THE CUTTING EDGE

(Editor's Note: This quarterly column is compiled by JCO Technology Editor Ronald Redmond. To help keep our readers on The Cutting Edge, Dr. Redmond will spotlight a particular area of orthodontic technology every three months. Your suggestions for future subjects or authors are welcome.)

This month's Cutting Edge gives us a peek at the future of our specialty. Cone Beam Computed Tomography (CBCT) and the three-dimensional analyses developed from it are destined to propel orthodontic diagnosis to the next level of excellence—and sooner than we might expect.

In the past, when a patient developed TMJ symptoms in the middle of treatment, we could only wish that our initial diagnostic records had included tomograms of the joints. In the future, the CBCT volume of the head will contain all the necessary diagnostic information. If you decide you need views of the TMJ in the middle of treatment, you simply return to the computer and "slice out" the data.

The authors touch on a conundrum of CBCT: orthodontists are still asking for two-dimensional diagnostic records to be generated from the 3-D data. As with most new systems, the gap between traditional clinical practice and technological advancement has been slow to close. While mainline orthodontists are still living in a 2-D world, orthodontic residents in many universities are becoming 3-D savvy. The new generation of orthodontists will not only embrace CBCT, but will require it.

W. RONALD REDMOND, DDS, MS

Three-Dimensional Radiographic Analysis in Orthodontics

The introduction of three-dimensional radiographic imaging with Cone Beam Computed Tomography (CBCT) has led to a multitude of clinical applications across all dental disciplines. Access to CBCT imaging services has increased at a near-exponential rate since the first device was introduced in the United States in 2000.

Advantages of 3-D imaging are numerous.[1] Studies have shown that radiation exposure is much lower for CBCT than for medical CT imaging—closer to the range of standard dental film series.[2,3] In orthodontics, we are just beginning to establish the potential diagnostic and therapeutic applications of 3-D imaging. Although our existing patient data are based primarily on two-dimensional records, we already know that 3-D imaging can provide more extensive and detailed patient evaluations.

This article describes a comprehensive analysis of the CBCT volume for orthodontic diagnosis and treatment planning. The analysis


Dr. Redmond


Dr. Huang


Dr. Bumann


Dr. Mah

contains elements that are familiar from our traditional orthodontic workup, but also includes improvements that are possible only with 3-D imaging and software tools.

Lateral and Frontal Cephalometric Views

A fundamental concept of 3-D imaging is that the resultant volume can be reformatted to

