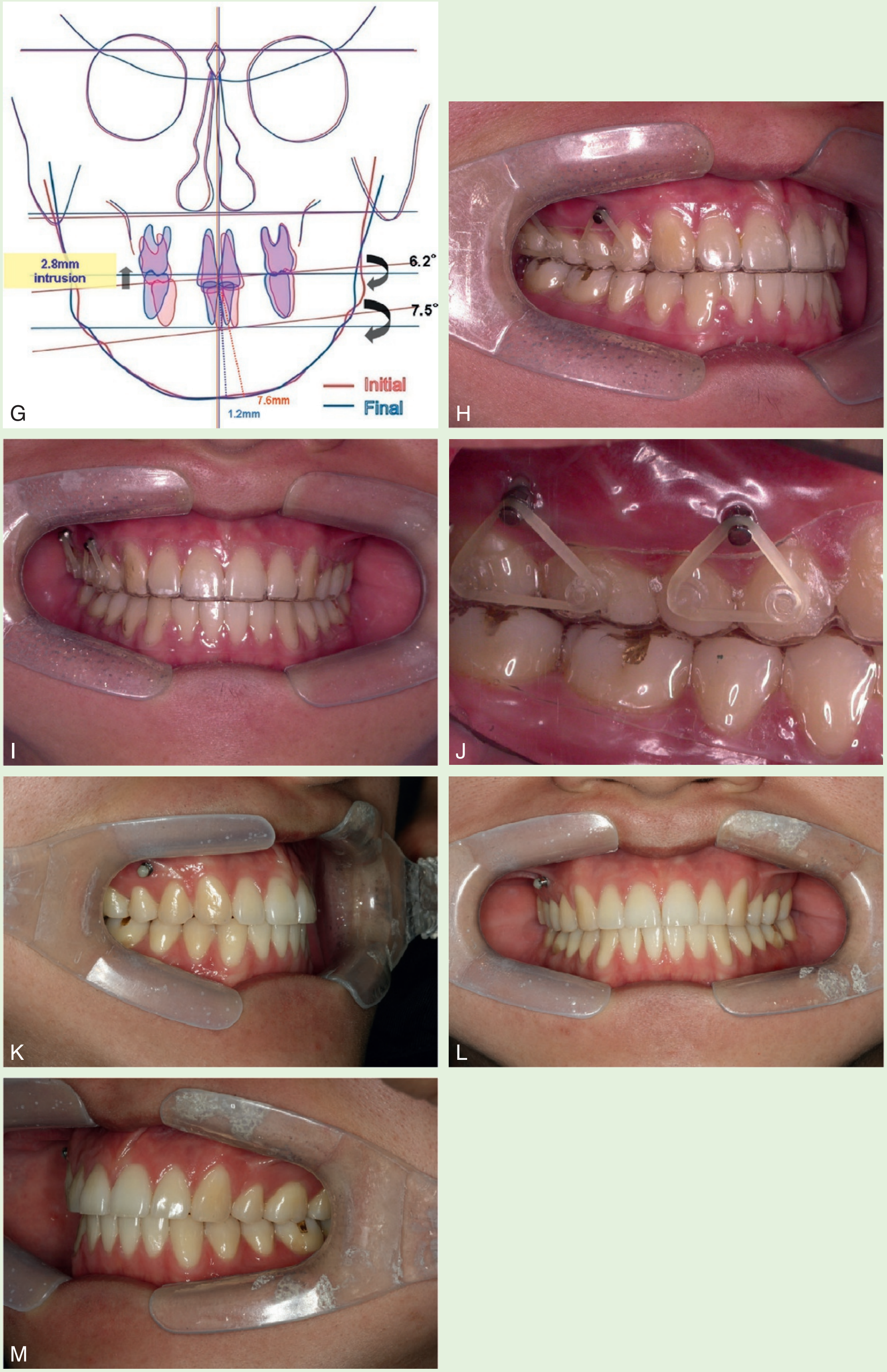


Fig. 24.57, cont'd G, Superimposition of posteroanterior cephalometric radiographs. H–J, Intraoral views with active retainers. K–M, Intraoral views at 27 months' retention.

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Aerosols in Orthodontics

Anthony Ireland

OUTLINE

At the time of writing, the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) COVID-19 pandemic is ongoing and as a result there has been intense interest in potential aerosol-generating procedures in both general dentistry and orthodontics. This chapter aims to provide an understanding of what an aerosol is, when it might be generated, what it may comprise, the potential health implications in the clinical setting, and how to reduce their impact.

WHAT IS AN AEROSOL?

As defined by Hinds,[1] an aerosol, or aero-solution, is a suspension of solid particles, liquid droplets, or a mixture of the two within a gas, and where the size of the individual particles or droplets are less than 100 µm in diameter.[2] The term *aerosol* was first associated with the work of F.G. Donnan, a British chemist during World War 1, who used it to describe microscopic and submicroscopic clouds of particles in air.[2] These clouds were considered analogous to a liquid colloidal suspension therefore displaying some degree of stability with respect to gravitational effects. This means an aerosol may remain present within the ambient air for minutes, hours, or even days once produced. The ability to display gravitational stability is not the sole defining characteristic of an aerosol. Other factors may include particle size, mass, density, electrostatic charge, concentration, thermal or Brownian motion with respect to the gas, the gas itself, temperature, and electromagnetic radiation.[2] As a result of their small size, aerosol particles—whether solid, liquid, or both—may also display properties that are very different to the bulk material from which they arise and may be affected by the way in which they are created.[3] This can affect their behavior in air, as well as any potential health effects. For example, some vapors may react to form larger solid particulates, whereas liquid droplets may similarly coalesce to form larger droplets or conversely begin to evaporate and form smaller droplets, which will behave in a different manner, principally as a result of their change in size.

Aerosols are common in everyday life and can arise as a result of domestic, social, industrial, or natural processes. Examples include fog, mist, volcanic emissions, smoke from fires, and car and factory emissions. While some aerosols may be unwanted, others are specifically engineered to be of benefit, for example paints and coatings used in industrial processes, and in healthcare inhalers used in the treatment of acute and chronic asthma.

WHAT HAPPENS TO AEROSOL PARTICLES AND DROPLETS ONCE GENERATED?

Once generated, aerosols and droplets may be of sufficiently large size and mass that they behave with a ballistic trajectory and end up being deposited onto a surface at some distance from the point of generation. What this means is that they move away from the source and land on a more distant surface in much the same way as a shell fired from an artillery piece, hence the term *ballistic trajectory* (Fig. 35.1). In dentistry this may result in particles being deposited onto the operator's hands (Fig. 35.2), the patient's face, or perhaps an adjacent work surface within the surgery. Although such particulates/droplets may not pose a direct inhalation risk because of their relatively large size and therefore behavior in air, they may potentially contaminate the surfaces on which they are deposited with infective material. Interestingly, work by Barker et al.,[4] who examined both "as received" and "clinically exposed" materials within the dental surgery showed low levels of bacterial contamination on both sets of materials, and therefore considered the risk of contamination from operative procedures on materials left on surfaces within the clinic to be low. However, more recent work using settling plates and fluorescein dye has demonstrated that splatter may be deposited some meters away from the point of generation.[5] This might be as a result of large aerosol droplets either landing directly onto a surface, or by smaller droplets coalescing and eventually settling under the influence of gravity.

