Click on the blue boxes around Figures 7, 9, 11, and 13 for short .AVI movie clips.
Fig. 7A movie = 12MB; others are 3-5MB.
Fig. 16 links to a YouTube video.

OVERVIEW

Cone-Beam Volumetric Imaging: A Two-Minute Drill

DANIEL S. GERMAN, DDS
JULIA GERMAN

(Editor's Note: In this quarterly column, JCO provides an overview of a clinical topic of interest to orthodontists. Contributions and suggestions for future subjects are welcome.)

Cone-beam volumetric imaging (CBVI), also called cone-beam computed tomography (CBCT), has been used in dentistry since 1998.[1,2] The images it produces are not improved digital images, but true three-dimensional images, without the distortion seen in either film pictures or digital cephalometric and panoramic x-rays. Taking advantage of this leap in diagnostic ability, clinicians have installed more than 2,000 CBVI machines in the United States alone. But with at least 500 slices of imagery now available for every patient, orthodontists need to determine what to do with all that diagnostic information.

This article proposes a system for displaying, creating, and reviewing diagnostic images in the typical orthodontic practice. We also present a template that displays traditional views (Fig. 1) as well as additional images from CBVI. Our German Template (Fig. 2) is easily printed on one 8.5" × 11" sheet of photographic paper for distribution to other treating doctors, or it can be displayed on a monitor for consultation or for viewing during patient visits.

We do not intend to address the controversial topics of when CBVI is appropriate for diagnostic use, its cost-benefit ratio, or the responsibility of the orthodontist regarding non-dental findings. Our purpose is to provide a reference for clinicians and a rationale for selecting a reasonable number of images to build, save, and review for each orthodontic patient undergoing CBVI.

Dr. German

Ms. German

Dr. German is an Assistant Clinical Professor at Ohio State University, Postle Hall, 305 W. 12th Ave., Columbus, OH 43210; e-mail: dgerman@germanorthodontics.com. He is in the private practice of orthodontics in Dayton, OH, and is the creator of the German Template. Ms. German is an engineering student at Case Western Reserve University, Cleveland.

Medical CT vs. CBVI

Conventional CT has been applied medically since 1971,[1,3] but its application in dentistry was limited until recently because of cost and radiation exposure. Operating the CBVI machine is about as simple as operating a panoramic x-ray machine. The x-ray source is a low-energy, fixed anode tube, similar to that of a panorex unit, in contrast with the high-output, rotating anode generator for medical CT. CBVI emits a cone-shaped x-ray beam rather than the linear, fan-shaped beam of medical CT machines. The CBVI beam travels through the patient, and the remainder beam is captured on an amorphous silicon flat panel or on the combination of an intensifier and a charge-coupled device (CCD) camera.[4,5] CBVI requires only one rotation around the patient, whereas medical CT requires many rotations.

Many factors enter into the calculation of effective radiation dose, including the amount of radiation generated, the sensitivity of various tissues to radiation, the type of machine, its settings, the use of shielding, and the field of view (FOV) included in the scan. Roughly speaking, however, patient exposure to radiation from CBVI is only about 20% of that from medical CT, and roughly equivalent to the exposure from a full-mouth periapical series.[6-13] The radiation exposure from a CBVI with large FOV is comparable to about one or two weeks of daily background radiation[14] (Table 1). Although the lower radiation used by CBVI compared to medical CT prevents clear visualization of many soft tissues, particularly the brain, it does render excellent images of hard tissues such as bones and teeth. CBVI can also provide airway assessments and other soft-tissue measurements.

Acquiring the Images

Scanning Procedure

The typical CBVI scan takes between 4.8 and 26.9 seconds to perform, depending on the machine, FOV, resolution, and indication for scanning. The scan is a pulsating x-ray that captures thin visual slices, which can then be built and saved into the images we are accustomed to seeing. A large FOV allows the capture of all structures required for cephalometric analysis. The size of the voxel (a 3D volumetric version of the 2D pixel element in digital photography and imaging) is

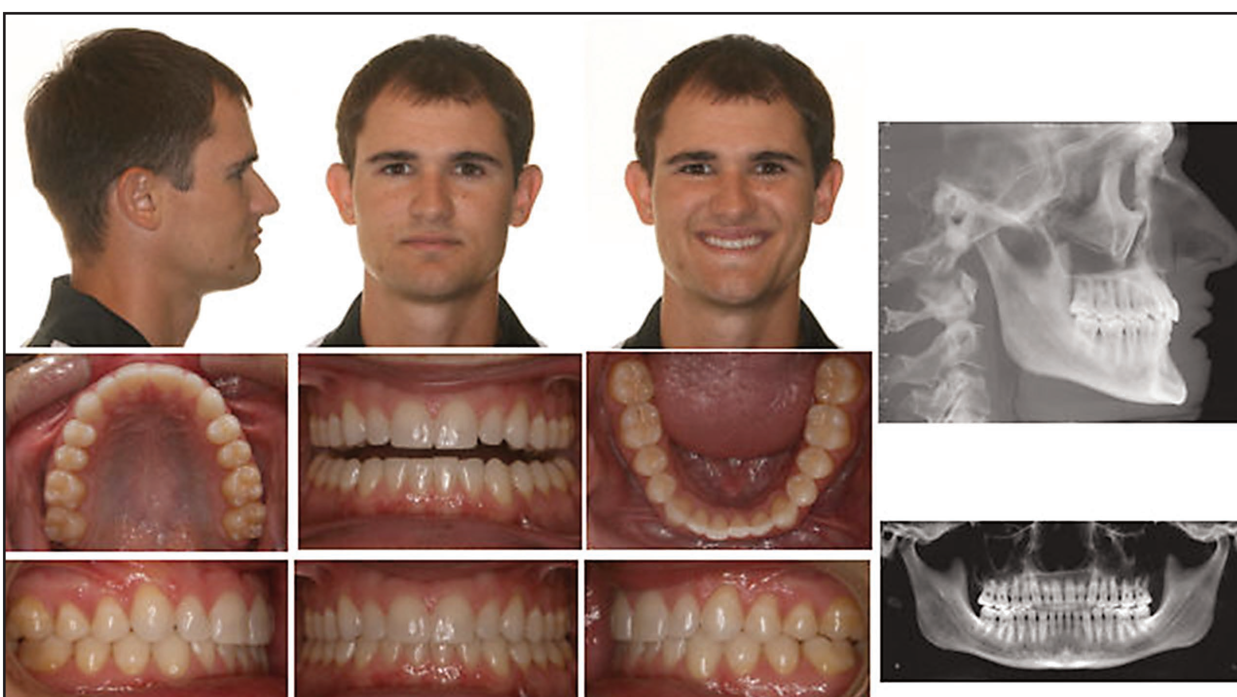

Fig. 1 Template of 11 images used before implementing CBVI. Center intraoral photo, with teeth apart, reveals anterior clinical crowns and associated gingival architecture for use in diagnosis and treatment planning.