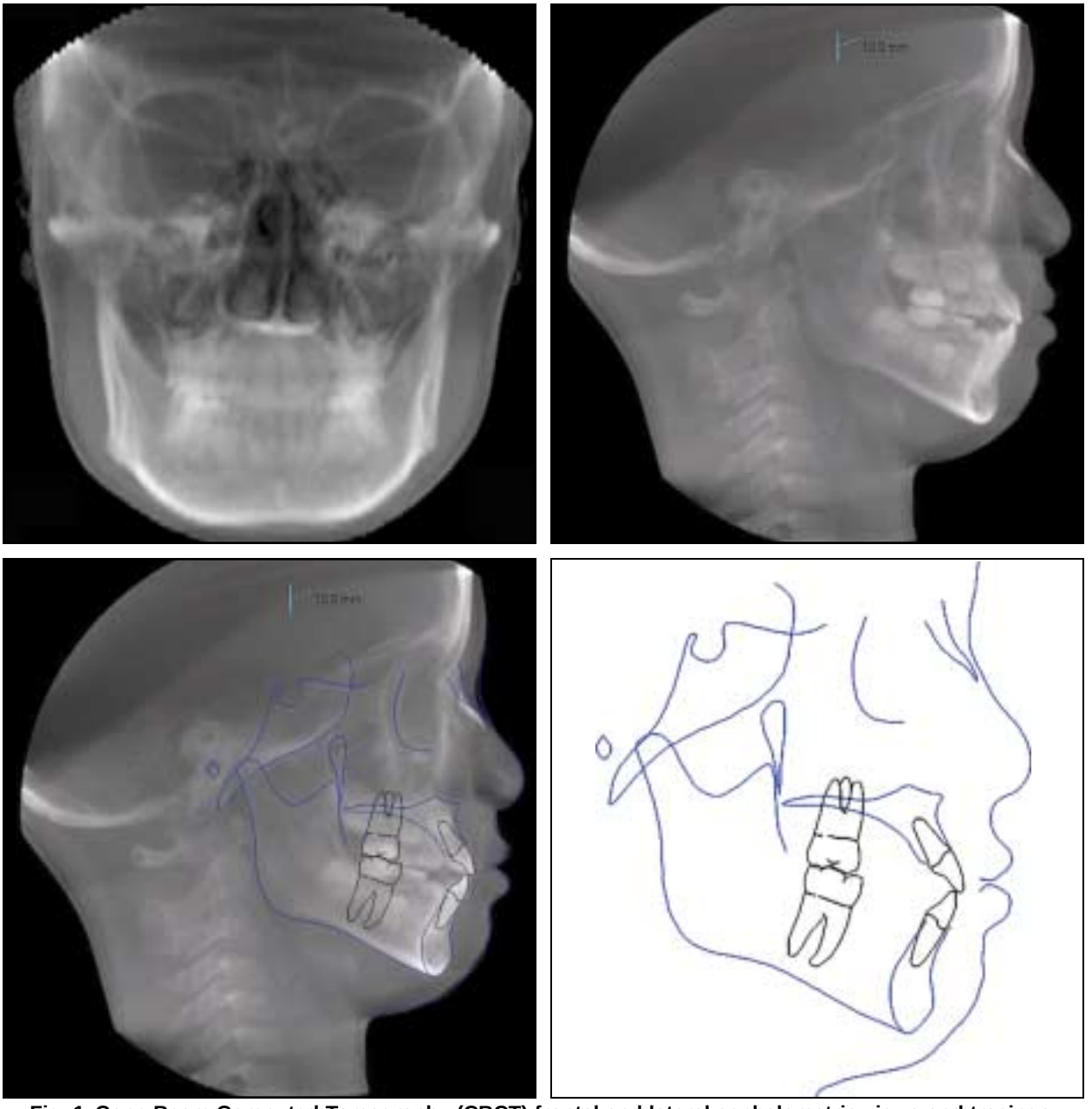

Fig. 1 Cone Beam Computed Tomography (CBCT) frontal and lateral cephalometric views and tracings.

provide infinite perspectives or viewpoints. Frontal and lateral cephalograms can thus be created and subsequently imported into any cephalometric analysis program to produce digital tracings and measurements (Fig. 1).

While the CBCT-generated lateral cephalogram may appear similar to a conventional headfilm, the CBCT has several distinct advantages that can enhance visualization. Conventional lateral cephalograms are derived from a technique called perspective projection; the geometric result is an inherent magnification of the image, depending on the distance from the structure to the film. For example, the difference between the left and right mandibular bodies can result in the double lower border of the mandible that we often see in conventional films. Even if the left and right porions were lined up and the patient's head was in perfect position, we are unable to determine whether the double structure was caused by a true skeletal asymmetry or a radiographic artifact. With CBCT, this projectional magnification is computationally corrected during primary reconstruction, creating an orthogonal image. When a standard of known length is placed in the field of view, the CBCT lateral cephalogram can be calibrated to a true 1:1 representation of the structure being imaged.

A major advantage of CBCT-generated frontal cephalograms is that the software is able to excise extraneous portions of the cervical spine and occiput, avoiding the superimposition of irrelevant structures. The CBCT frontal cephalogram provides a remarkably clear image of pertinent maxillofacial structures and thus a truer representation of cranial relationships.

Many groups around the world are developing 3-D cephalometric analyses; when these become more standardized, they will greatly augment the comprehensive patient analysis. At present, however, most orthodontic treatment planning is still based on the lateral and frontal cephalometric views.

Skeletal Views

The volumetric 3-D skeletal view is a new way to visualize the relationships of maxillomandibular structures to the cranial base (Fig. 2). These images allow surface inspection of the osseous morphology of the jaws.