Although larger particles and droplets may have a ballistic trajectory, smaller particles may remain suspended in relatively nonturbulent ambient air for minutes, hours, or even days.[6] The exact timing will therefore to

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Interceptive Guidance of Occlusion with Emphasis on Diagnosis

Jack G. Dale[*,†] *and Hali C. Dale*

The concepts behind guided extraction and orthodontic treatment have been developed over time and are reflected herein to be most current. Over the years, there have been a number of "champions" of the technique who worked hard to teach the concepts involved. Dr. Warren R. Mayne, one of the original champions, worked with Dr. Tom Graber and contributed the guided extraction chapter in the first and second editions of this text. Both the authors and the editors recognize his initial contributions. We are all happy to see the concepts underlying guided extraction still relevant for today's clinician.

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OUTLINE

This Classic Chapter in Orthodontics is taken from our fifth edition published by Elsevier in 2012. It is presented as then written. The chapter contains perspectives and information that remain valuable to orthodontic residents and clinicians.

As we learn more about growth and its potentials, more about the influences of function on the developing denture, and more about the normal mediodistal position of the denture in its relation to basal jawbones and head structures, we will acquire a better understanding of when and how to intervene in the guidance of growth processes so that Nature may better approximate her growth plan for the individual patient. In other words, knowledge will gradually replace harsh mechanics, and in the not-too-distant future the vast majority of orthodontic treatment will be carried out during the mixed-dentition period of growth and development and before the difficult age of adolescence.

—Charles H. Tweed

The term *serial extraction* was first introduced by Kjellgren[1,2] in 1929. Special knowledge is required to carry out this procedure successfully. Unfortunately, Kjellgren's phrase resulted in the indiscriminate removal of teeth by individuals who have not appreciated the requisite knowledge. A common misconception is that the procedure is easy because it implies simply the removal of teeth serially.

Hotz,[3] however, referred to the procedure as *guidance of eruption*. This is a better title than Kjellgren's because it implies that knowledge of growth and development is necessary to direct the teeth as they erupt into occlusion. The term *guidance of occlusion* is even more appropriate because clinicians are interested in the final destination of

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* For more about this author click here

† An article in memoriam of author Jack G. Dale can be found at the following link: http://www.sciencedirect.com/science/article/pii/S0889540616001827

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Functional Appliances

*Thomas M. Graber**

OUTLINE

This Classic Chapter in Orthodontics is taken from our fourth edition of Orthodontics: Current Principles and Techniques published by Elsevier. It is presented as then written with added references to related seventh edition textbook chapters and authors. The chapter contains perspectives and information that remain valuable to orthodontic residents and clinicians. The underlying principles of functional appliances have not changed.

The stomatognathic system consists of the teeth, the periodontal membranes, alveolar and basal bone, the temporomandibular joints (TMJs), and the motivating and draping neuromusculature. This is a living, viable, and remarkably adaptive system, particularly during the period of growth and development of the craniofacial complex. Bone may be one of the hardest tissues in the human body, but it is also one of the most responsive to environmental stimuli. For example, persons have known for many centuries that the membranous bone cranial structures can be deformed by binding an infant's skull, as was done by the Inca Indians.[1] Pathologic manifestations can result in bizarre craniofacial asymmetries and deformities that involve cranial and mandibular structures. Practitioners can learn much about the normal condition from pathologic conditions.

Orthopedic surgeons have corrected skeletal endochondral deformities for many years, primarily in growing individuals. However, influencing endochondral bone is known to be a greater challenge. The chapters in this book by Hatch and Sun (Chapter 4) and Huja and Roberts (Chapter 5) describe the *raison d'être* for this tissue reaction, and the reader should become familiar with the minutiae to better understand important factors such as the way appliances work, the best time to use them, and their limitations. An orthodontic practitioner cannot help but be excited by the prospect of using the patient's own functional forces to achieve orthopedic and orthodontic correction of dentofacial abnormalities. Indeed, previous overconcentration on the mechanical aspects of orthodontics has been a barrier to the full realization of the magnitude of influence that is possible. Orthodontics is not only the appliance, but it is about which appliances, why, when, and for how long.

ORIGIN

Theories on bone plasticity may be traced to Wolff[2] and Roux,[3] who believed that form and function were intimately related. Changes in functional stress produced changes in internal bone architecture and external shape. Recent research has supported Roux's concept of functional "shaking of the bone," and the anabolic stimulus applied to achieve the optimal morphogenetic pattern.[4-6]

Early in the twentieth century, Pierre Robin of France introduced the plastic monobloc as a passive positioning device. This device was used in neonates with micromandibular development to prevent glossoptosis, which is literally a blocking of the airway by the tongue.[7] This congenital abnormality of development has been called Pierre Robin syndrome and is usually associated with cleft palate. The Robin appliance was modified from bite-jumping vulcanite maxillary anterior guide planes designed by Norman Kingsley.[8] However, the Kingsley guide plane was attached to teeth, whereas Robin had to use his monobloc as a removable device because newborns have no teeth.

ANDRESEN ACTIVATOR

Viggo Andresen of Norway also was familiar with the writings of American authors Norman Kingsley[8] and Calvin Case.[9] Their use of bite-jumping appliances was common among other orthodontists at the end of the 19th century. Even Angle originally resorted to and recommended such appliances for patients with mandibular retrusion.[10] Also on Andresen's bookshelf was a favorite of his, the orthodontic textbook

* For more about this author click here

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Treatment of the Face with Biocompatible Orthodontics

Dwight Damon

OUTLINE

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Author's Note:
The principles underlying orthodontic treatment planning and mechanotherapy discussed within this "classic" chapter remain correct. Readers are recommended to reference current iterations of appliances, including archwire type and sequencing, as they integrate these concepts into their patient practices.

THE DAMON SYSTEM CONCEPT

The philosophy underlying the intended use of the Damon System (Ormco Corporation, Orange, CA) is to approximate biologically induced, tooth-moving forces in each phase of orthodontic treatment. The Damon System achieves this goal by means of a passive, virtually friction-free, self-locking, fixed-appliance conduit that maximizes the full potential of today's high-tech archwires. By doing so, the Damon System provides a reliable and simple means of achieving the best possible facial balance for each patient through the use of light forces that foster corrective functional adaptation of the archform while maximizing patient comfort during treatment. This functional adaptation is similar to the *Fränkel effect* in its posterior arch-widening results. Traditional treatment planning has long been based on maintaining the original archform for stability. In patients with muscle imbalance and collapsed archforms, tooth mass often had to be eliminated. Extensive clinical results indicate that clinicians can now maintain most complete dentitions, even in severely crowded arches, by using very light–force, high-tech archwires in the passive Damon appliance that alter the balance of forces among the lips, tongue, and muscles of the face. This alteration creates a new force equilibrium that allows the archform to reshape itself to accommodate the teeth; the body, not the clinician, determines where the teeth should be positioned. The author refers to this phenomenon as "physiologically determined" tooth positioning. Computed tomographic (CT) scans taken of patients just debonded and those in retention for longer than 5 years demonstrate that using light forces in a passive tube with a small wire-to-lumen ratio enables teeth to be bodily moved, without excessive tipping, in all planes of space and that alveolar bone will follow. This compelling research calls for a significant shift in thinking and treatment planning, reducing and even eliminating the need for molar distalization, extractions (excluding those deemed appropriate for bimaxillary protrusive cases), and rapid palatal expansion.