TABLE 1
EFFECTIVE RADIATION DOSES[14]

Examination	Exposure (µSv)	Equivalent Natural Background Radiation
Dental		
Panoramic	3-11	One-half to one day
Cephalogram	5-7	One-half to one day
Occlusal film	5	One-half day
Bitewing	1-4	One-half day
Full-mouth series	30-170	4-21 days
TMJ series	20-30	3-4 days
CBCT exam	40-135	4-17 days
Medical		
Chest x-ray	100	10-12 days
Mammogram	700	88 days
Medical CT	8,000	1,000 days

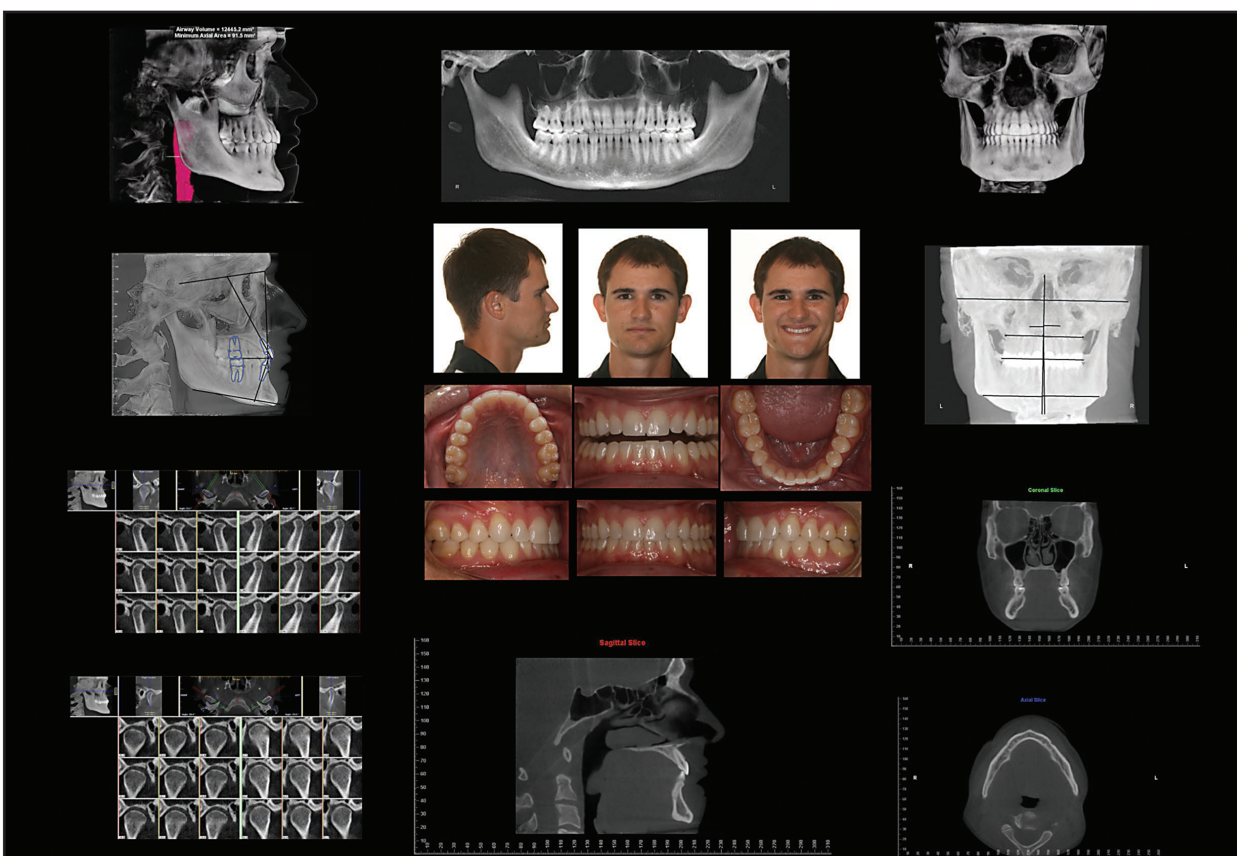

Fig. 2 German Template of photographic and radiographic images used for diagnosis, progress checks, and distribution to other doctors.

rather large (typically .3mm) when capturing a large FOV. As the FOV is reduced, voxel sizes can be reduced down to .125mm. Voxel sizes will almost certainly become smaller in the future, particularly in endodontic and periodontal practices, which need to view small structures and subtle pathology.

Data Acquisition

Time required: one minute. In our practice, the orthodontic technician positions the patient in the same way as for panoramic or cephalographic imaging. The time required is about the same as for x-rays using a combination pan-ceph machine. In contrast to traditional x-ray procedures, however, many practices have the patient wear a chin cup during CBVI to prevent motion.

More than 30 different machines are commercially available. We use the 14-bit i-CAT* machine (Fig. 3), which can capture about 500 slices in an average nine-second scan with a .3mm voxel size. This FOV is large enough to image the facial anatomy needed for traditional cephalometric measurements. For progress panoramic views, however, we use a smaller FOV. Although similar images can be made in two dimensions with some cone-beam machines (using slightly less radiation), we prefer to have the benefits of 3D for progress panoramic images, so we can visualize the boundaries of tooth movement relative to the available bone and more accurately assess the true root lengths and positions.

Fig. 3 14-bit i-CAT* machine resembles traditional pan-ceph machine.

Building the Images

Time required: six minutes. From the computerized slices of the scan, the technician builds and saves the German Template images required for routine orthodontic diagnosis (Fig. 2), along with images of areas of interest such as impactions, supernumerary teeth, pathologies, and other suspicious findings. The i-CAT machine comes with the software needed to build many of these images, but third-party software can provide additional features. We use Dolphin 3D** software to build and save the images.

Initial data slices from the scan are preserved in the universal Digital Imaging and Communications in Medicine (DICOM)*** format, which compresses the original 200MB of data by 3:1 with no loss of quality. These files are saved on a local hard drive and an off-site server. The images are saved in 2D format or occasionally as a short movie clip.†

*Registered trademark of Imaging Sciences International, Inc., 1910 N. Penn Road, Hatfield, PA 19440; www.imagingsciences.com.

**Dolphin Imaging and Management Solutions, 9200 Eton Ave., Chatsworth, CA 91311; www.dolphinimaging.com. Next version of software will include German Template.

***Service mark of the National Electrical Manufacturers Association, 1300 N. 17th St., Suite 1752, Rosslyn, VA 22209; www.medical.nema.org.

†Movie clips of various slices in this article are available for Figures 7, 9, 11, 13, and 16.