The alveolar bone height is particularly im-

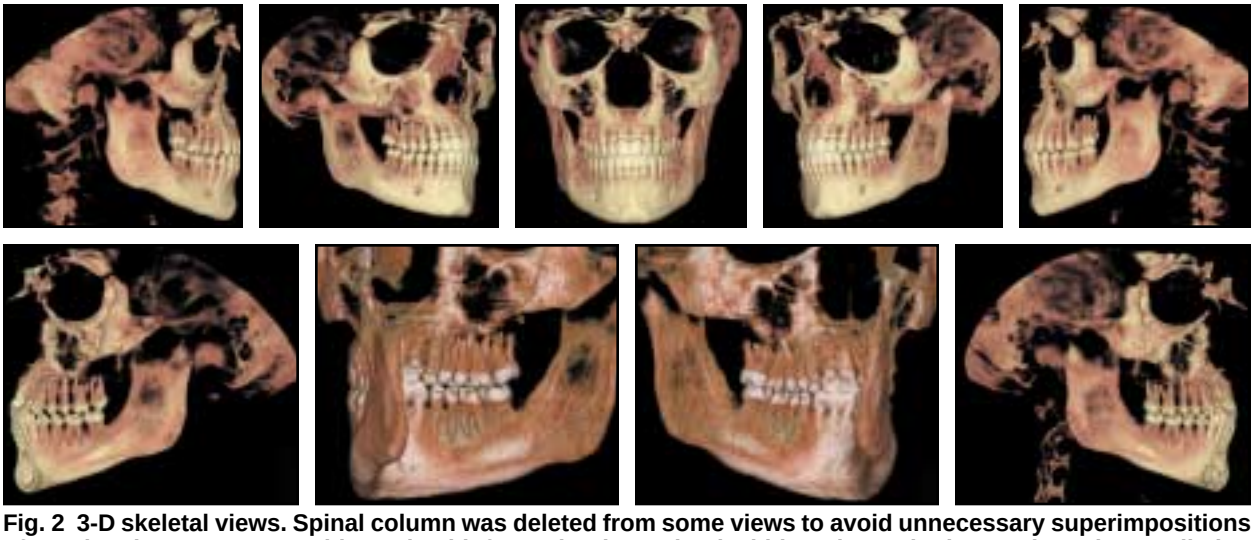

Fig. 2 3-D skeletal views. Spinal column was deleted from some views to avoid unnecessary superimpositions of overlapping structures. This excised information is retained within volumetric data and can be recalled at any time. Images in lower row are lingual views.