Practicing orthodontist Alan Pollard describes the Damon appliance system as unique in offering "rapid alignment with gentle forces, functional adaptation and accurate, predictable tooth positioning with micro precision." He continues, "It provides a well-documented means,

CASE STUDY 40.1 Achieving Facial Harmony with Facially Driven Treatment Planning—cont'd

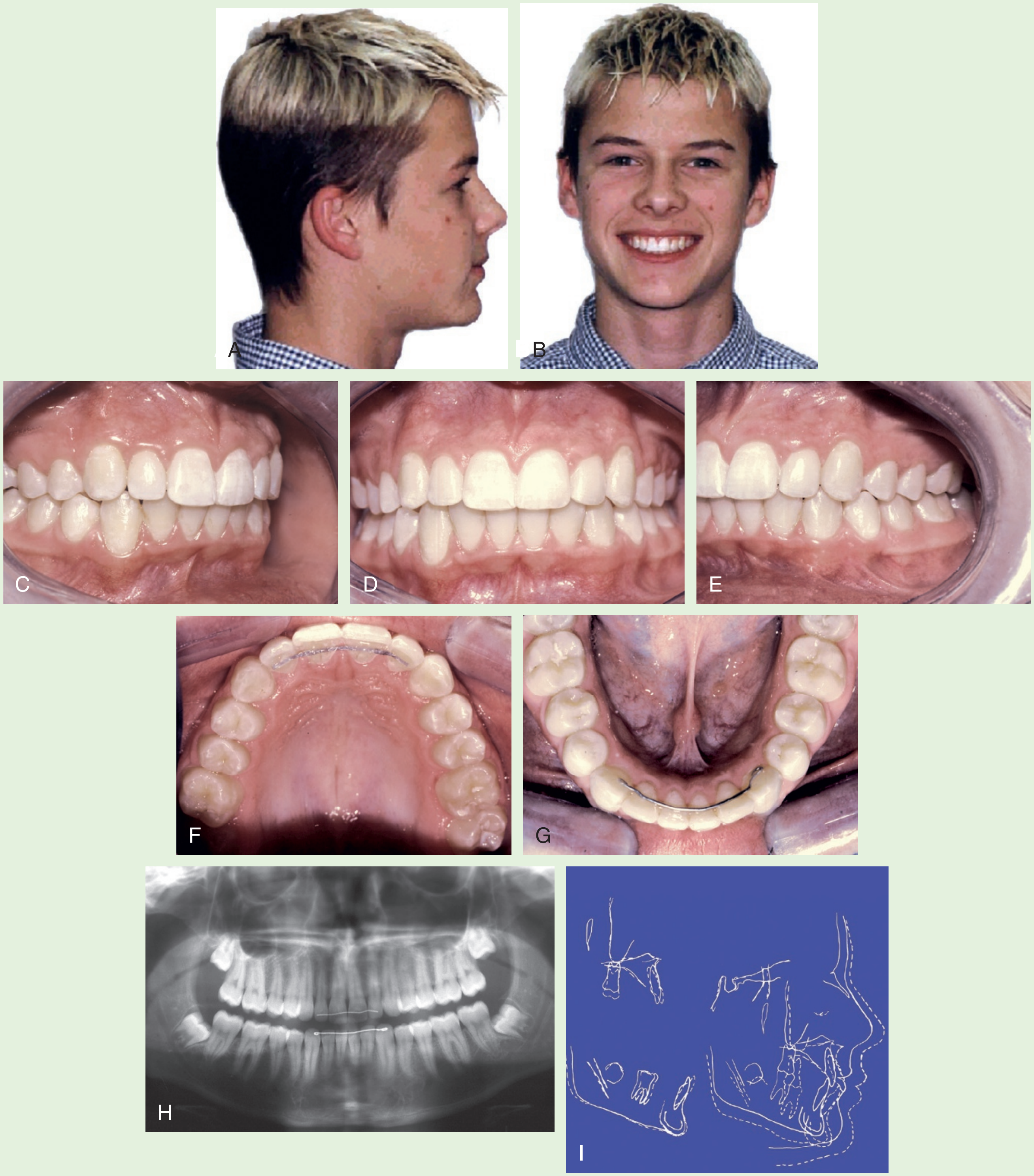

Fig. 40.12 **A–I,** Posttreatment records of CB. Total treatment time: 33 months, 2 weeks with 16 appointments. The length of treatment was dictated, in part, by the time required for the canines to erupt into the arch and the fact that the patient did not keep his appointments for 6 months during midtreatment.

Continued

CASE STUDY 40.1 Achieving Facial Harmony with Facially Driven Treatment Planning—cont'd

Fig. 40.13 These photographs track the maturation of CB's profile from 13 years, 4 months to 20 years, 8 months, clearly demonstrating how well the Damon System served CB in precluding extraction therapy.