Orthodontist's Review

For a routine adolescent case, this is a two-minute drill. In our practice, the doctor always reviews the German Template and other images built by the technician. If desired (and always for new patients), the orthodontist can then review all 500 slices of the scan in all three dimensions—sagittal, coronal, and axial—by continuous scrolling, using the Dolphin software. Careful examination of the images is required, because periapical lesions and periodontal problems that might not be evident on periapical films are often visible in CBVI.[15,16] The clinician can also identify non-dental pathology—which is reportedly present in more than 21% of orthodontic patients undergoing CBVI,[17] and especially in older patients—for referral to the appropriate specialist (primary-care physician, otolaryngologist, allergist, vascular specialist, or oral surgeon). The orthodontist saves additional views of interest from the slices and occasionally overwrites some of the images saved by the technician in the German Template. The template images are then sent to the general dentist and other treating doctors, either electronically or as hard copies.

Some orthodontists may opt to have all the images read by an oral and maxillofacial radiologist rather than doing their own evaluation. Whole scans or individual images can be uploaded by a privacy-compliant method to the radiologist, who can then e-mail back the report. This method can be particularly cost-effective in the management of patients with complex histories, who may also have imaging from other modalities for review.

Evaluating the Images

Panoramic View

Because the teeth are not separated during scanning (Fig. 4A), there will be some vertical overlap. We prefer this arrangement because we like to view the condyles in the fossae during maximum intercuspation, or in centric relation if appropriate. The occlusion can then be assessed with a concurrent view of the condylar position. If the teeth were separated, TMJ images might misrepresent the condylar position in the glenoid fossa, and cephalometric measurements might also be altered. Other views, such as the embossed panoramic view (Fig. 4B) and the maximum intensity projection (MIP) panoramic view (Fig. 4C), can be produced by clicking the corner of the image in the Dolphin program.

The focal trough used to build the panoramic images can be altered for better visualization of one arch over another. In cases of extreme horizontal overjet, the focal trough may not capture the upper and lower anterior teeth in the same view. In such instances, we save two panoramic images: one with the maxillary teeth in focus, the other with the mandibular teeth in focus.

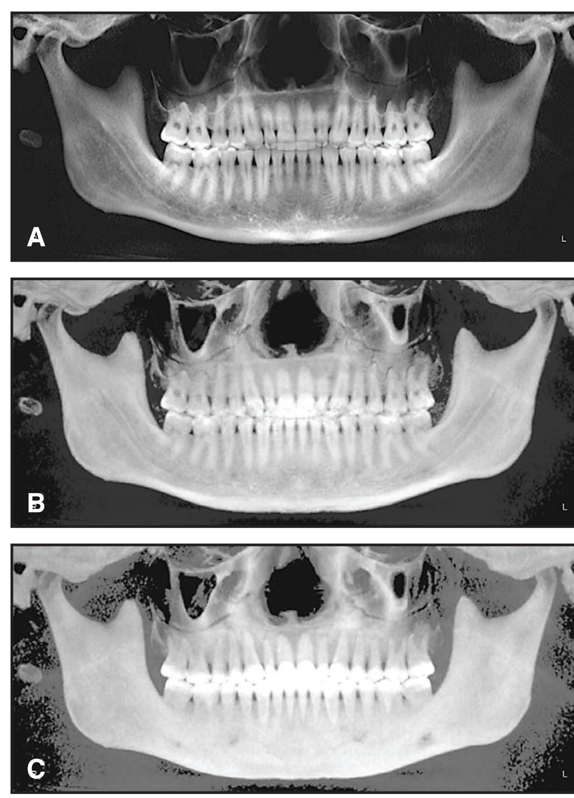

Fig. 4 A. Typical panoramic image from CBVI with teeth in occlusion. Toggling between images can help pinpoint suspicious areas for additional review. B. Embossed panoramic view. C. Maximum intensity projection (MIP) panoramic view. (These and following images were created with Dolphin 3D software unless otherwise noted.)**

Lateral Cephalometric View

The lateral cephalometric view can be built in a 2D format to allow comparison against established norms (Fig. 5A). Lateral cephalometric images can also be created in 3D versions for superior evaluation and to view the right and left sides of the face simultaneously. Whenever it is difficult to identify landmarks,[18] the image can be embossed in the same manner as a panoramic film (Fig. 5B). Wearing a chin cup during the scanning procedure can distort measurements of the surrounding soft tissues, but those areas can readily be measured clinically or from photographs. If an older patient is being scanned for surgical planning, it may be advisable to forgo the chin cup.

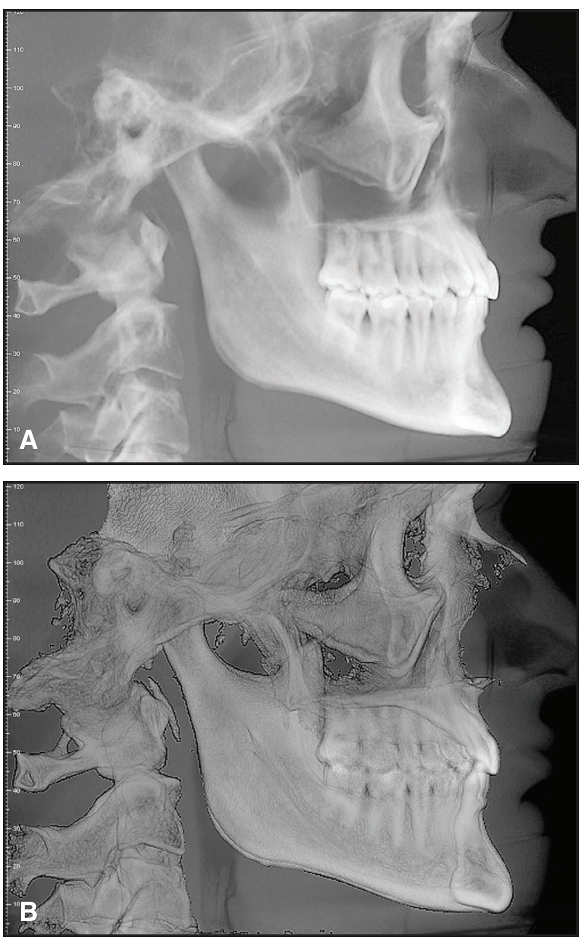

Fig. 5 A. Typical 2D lateral cephalometric CBVI image with teeth in maximum intercuspation. Wearing chin cup during scanning procedure may distort landmarks by obscuring chin, requiring measurements to be made clinically or from photographs. B. Embossed version of cephalometric image can assist in identification of difficult anatomic landmarks.

The lateral cephalogram may be of little value in planning treatment for patients with Class II, division 1 malocclusions, even in determining whether extractions or expansion are indicated.[19] CBVI can provide additional diagnostic information on the anatomy and skeletal structures by rotating the 3D image of the skull into different positions. Incidental findings such as an extra mental foramen may also appear (Fig. 6).