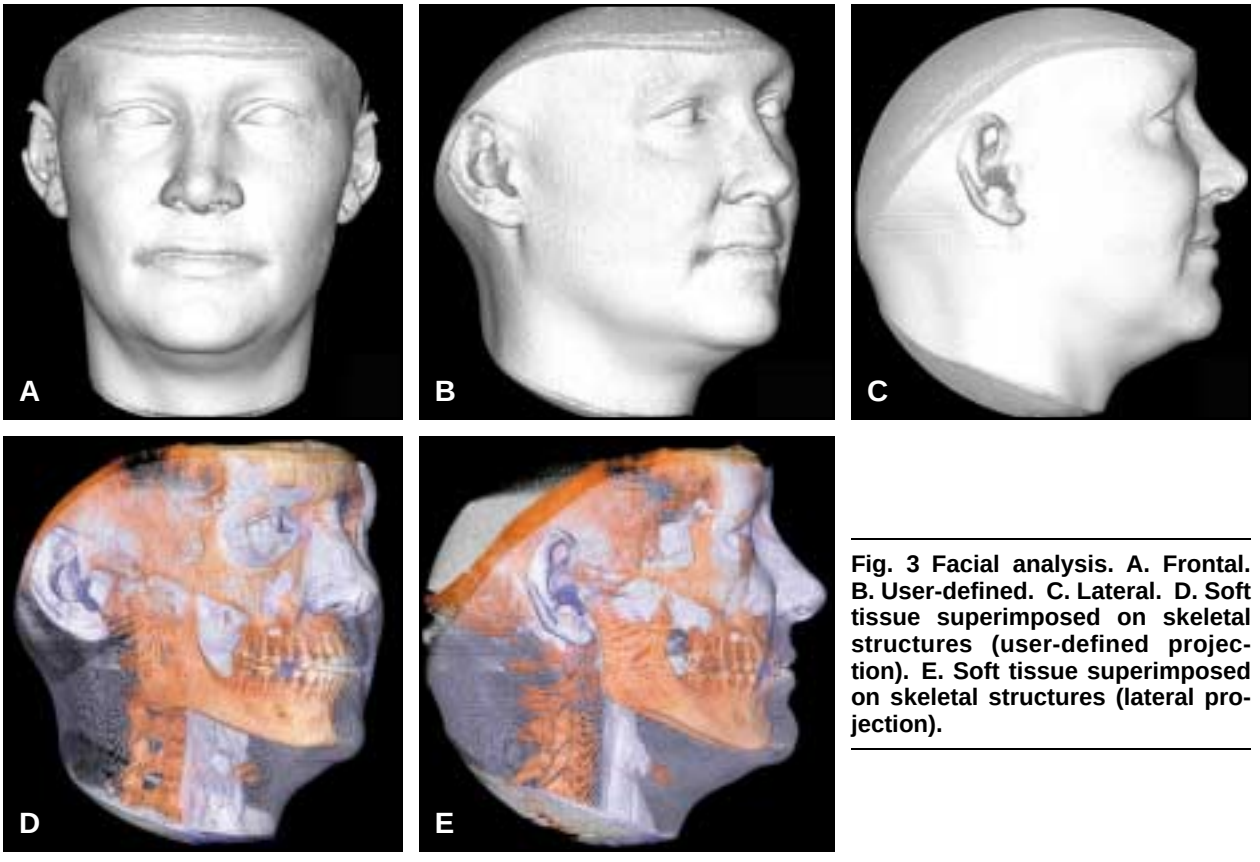

Fig. 3 Facial analysis. A. Frontal. B. User-defined. C. Lateral. D. Soft tissue superimposed on skeletal structures (user-defined projection). E. Soft tissue superimposed on skeletal structures (lateral projection).

portant in adults and periodontally compromised patients. Surface irregularities due to ectopic teeth, bone dehiscences, salivary gland invaginations, and other abnormalities can be visualized in the 3-D images. Since these surface irregularities sometimes extend deep into the alveolus between the roots, their accurate identification is of great benefit to the orthodontist in treatment planning.

An entirely new resource for occlusal assessment is the lingual view—as if the clinician were looking from the back of the patient's head into the oral cavity. This has been made possible only with recent enhancements in CBCT software features.

Facial Analysis

A conventional facial photograph is a simple two-dimensional representation that is not correlated with the supporting skeleton. The 3-D volume can provide any frontal, lateral, or user-defined view of the face, and by changing the translucency of the image, one can determine the specific relationship of the soft tissues to the skeleton (Fig. 3). This has significant implications in the planning of tooth movements, orthognathic surgery, or other therapies that could alter facial appearance.

Alveolar Ridge Shape and Volume

The frontal views of the dental arches enable the clinician to assess vertical and transverse dimensions and volume, and to evaluate interarch discrepancies and vertical limits of tooth movement (Fig. 4A). The frontal view can be correlat-