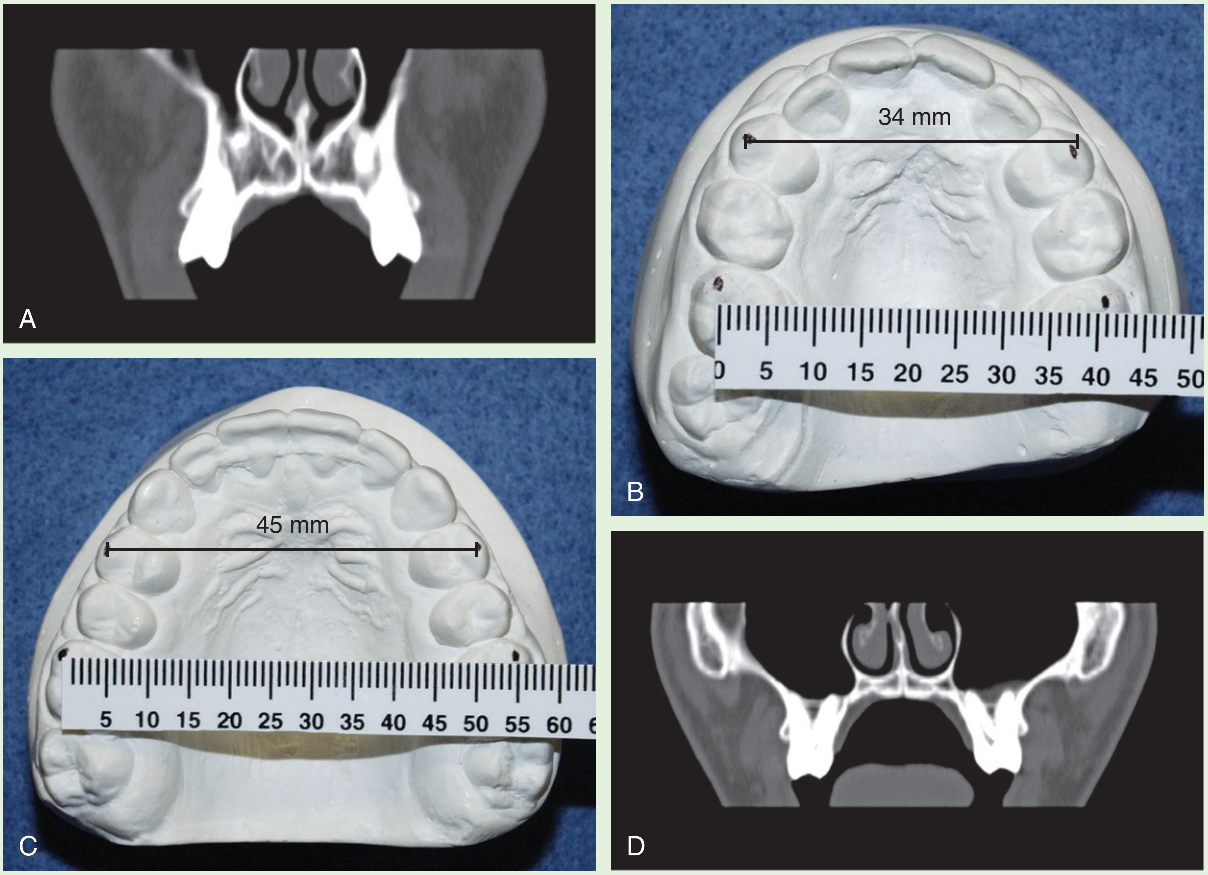

Fig. 40.14 Comparisons of pretreatment and posttreatment upper arch plaster models for CB with computed tomographic scans. Pretreatment and posttreatment plaster models of the upper arch show 11-mm change in first premolar width (and an estimated 12- to 13-mm change in second premolar width) and 14-mm change in first molar width. The bony contours on the buccal of the first premolars and first molars are evident. Vertical scans taken 5 years, 3 months into retention show healthy alveolar bone. **A,** Scan of upper first premolars at 5 years, 3 months in retention. **B,** Pretreatment. First premolars: 34 mm; first molars: 41 mm. **C,** Posttreatment. First premolars: 45 mm; first molars: 55 mm. **D,** Scan of upper first molars 5 years, 3 months in retention.

CASE STUDY 40.1 Achieving Facial Harmony with Facially Driven Treatment Planning—cont'd

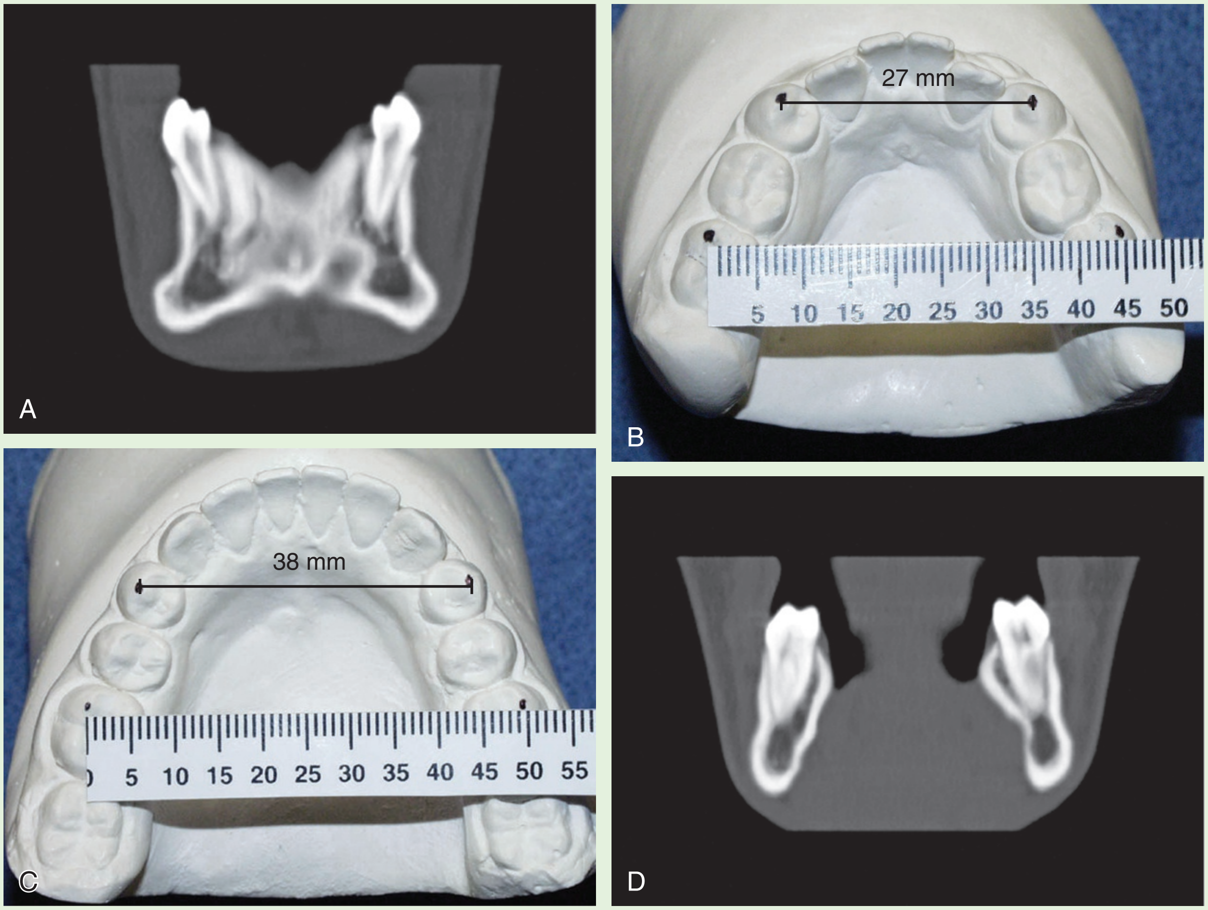

Fig. 40.15 Comparisons of pretreatment and posttreatment lower arch plaster models for CB with computed tomographic scans. Pretreatment and posttreatment models of lower arch show 11-mm change in first premolar width and 5-mm change in first molar width. Vertical scans, taken 5 years, 3 months into retention, show healthy alveolar bone. **A,** Scan of lower first premolars 5 years, 3 months in retention. **B,** Pretreatment. First premolars: 27 mm; first molars: 44.5 mm. **C,** Posttreatment. First premolars: 38 mm; first molars: 49.5 mm. **D,** Scan of lower first molars 5 years and 3 months in retention.

Fig. 40.16 The horizontal computed tomographic scan of CB's upper arch illustrates the well-shaped archform.

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CASE STUDY 40.1 Achieving Facial Harmony with Facially Driven Treatment Planning—cont'd

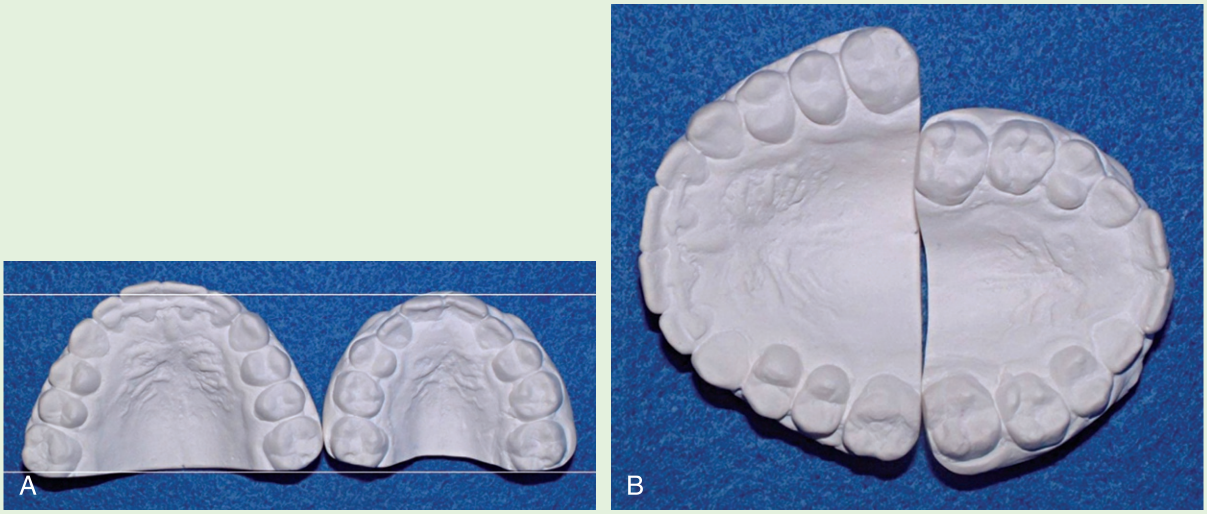

Fig. 40.17 A, B, Plaster models demonstrate that the arch length gain was in the transverse achieved through bodily movement of the teeth and desirable tipping of the posterior teeth. The improvement in palatal contours is also evident.