The lateral cephalometric view can be used to assess the developmental stage of the cervical vertebrae for determining skeletal maturation,[20] which could eliminate the need for hand-wrist films. The airway can be viewed in color, either in conjunction with hard tissues or alone, and the Dolphin 3D software can calculate the airway volume and the area of greatest restriction (Fig. 7). Given the morbidity associated with obstructive apnea, further investigation into the clinical relevance of airway measurements is needed.[21] For example, scanning might be used to measure

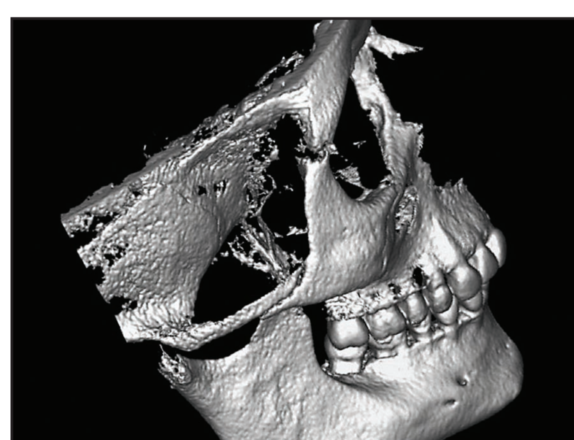

Fig. 6 Hard-tissue skull image will reveal pathology, atypical anatomic findings such as extra mental foramen (shown here), and ectopic teeth. Skull can be rotated and viewed from different perspectives.

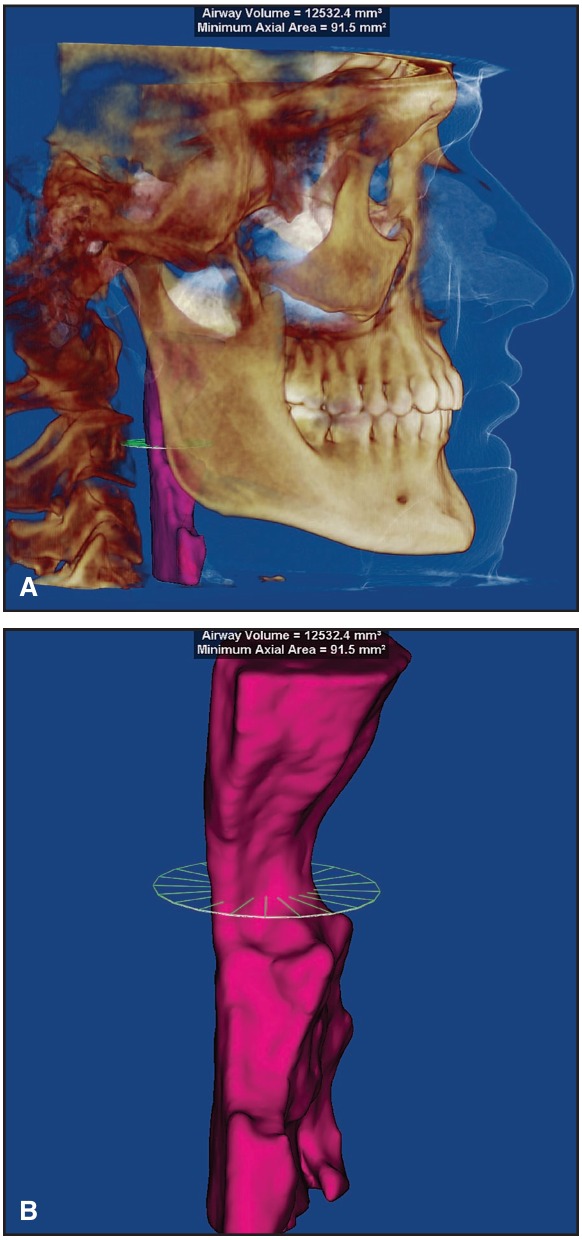

Fig. 7 A. Airway colored pink for ease of viewing, with green slice placed through airway by Dolphin 3D software to identify region of greatest constriction. Volumetric measurement and location of constricted area are relevant to both diagnosis of apnea and orthodontic treatment planning. Location of constricted region is most easily appreciated by seeing airway as part of skull projection. B. Airway without skull image, allowing rotation for better assessment of airway morphology. If viewed from only one axis, elliptical airway can be misidentified as wide.

changes in airway space resulting from the placement of an intraoral apnea appliance.

Lateral View (Sagittal Slice)

A trough of alveolar bone exists for movement in the buccal, lingual, and apical directions. When teeth are forced into cortical bone, root resorption or other compromise may occur. The sagittal slice gives a clear view of the upper or lower incisors within the alveolar bone, visually establishing the potential range of orthodontic movement for each tooth (Fig. 8). Both sets of

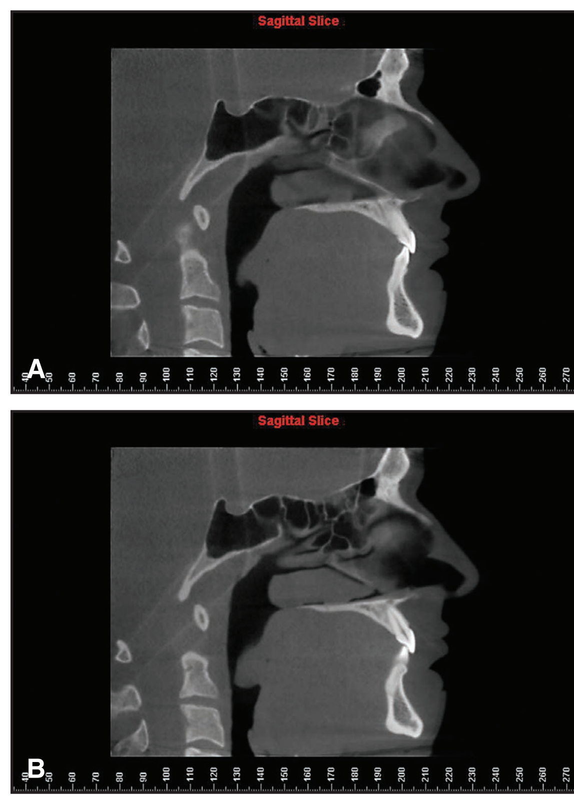

Fig. 8 A. Sagittal view of lower central incisor identifies position of tooth relative to available bone. Upper central incisor is not in focus, requiring second slice. B. Sagittal view of upper central incisor allows visualization of realistic boundaries of tooth movement. Tooth shown cannot be moved far superiorly due to lack of bone apical to tooth; bone is adequate for lingual root torquing, but anterior movement would cause deleterious effects.

incisors can sometimes be well visualized in one image. In addition, the sagittal image can be altered to include other teeth, which may be of particular value in cases involving trauma and endodontic therapy; in Class II, division 2 cases with torque differences between the central and lateral incisors; and in progress views for recognition of root resorption.