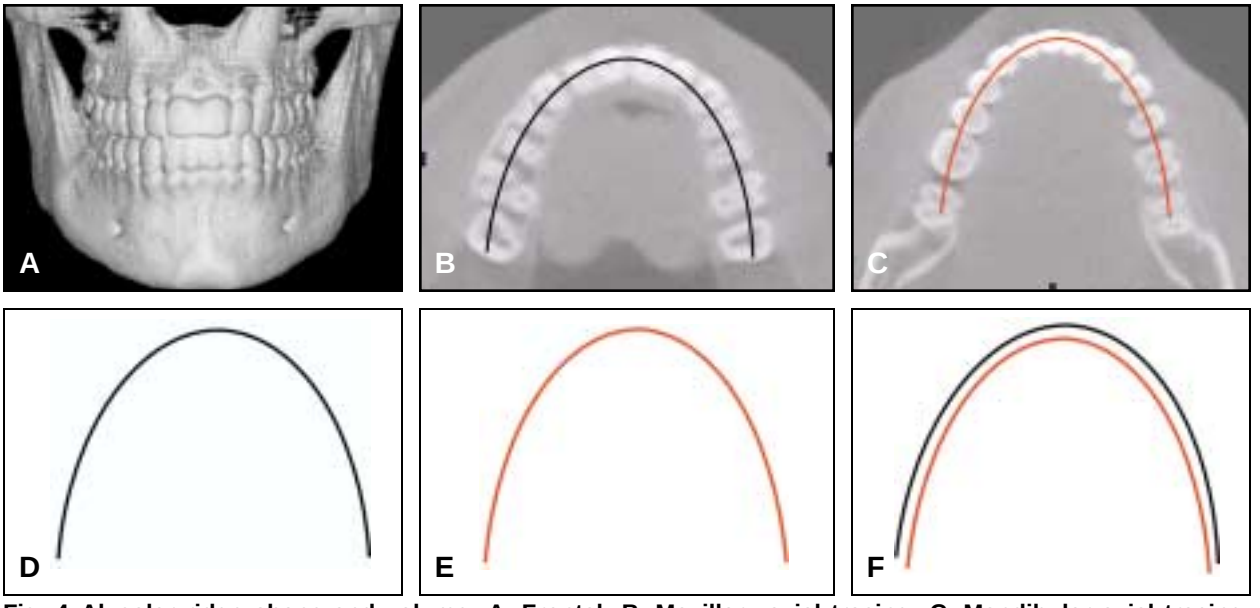

Fig. 4 Alveolar ridge shape and volume. A. Frontal. B. Maxillary axial tracing. C. Mandibular axial tracing. D. Maxillary archform. E. Mandibular archform. F. Maxillary-mandibular archform coordination.

ed with TMJ views to show the relationship of the TMJs to the intercuspal positions.

The occlusal views of the arches reveal relative tooth positions and the shape of the alveolar bone support (Fig. 4B,C). Archform tracings are typically made at the height of the alveolus, but can be varied according to the user's preference (Fig. 4D,E). The archforms can then be superimposed to reveal discrepancies or compatibility (Fig. 4F). They can also be printed at full size for selection and fabrication of archwires. In the future, these images will be usable for arch-length measurements and Bolton analysis.

3-D Review of the Dentition

The panoramic view of the dentition is similar to a traditional panoramic x-ray, but is remarkably clearer because there is no superimposition of the spinal column and contralateral side (Fig. 5A). In addition, there are no projection artifacts such as the burnout area often observed in the anterior region.

Left and right tooth pair views are used to check for asymmetries and to verify the positions of the roots relative to the buccal and lingual cortical plates of alveolar bone support (Fig. 5B-H). Some patients have alarmingly thin alveolar bone around the roots. Early identification of this condition, which would not be noticed in traditional orthodontic records, allows the orthodontist to make better treatment decisions and to seek interdisciplinary collaboration if necessary.

The 3-D views of the dentition are reminiscent of textbook images describing dental development (Figs. 5I-K). In the mixed dentition, these projections effectively illustrate all erupted, erupting, and developing teeth, their relative positions, and the overall formation of root structures. Thus, they improve the ability of the clinician to manage tooth eruption and to intervene as soon as possible when problems arise.