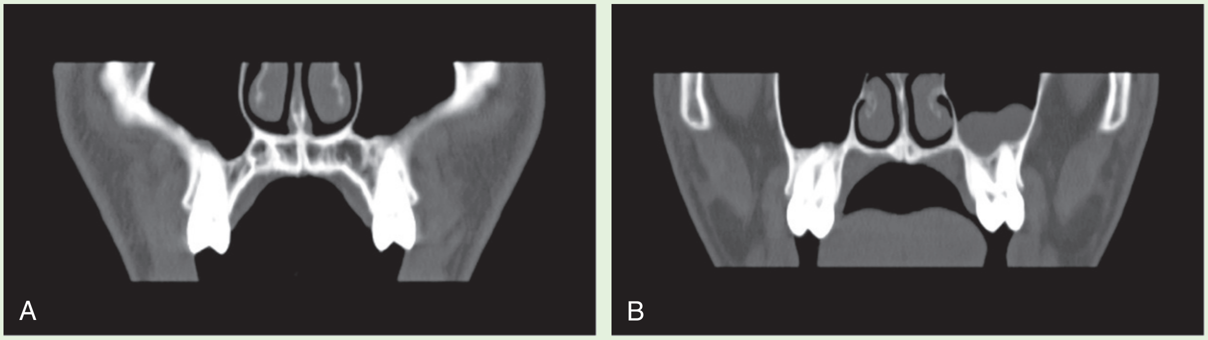

Fig. 40.18 Computed tomographic scans of CB taken 5 years, 3 months into retention. **A,** Scan of upper second premolars illustrates the excellent tooth position and surrounding bone structure that resulted from bodily movement without a high-force rapid palatal expander. **B,** Scan of upper second molars illustrates the delicate bony architecture of this area and challenges clinicians to consider lowering forces and using an alternative to rapid palatal expansion.

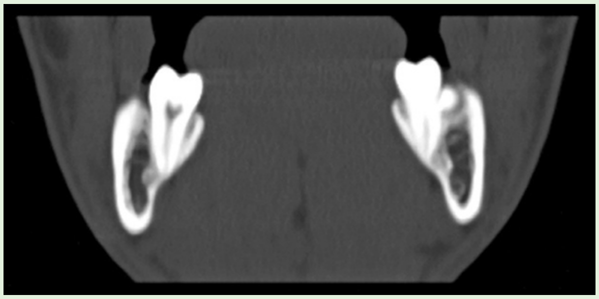

Fig. 40.19 The bony architecture in the second molar area of a collapsed arch encourages second molars to erupt lingually inclined. By helping the tongue assume a normalized position via posterior arch adaptation, second molars have a greater chance of erupting in a more upright position.

CASE STUDY 40.6 Youth with Herbst Appliance Treatment Demonstrates Typical Response—cont'd

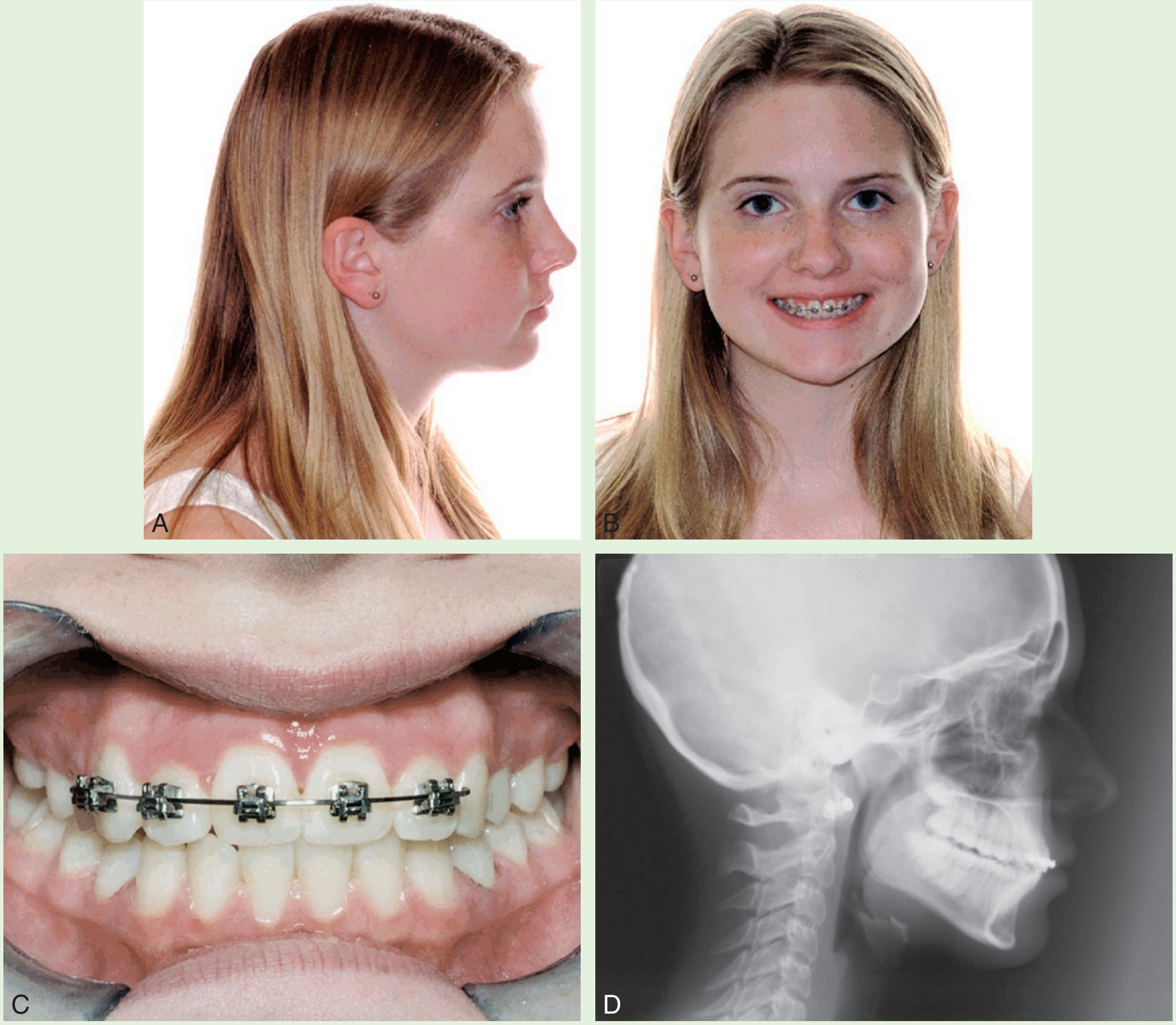

Fig. 40.61 A–D, Phase 1 posttreatment records of KP with Herbst appliance (Herbst appliance treatment time: 16 months with seven appointments). Records taken after Herbst appliance treatment demonstrate Class I dentition and improved facial symmetry.