This kind of diagnostic assessment is important when trying to camouflage maxillomandibular discrepancies, make space for crowded teeth, minimize movement of periodontally compromised teeth, close extraction spaces, open space for future prosthetics, or even determine the appropriateness of orthodontic therapy, as in retreatment cases (Fig. 9). The lateral images allow the clinician to determine the maximum possible change in the buccolingual torque of an incisor and the limits of intrusion or extrusion. Because the distortion in these images is minimal, millimetric and angular measurements could eventually be inte-

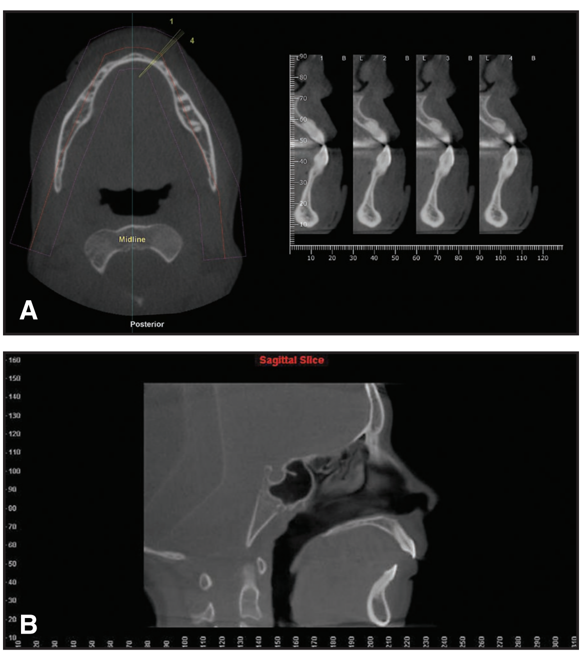

Fig. 9 A. Cross-sectional slices of middle-age patient desiring retreatment for relapse (right), showing limited bone availability to resolve Class III crowded dentition. Upper roots are confirmed as short, rather than merely appearing short from excessive flaring (as can occur with panoramic x-ray). Axial view (left) shows narrow trough of bone in which lower incisor roots can be housed (this view requires scrolling through slices to truly evaluate bone availability). Only limited buccolingual tooth movement can take place without periodontal compromise (compare to more typical amount of alveolar bone in axial image of German Template, Fig. 2). B. Sagittal view of different patient's incisors and bone, showing skeletal changes required for overjet resolution. Dental movement alone would force teeth out of existing bone. Lower incisor is already flared, contraindicating additional anterior movement.

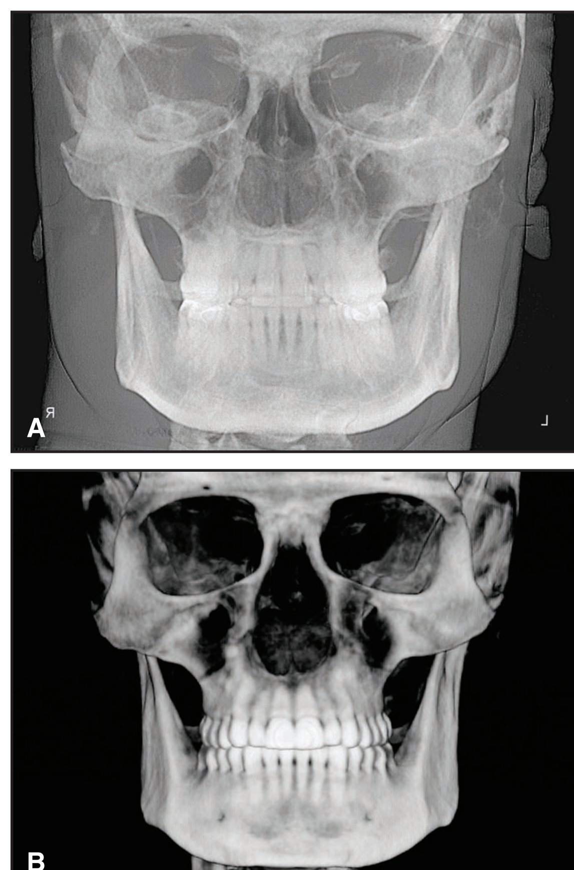

Fig. 10 A. 2D or 3D frontal cephalometric view can be altered to facilitate landmark identification, as in previous illustrations of embossed and MIP views. B. Hard-tissue frontal view of skull allows better assessment of anatomical landmarks, dental roots, and ectopic teeth than traditional frontal x-ray. View can be rotated for best evaluation of complete anatomy and positions of erupted and unerupted teeth.

grated with interactive digital setups in planning treatment for products such as Invisalign,††† OrthoCad iQ,‡ SureSmile,‡‡ and others.

Frontal Cephalometric View

The frontal view can be created in either 2D or 3D. Historically, frontal films have been difficult to trace and assess due to poor visualization of landmarks, but the 3D version can alleviate this problem. The hard-tissue version of the frontal view provides a better diagnostic look at the skeleton and offers the ability to evaluate the root structure and potential pathology (Fig. 10). The 3D view with skull rotation allows the clinician to fully appreciate the maxillofacial skeleton.

Coronal View (Transverse, or Nose-to-Occiput Slices)

The coronal image can be focused on any of the posterior teeth to establish the buccolingual inclination of the teeth within the supporting bone (Fig. 11). The width of the maxilla and dimensions of the alveolar bone can be accurately measured

†††Registered trademark of Align Technology, Inc., 881 Martin Ave., Santa Clara, CA 95050; www.aligntech.com.

‡Registered trademark of Cadent, Inc., 640 Gotham Parkway, Carlstadt, NJ 07072; www.cadentinc.com.

‡‡Registered trademark of OraMetrix, Inc., 2350 Campbell Creek Blvd., Suite 400, Richardson, TX 75082; www.suresmile.com.

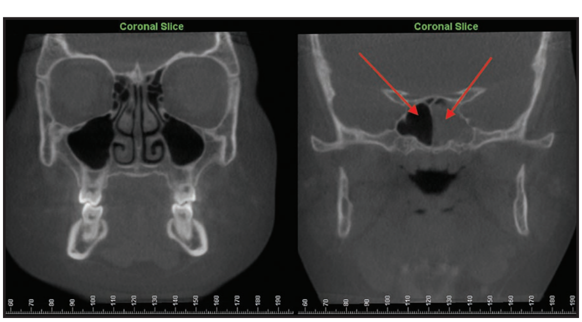

Fig. 11 Coronal image (transverse plane) provides additional information regarding buccolingual inclination of posterior teeth and amount of available bone. Right image shows importance of scrolling through slices rather than simply viewing saved images in German Template. Infected left sphenoid sinus can be easily detected, allowing appropriate referral and avoiding potentially serious medical problem.