Temporomandibular Joints

Both coronal and sagittal sections of the TMJ are included in the 3-D orthodontic analysis, along with axial views to help orient the

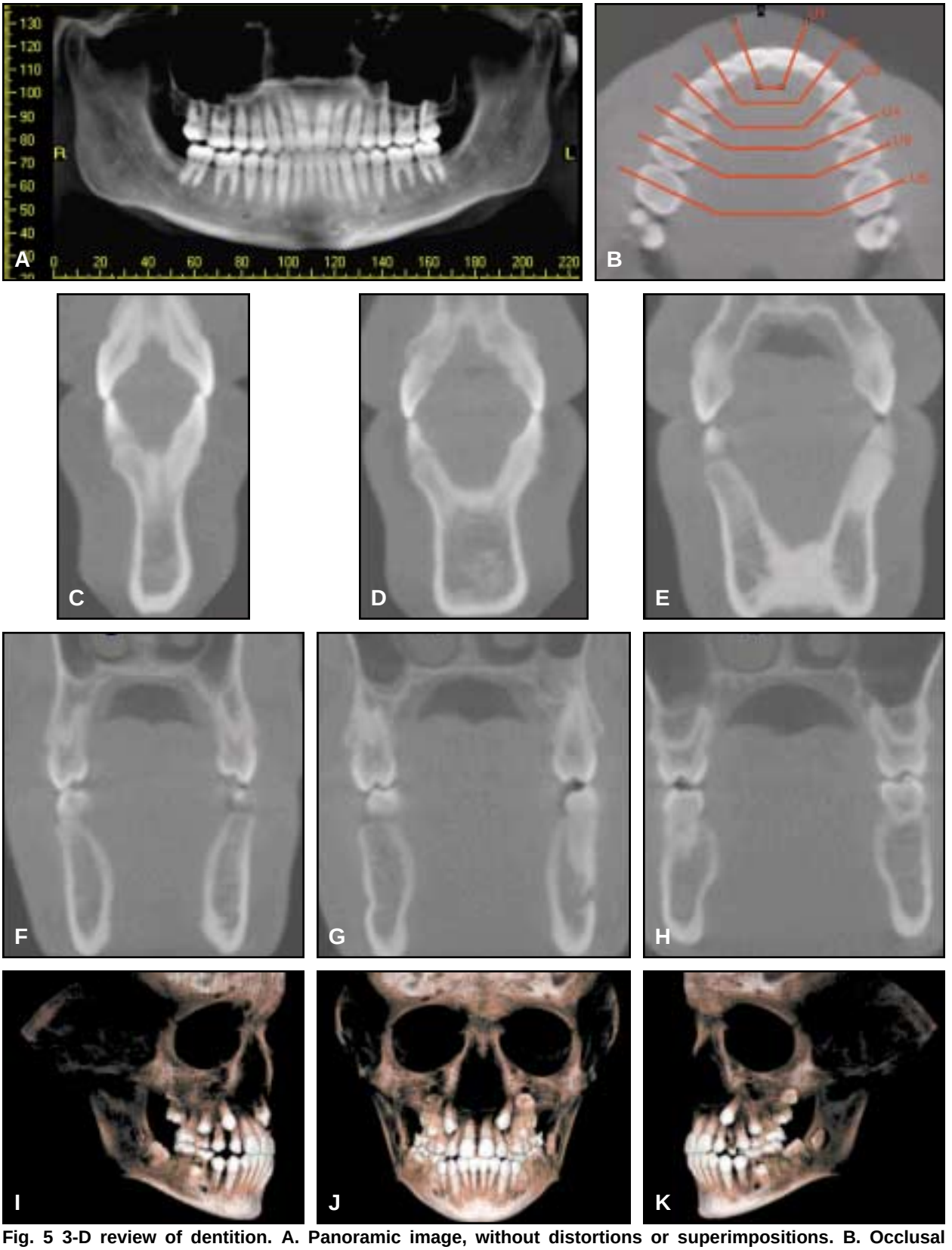

Fig. 5 3-D review of dentition. A. Panoramic image, without distortions or superimpositions. B. Occlusal index of maxillary tooth pairs. (Mandibular tooth pairs can be generated separately.) C. Maxillary central incisors. D. Maxillary lateral incisors. E. Maxillary canines. F. Maxillary first premolars. G. Maxillary second premolars. H. Maxillary first molars. I-K. 3-D views of dentition. Unlike conventional radiographs, 3-D images show minimal starburst artifacts from metal bands cemented to first molars.

coronal and sagittal sections (Fig. 6). These joint views can be correlated with the occlusal views because they are all produced from one volume. Functional shifts can occasionally be detected as differences between the left and right TMJ views.