BOX 40.7 Case 40.6 (KP) Treatment Sequence

Phase 2 Posttreatment Herbst Appliance

1. This patient's canines were slightly toed in. Selected special torques (+7 degrees) for upper and lower canines to help upright them.
2. **First appointment:** Bonded maxillary and mandibular 7 to 7. Placed continuous maxillary and mandibular 0.014-inch NiTi Align SE archwires with crimpable stops.
3. **Second appointment at 2 months, 2 weeks:** Placed upper 0.016- × 0.025-inch NiTi Align SE. Placed lower 0.014- × 0.025-inch NiTi Align SE.
4. **Third appointment at 4 months, 3 weeks:** Took panoramic radiograph to evaluate root angulations and bracket positions (Fig. 40.62).
5. **Fourth appointment at 7 months, 2 weeks:** Placed maxillary 0.019- × 0.025-inch posted stainless steel archwire with tiebacks. Placed mandibular 0.016- × 0.025-inch posted stainless steel archwire with tiebacks, which kept the play in the bracket tube to help eliminate binding and help close the posterior occlusion when trying to close the bite vertically. Started bilateral V-elastics (Fig. 40.63).
6. **Fifth appointment at 9 months, 3 weeks:** Adjusted upper and lower archwires. Continued full-time V-elastics. Added Class II elastics for night wear only.
7. **Sixth appointment at 12 months:** Adjusted maxillary and mandibular archwires. Posterior occlusion was hard to close because of tongue repositioning.
8. **Seventh appointment at 13 months, 2 weeks:** Checked occlusion. Continued full-time elastics.
9. **Eighth appointment at 15 months, 1 week:** Adjusted maxillary and mandibular archwires. Continued full-time elastics.
10. **Ninth appointment at 17 months**: Debonded arches (Fig. 40.64). Initiated fixed retention by bonding 0.016- × 0.022-inch Bond-a-Braid braided wire onto the maxillary teeth lateral to the lateral incisor and bonding 0.026-inch stainless steel round wire onto the mandibular teeth canine to canine because of the severity of the initial crowding. The patient was instructed to wear clear plastic overlay retainers for upper and lower arches and the Damon splint for night retention for an activator type of effect until patient is finished growing.

CASE STUDY 40.6 Youth with Herbst Appliance Treatment Demonstrates Typical Response—cont'd

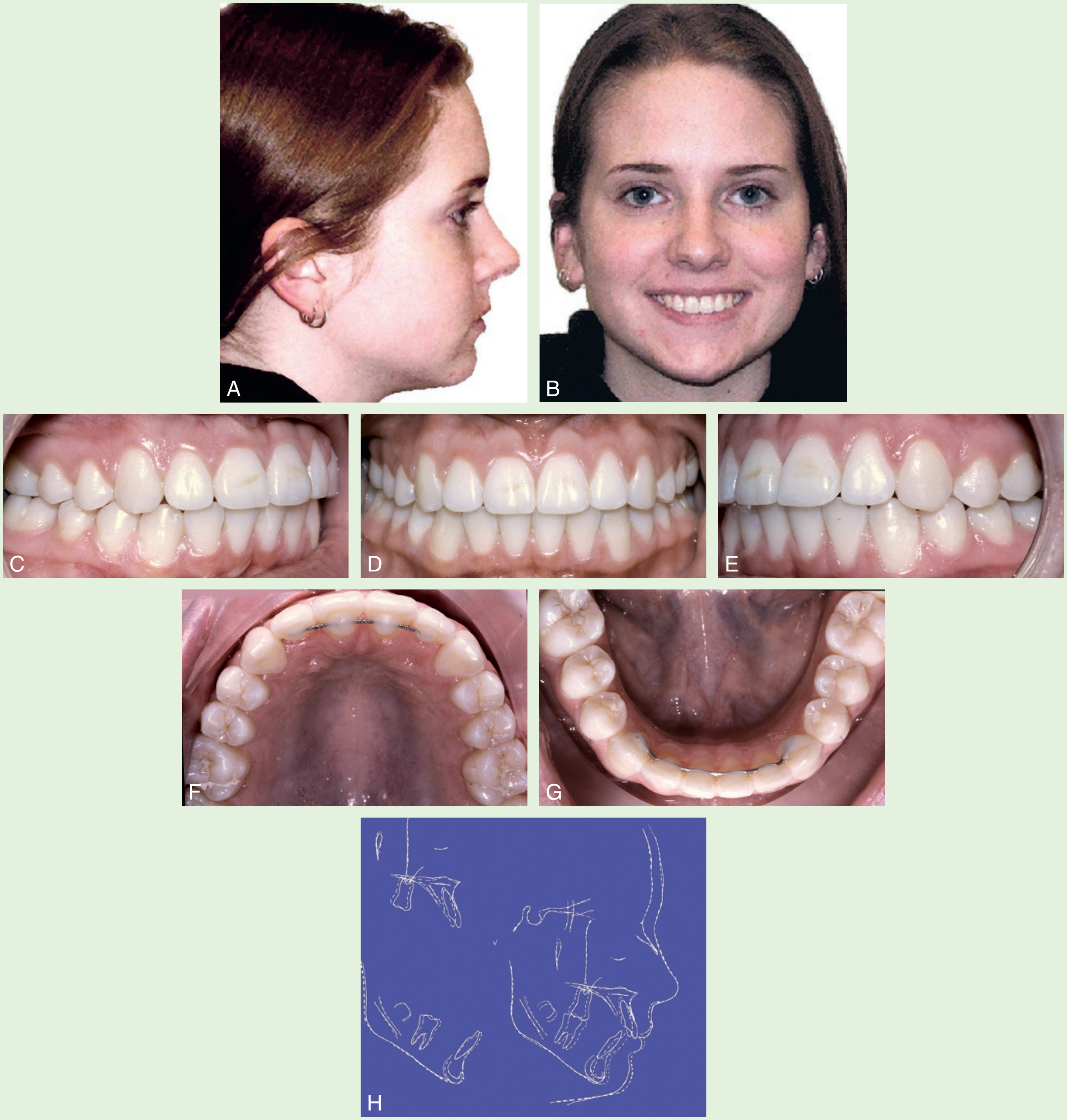

Fig. 40.64 A–H, Posttreatment records for KP. Total phase 1 and phase 2 treatment time: 33 months with 16 appointments.

CASE STUDY 40.6 Youth with Herbst Appliance Treatment Demonstrates Typical Response—cont'd

Fig. 40.68 A–H, Retention records for KP at 1 year in retention.