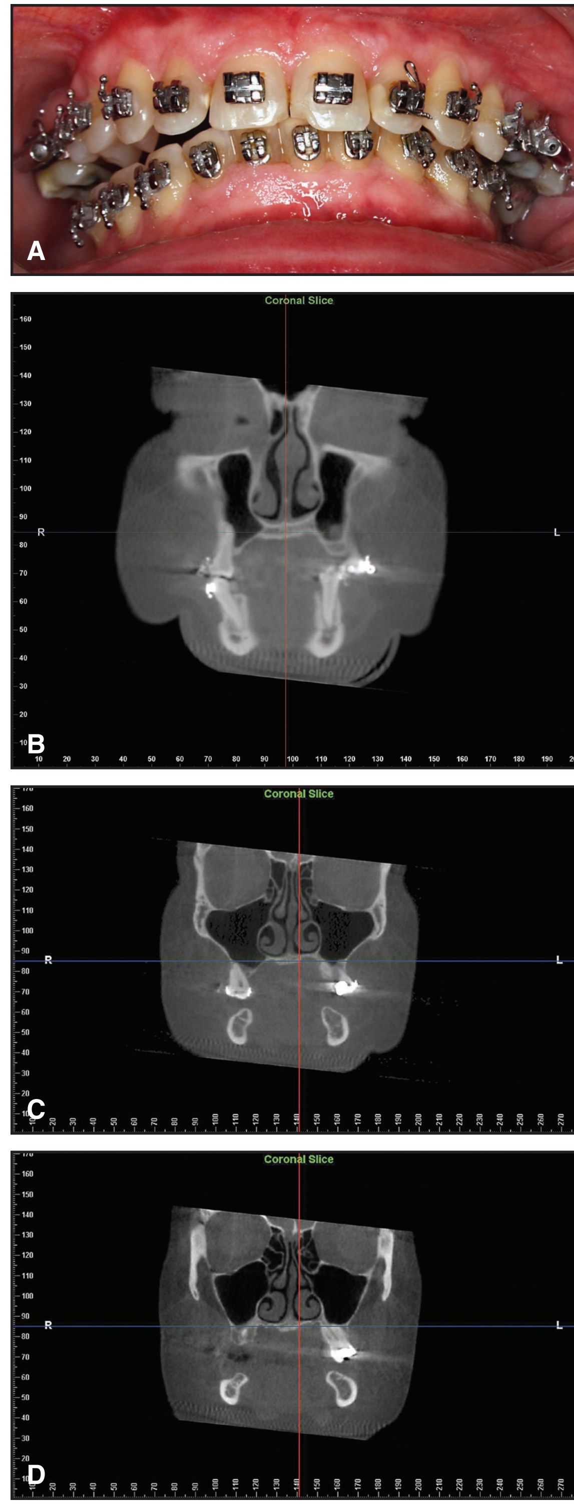

Fig. 12 A. In this patient with buccal crossbite tendency, transverse discrepancy could be dental, skeletal, or both. B. Coronal image reveals excessive buccal crown and lingual root torque of lower right second premolar as compensation to achieve better occlusion with upper dentition. Premolar has been tipped excessively in attempt to resolve buccal crossbite. C. Upper right molar is in appropriate buccolingual position. D. Upper left molar would benefit from lingual crown movement, which could avoid need for surgery to correct crossbite.

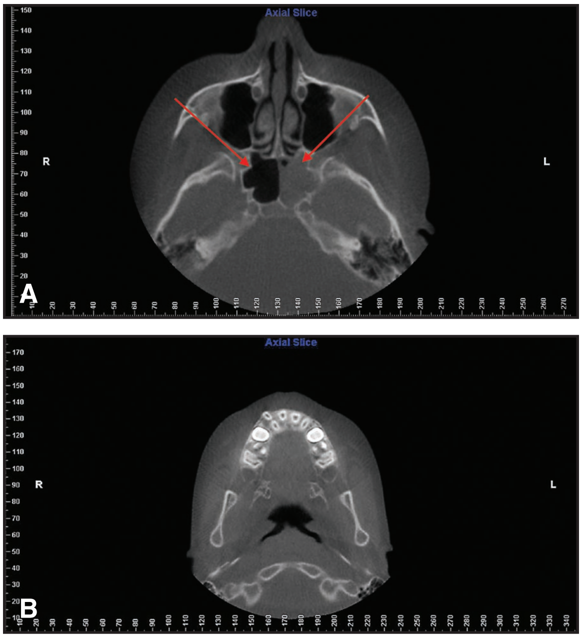

Fig. 13 A. Axial slice shows condylar axis and buccolingual width of alveolar process in superior views. Incidental findings such as calcification of vessels are occasionally noted in inferior views; displayed image clearly shows pathology of left sphenoid sinus. B. Axial view reveals supernumerary upper anterior tooth and indicates width of alveolar bone.

to help determine how much the transverse dimension can be altered in the buccal or lingual dimension in nongrowing patients. Furthermore, the buccolingual inclinations of the teeth can be measured to determine whether buccolingual crown or root torque is indicated or possible. This view often reveals situations in which the lower molars may be compensating for a narrow maxilla through excessive lingual crown torque. Such compensations may be removed when orthodontic appliances are applied, causing the lower teeth to become upright and thus creating unanticipated transverse discrepancies (Fig. 12).

Our standard coronal (transverse) evaluation measures the dimensions of the palate and the axial inclinations of the first molars, which often differ from the inclinations of the other posterior teeth. If other posterior teeth require assessment, additional transverse images can easily be built. The coronal view also displays various sinuses and the osteomeatal complex, often leading to incidental findings related to the airway.

Axial View (Foot-to-Head Slices)

The axial view will occasionally reveal ectopic and supernumerary teeth (Fig. 13). If pathology is present, we suggest saving the axial slice that best visualizes it. Otherwise, we save the view shown in Figure 2, which includes the condylar axes, nasal septum, and maxillary sinuses.

Sagittal TMJ View

Although some practices continue to request TMJ studies on routine orthodontic patients, most orthodontists now limit imaging of the TMJ, other than the panoramic radiograph, to patients with symptoms or pathology. Normative measurements have been reported as 1.3mm of joint space in the anterior portion of the condylar fossa (or a ratio of 1:1), 2.1mm of space on the distal aspect of the fossa (ratio of 1.6:1), and 2.5mm of space on the superior aspect of the fossa (ratio of 1.9:1).[22] When assessing the integrity of the condyles and fossae, we should remember that asymptomatic patients often develop arthritis and reduced joint space with age.[23]

The anatomy of the condyles is clearly depicted with CBVI, more accurately than in panoramic projections and corrected-angle linear tomography.[24] Although the condylar axis is easily visualized in the axial view, the software also provides a number of slices through the TMJ (Fig. 14). The coronal view displays an anteroposterior view of the condyle within the fossa, which sometimes provides a better assessment of the condylar flattening associated with arthritis. Although some clinicians elect to perform a second scan to determine the extent and ability of the condyles to translate relative to the articular eminence, we do not, unless requested by a referring doctor who has been treating the patient for TMD with orthotics.