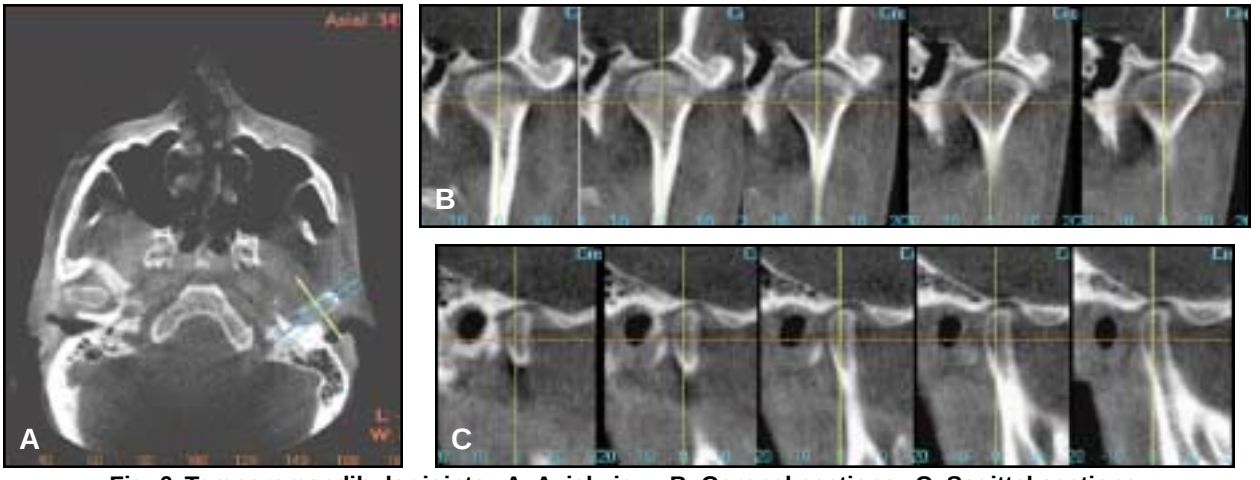

Fig. 6 Temporomandibular joints. A. Axial view. B. Coronal sections. C. Sagittal sections.