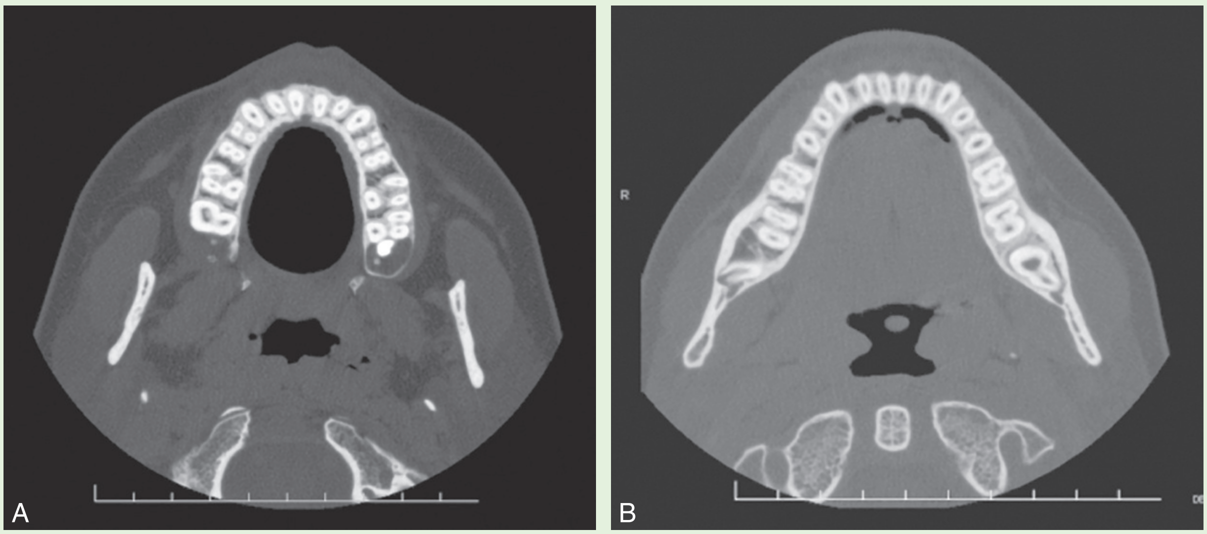

Fig. 40.69 Horizontal computed tomographic scans of KP's upper arch (A) and lower arch (B) taken after 2 years, 6 months in retention.

CASE STUDY 40.7 **Youth with Herbst Appliance Treatment Demonstrates the Definitive Response**

This case was selected because it definitively demonstrates what the Damon System has to offer: a gold standard for gaining space in a full Class II occlusion. By simply normalizing the position of the mandible, the muscles of the face and tongue have a completely different impact on the surrounding structures, which gives the patient a second chance for normal physiologic adaptation to take place. This case is also a great example of form after function. What is exciting is that with a little time and effort, using simple mechanics, and allowing physiologic adaptation to occur, the patient can be treated with respect for the maturing face and profile.

The patient in Case 40.7 (KR) was 11 years, 6 months of age with a Class II, division 2 crowded dentition (Fig. 40.70). She had a prominent nose but a good chin button. She lacked lateral facial support and arch length and

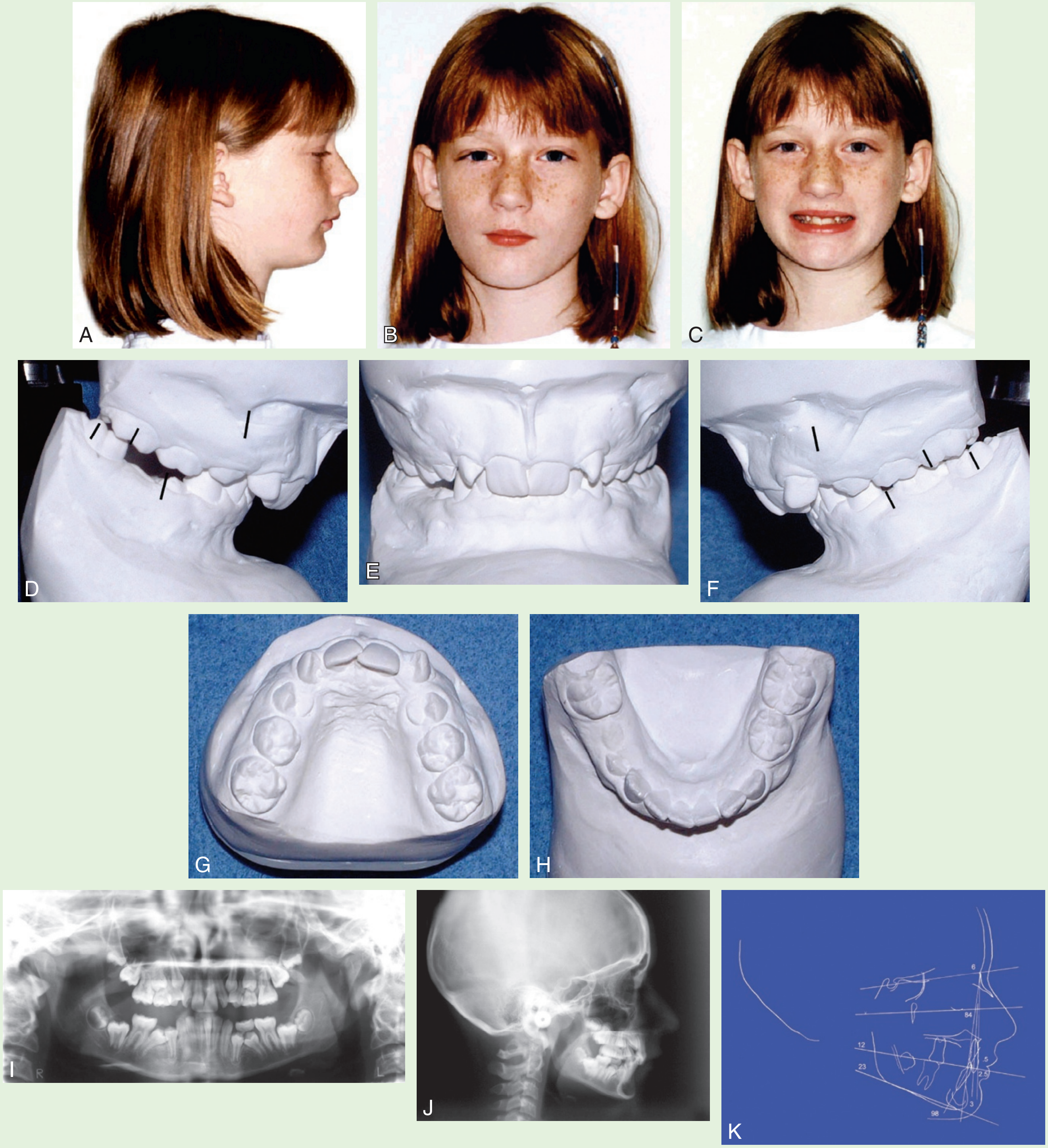

Fig. 40.70 A–M, Pretreatment records for Case 40.7 (KR, age 12 years, 5 months). Diagnosis: Class II, division 2 crowded dentition; retrusive mandible and lacking lateral facial support, arch length and arch width in both arches; 100% overbite, overerupted upper and lower incisors; prominent nose and good chin button.