Diagnostic Models View

Third-party software such as Anatomage§ allows digital construction of dental casts, trimmed according to ABO standards (Fig. 15). An additional benefit of these views is the ability to evalu-

§Anatomage, 111 N. Market St., Suite 800, San Jose, CA 95113; www.anatomage.com.

Fig. 14 A. Sagittal view of TMJ depicts condylar position during occlusion. Hard-tissue skull images (Figs. 6,7) can be used to confirm occlusion relative to condylar position. B. Coronal slices of TMJ provide nose-to-occiput views of condyles. Dolphin 3D software helps locate condylar axes, then produces associated perpendicular views to assess condylar location in fossa and morphology of condylar process. (These images were produced with i-CAT software and saved in Dolphin patient records and German Template.)

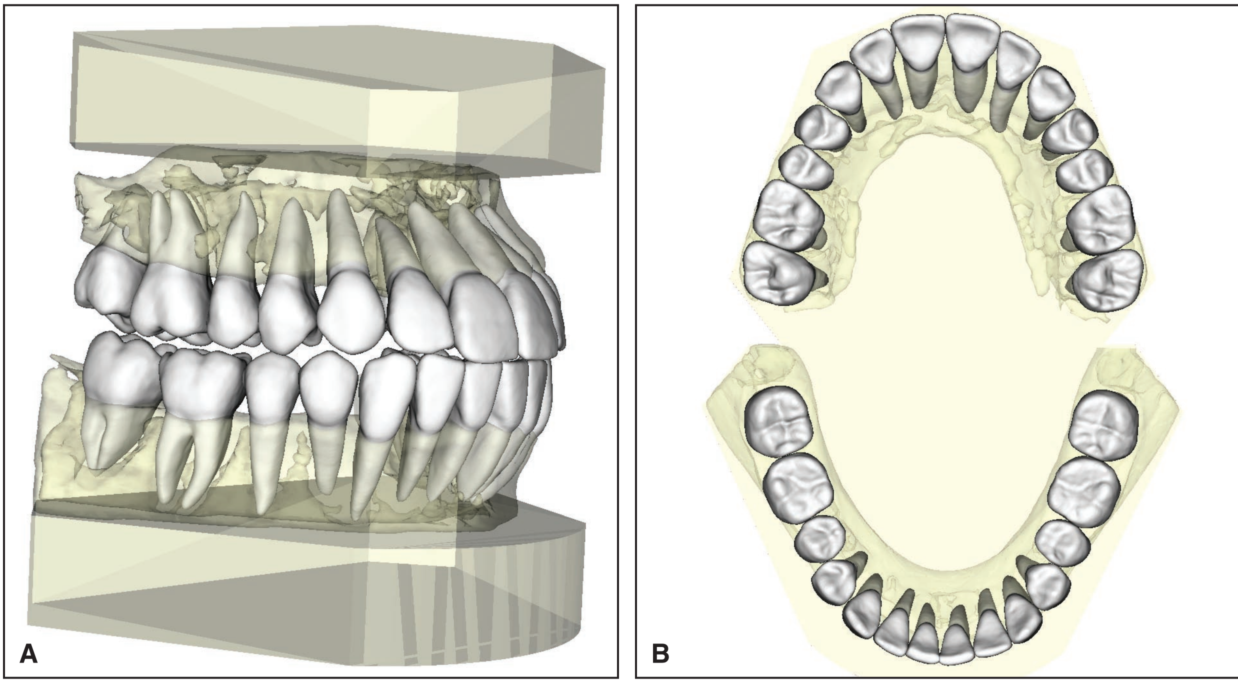

Fig. 15 A. Digital models created from CBVI show teeth on bases trimmed to ABO standards, with added benefit of seeing root positions. Data with teeth in occlusion are captured simultaneously with other views. B. Occlusal views could potentially be used to assess tooth size, arch-length deficiency, and arch dimensions, pending appropriate research. (These images were produced with Anatomage software.)

ate the roots and some of the alveolar structure. The occlusion in the digital models is identical to that displayed in the sagittal TMJ view and the cephalometric images.

The Future

CBVI images can now be merged with photographs for treatment planning (Fig. 16). Additional enhancements to the interactive software might include the ability to measure the volume of root structure for each tooth and the quantity and density of surrounding bone, which would allow this information to be used to position teeth.

Force systems are becoming more complex as the underlying engineering is better understood, and their determination is further complicated by contacting teeth, opposing teeth, mastication, and parafunction.[25] CBVI software might be able to determine the appropriate moment-to-force ratios needed to shift teeth into orthodontist-determined positions without moving them beyond their alveolar boundaries. The optimal force could then be applied to each tooth at each appointment, using aligners or a combination of indirect-bonded brackets and mechanically formed wires. Teeth would be placed efficiently in ideal positions that would cause the least discomfort to the patient. With upgrades to present technology, appliance systems could even be fabricated directly from CBVI findings.

CBVI provides a quantum leap in diagnostic capability, as well as the potential for integrating treatment and designing interactive clinical setups with other doctors. In the future, orthodontic patient records might be limited to a set of photographs and CBVI images, as in the German Template. We appreciate that there is little, if any, scientific basis to certain components of the proposed German Template. Considering that the technology has been in use for nearly a decade, however, practitioners need some sort of image-display protocol to implement while research refines the information that needs to be assessed. Over time, the profession will undoubtedly revise these standardized series of images to review and save for each patient. But the end result is that the orthodontist will be able to quickly glean the required diagnostic information and correlate it with findings from the clinical examination for precise, predictable treatment planning.

REFERENCES

1. Cattaneo, P.M.; Bloch, C.B.; Calmar, D.; Hjortshøj, M.; and Melsen, B.: Comparison between conventional and cone-beam computed tomography-generated cephalograms, Am. J. Orthod. 134:798-802, 2008.
2. Mozzo, P.; Procacci, C.; Tacconi, A.; Martini, P.T.; and