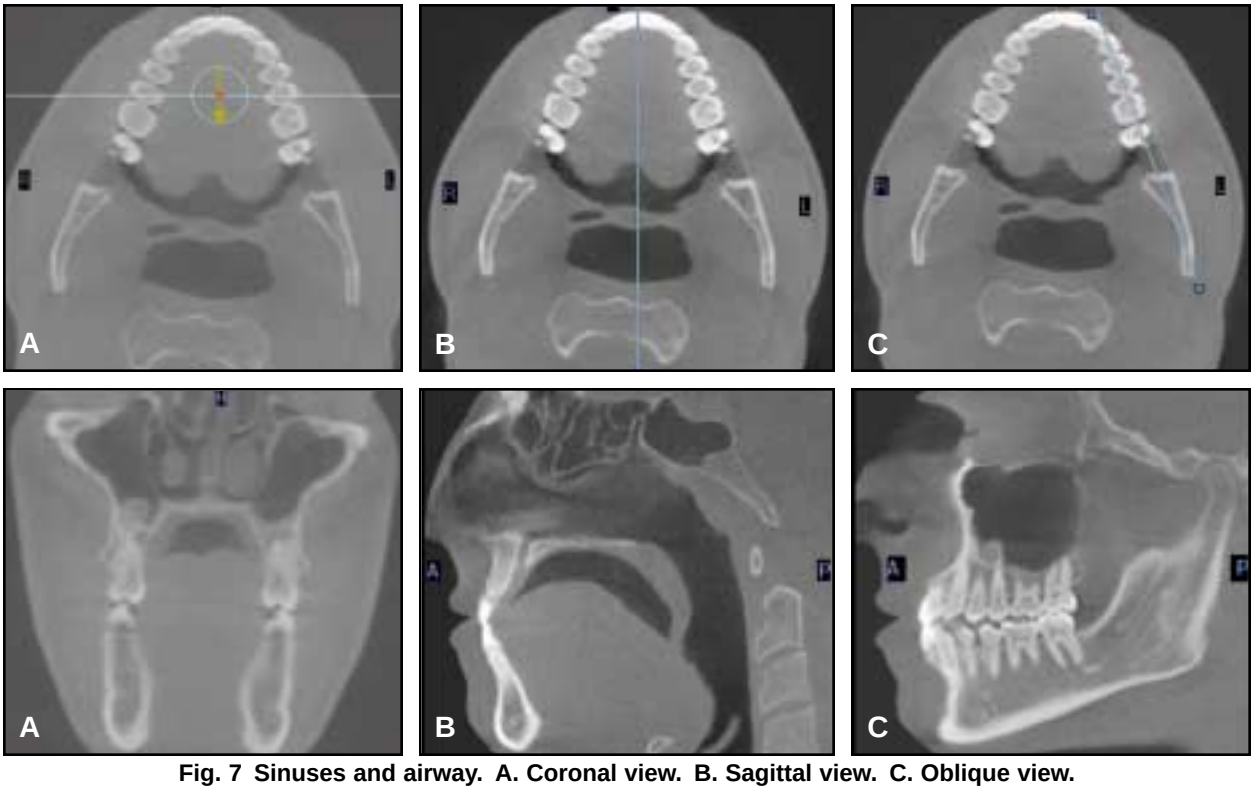

Fig. 7 Sinuses and airway. A. Coronal view. B. Sagittal view. C. Oblique view.

Sinuses and Airway

The last component of the 3-D orthodontic analysis is a coronal, sagittal, and oblique review of the sinuses and airway (Fig. 7). This information is particularly relevant to the orthodontist, since mouthbreathing and consequent airway obstruction is considered a prime etiology of malocclusion. Indeed, a review of 500 patients imaged by CBCT showed that approximately 25% have significant airway findings. Airway patency or obstruction is often a factor in deciding between orthodontic and orthognathic therapies.

Conclusion

The comprehensive 3-D analysis presented here is the first to be based on CBCT data, as well as elements from traditional orthodontic analyses. The goal is to extract pertinent details from the image volume and to provide the orthodontist with clinical applications of this information. Ongoing development of 3-D imaging promises to enhance the precision and effectiveness of our diagnosis and treatment planning.

JOHN HUANG, DMD, DMS
Assistant Professor
Director, 3-D Craniofacial Function
and Imaging Laboratory
University of California, San Francisco
707 Parnassus Ave., Box 0438
San Francisco, CA 94143
e-mail: drjohnhuang@post.harvard.edu

AXEL BUMANN, DDS, PHD
Assistant Clinical Professor
Division of Craniofacial Sciences and Therapeutics
University of Southern California
Los Angeles, CA

JAMES MAH, DDS, MS, MRCD, DMS
Associate Clinical Professor
Director, Craniofacial Virtual Reality Laboratory
University of Southern California
Los Angeles, CA
e-mail: jamesmah@usc.edu

REFERENCES

1. Mah, J. and Hatcher, D.C.: Current status and future needs in craniofacial imaging, Orthod. Craniofac. Res. 6(suppl. 1):10-16, 2003.
2. Mah, J.K.; Danforth, R.A.; Bumann, A.; and Hatcher, D.: Radiation absorbed in maxillofacial imaging with a new dental computed tomography device, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 96:508-513, 2003.
3. Ludlow, J.B.; Davies-Ludlow, L.E.; and Brooks, S.L.: Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit, Dentomaxillofac. Radiol. 32:229-234, 2003.
4. Cha, J.; Sinclair, P.M.; and Mah, J.M.: The prevalence of incidental findings in the maxillofacial area utilizing 3-dimensional cone beam imaging (in preparation).