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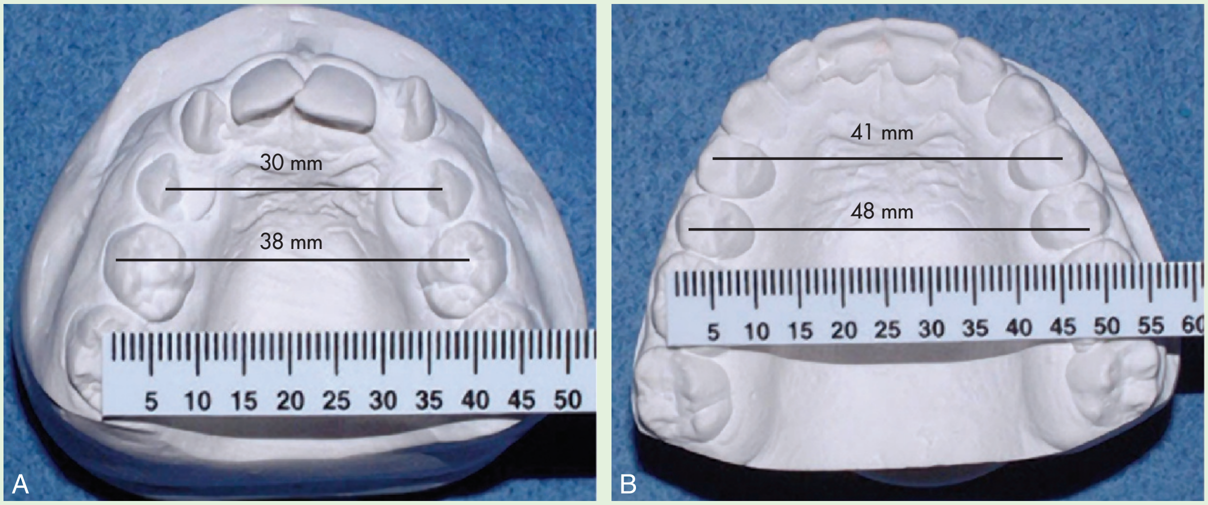

Fig. 40.77 Comparisons of pretreatment and posttreatment upper arch plaster models for KR. **A,** Pretreatment. First premolars: 30 mm; second premolars: 38 mm; first molars: 45 mm. **B,** Posttreatment. First premolars: 41 mm; second premolars: 48 mm; first molars: 52.5 mm. Pretreatment and posttreatment plaster models of upper arch show 11-mm change in first premolar width, 10-mm change in second premolar width, and 7.5-mm change in first molar width.

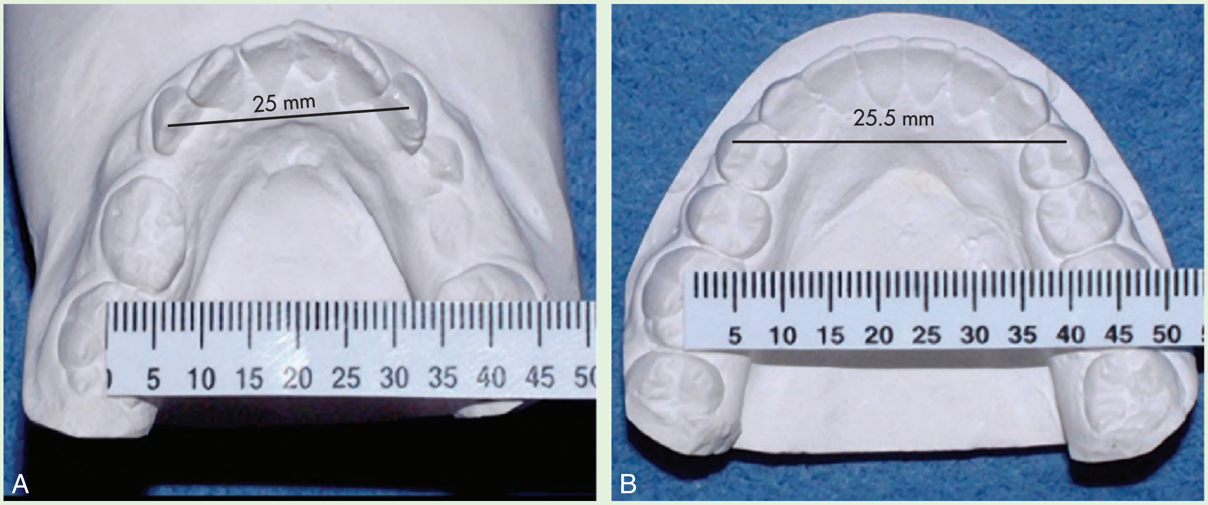

Fig. 40.78 Comparisons of pretreatment and posttreatment lower arch plaster models for KR. **A,** Pretreatment. Canines: 25 mm; first molars: 41 mm. **B,** Posttreatment. Canines: 25.5 mm; first molars: 46 mm. Pretreatment and posttreatment plaster models of lower arch show 0.5-mm change in canine width and 5-mm change in first molar width.

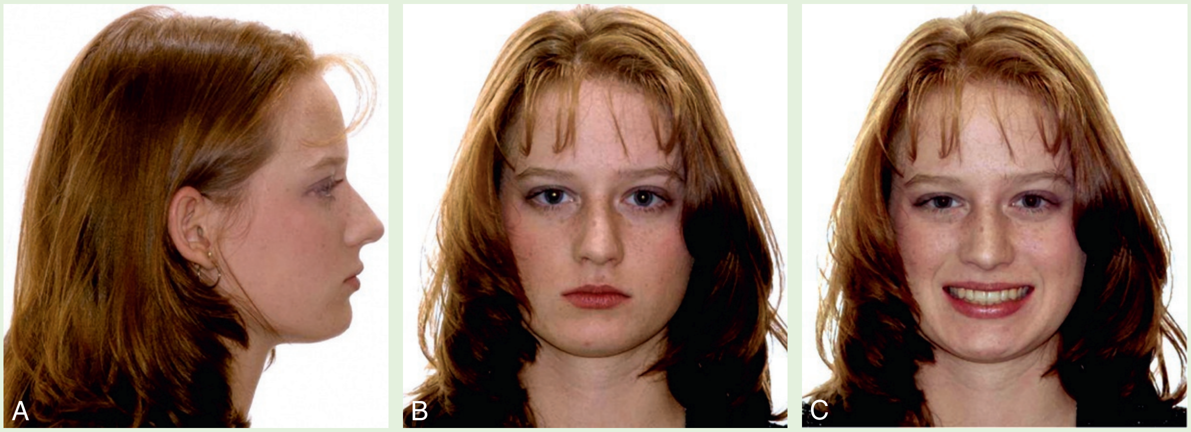

Fig. 40.79 **A–C,** KR at age 16 years, 3 months with longer than 20 months in retention.

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Fig. 40.84 Fabrication of the Splint Retainer. A, Trim models and remove any occlusal bubbles. Cut groove in base of models with acrylic bur in alveolar ridge area *(arrows)*. **B,** Apply sticky wax to the models together with three toothpicks. Paint Al-Cote separating agent (Dentsply, York, PA) on both model bases. **C,** Mount upper and lower models on simple articulator. **D,** Carefully separate models from their bases at the separating agent joint. **E,** Remove plaster from the center of both models, and use vacuum application of Essex A+ (Raintree Essix, Metairie, LA) or Biocryl (Great Lakes Orthodontics, Tonawanda, NY). Block out undercuts with Wonderfill (Dental Creations, Waco, TX). **F,** Trim retainer material on the model, and place the models back on the articulator with sticky wax. **G,** Mix acrylic, and place it between the models from middle canine to posterior canine on the buccal and lingual aspects. **H,** Leave airway in anterior area canine to canine. Amount of airway is determined by the needs of the patient. **I,** Place acrylic beyond the tip of the upper canine. Leave it short of the cusp tip *(arrow)*. A fracture line sets up if patients clench their teeth. **J,** Relieve any undercuts with acrylic bur on upper canine. **K,** Note how tongue is contained *(arrows)*.