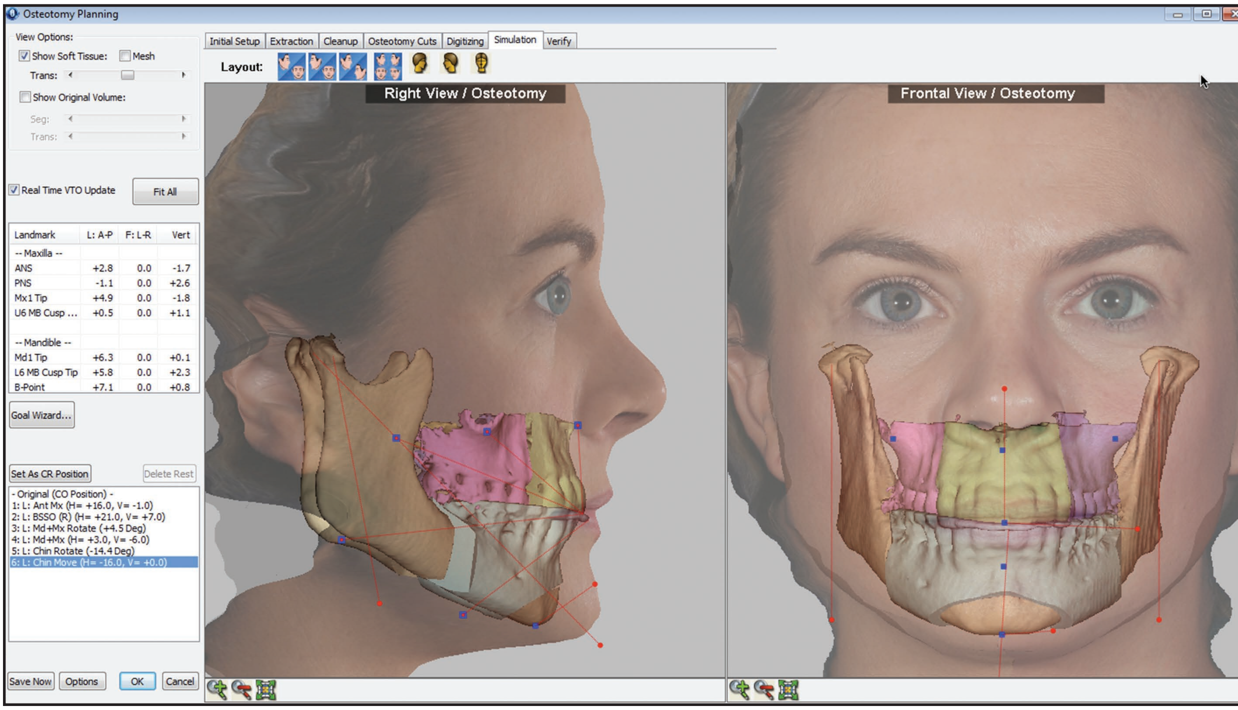

Fig. 16 CBVI combined with photography for surgical planning; visual treatment objectives established using Dolphin 3D softwarb+%Qefp ifkh t fii q^hb vl r q ^Vl r Qr _b sfabl l c^ Al imefk `^pb mdbpbkq^qfl k abj l +&

Andreis, I.A.: A new volumetric CT machine for dental imaging based on the cone-beam technique: Preliminary results, Eur. Radiol. 8:1558-1564, 1998.

3. Hounsfield, G.N.: Computerized transverse axial scanning (tomography), Part 1: Description of system, Br. J. Radiol. 68:H166-H172, 1995.
4. White, S.C.: Cone-beam imaging in dentistry, Health Phys. 95:628-637, 2008.
5. Mah, J. and Hatcher, D.: Three-dimensional craniofacial imaging, Am. J. Orthod. 126:308-309, 2004.
6. Palomo, J.M.; Rao, P.S.; and Hans, M.G.: Influence of CBCT exposure conditions on radiation dose, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 105:773-782, 2008.
7. Danforth, R.A.; Peck, J.; and Hall, P.: Cone beam volume tomography: An imaging option for diagnosis of complex mandibular third molar anatomical relationships, J. Calif. Dent. Assoc. 31:847-852, 2003.
8. Mah, J. and Hatcher, D.: Current status and future needs in craniofacial imaging, Orthod. Craniofac. Res. 6:10-16, 2003.
9. Sukovic, P.: Cone beam computed tomography in craniofacial imaging, Orthod. Craniofac. Res. 6:31-36, 2003.
10. Ludlow, J.B.; Davies-Ludlow, L.E.; Brooks, S.L.; and Howerton, W.B.: Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT, Dentomaxillofac. Radiol. 35:219-226, 2006.
11. Ludlow, J.B.; Davies-Ludlow, L.E.; Brooks, S.L.; and Howerton, W.B.: 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.
12. Schulze, D.; Heiland, M.; Thurmann, H.; and Adam, G.: Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography, Dentomaxillofac. Radiol. 33:83-86, 2004.
13. 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.
14. Mah, J.K.: X-ray imaging and oral healthcare, Radiology Centennial, American College of Radiologists, Reston, VA, 2006.
15. Lofthag-Hansen, S.; Huumonen, S.; Gröndahl, K.; and Gröndahl, H.G.: Limited cone-beam CT and intraoral radiography for the diagnosis of periapical pathology, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 103:114-119, 2007.
16. Vandenberghe, B.; Jacobs, R.; and Yang, J.: Detection of periodontal bone loss using digital intraoral and cone beam computed tomography images: An in vitro assessment of bony and/or infrabony defects, Dentomaxillofac. Radiol. 37:252-260, 2008.
17. Cha, J.Y.; Mah, J.; and Sinclair, P.: Incidental findings in the maxillofacial area with 3-dimensional cone-beam imaging, Am. J. Orthod. 132:7-14, 2007.
18. Adenwalla, S.T.; Kronman, J.H.; and Attarzadeh, F.: Porion and condyle as cephalometric landmarks—an error study, Am. J. Orthod. 94:411-415, 1988.
19. Nijkamp, P.G.; Habets, L.L.; Aartman, I.H.; and Zentner, A.: The influence of cephalometrics on orthodontic treatment planning, Eur. J. Orthod. 30:630-635, 2008.
20. San Román, P.; Palma, J.C.; Oteo, M.D.; and Nevado, E.: Skeletal maturation determined by cervical vertebrae development, Eur. J. Orthod. 24:303-311, 2002.
21. Ogawa, T.; Enciso, R.; Shintaku, W.H.; and Clark, G.T.: Evaluation of cross-section airway configuration of obstructive sleep apnea, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 103:102-108, 2007.
22. Ikeda, K. and Kawamura, A.: Assessment of optimal condylar position with limited cone-beam computed tomography, Am. J. Orthod. 135:495-501, 2009.
23. Alexiou, K.; Stamatakis, H.; and Tsiklakis, K.: Evaluation of the severity of temporomandibular joint osteoarthritic changes related to age using cone beam computed tomography, Dentomaxillofac. Radiol. 38:141-147, 2009.
24. Honey, O.B.; Scarfe, W.C.; Hilgers, M.J.; Klueber, K.; Silveira, A.M.; Haskell, B.S.; and Farman, A.G.: Accuracy of cone-beam computed tomography imaging of the temporomandibular joint: Comparisons with panoramic radiology and linear tomography, Am. J. Orthod. 132:429-438, 2007.
25. Katona, T.R.: An engineering analysis of dental occlusion principles, Am. J. Orthod. 135:696.e1-696.e8, 2008.