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## The Future of Dental and Maxillofacial Imaging

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This issue of *Dental Clinics of North America* has covered old and new imaging modalities, their current applications, and some more contemporary applications such as image-guided surgery. What is left to be said?

I will start first with what dentists and oral and maxillofacial radiologists will most likely not do, even with our newest imaging technique—cone beam volumetric tomography (CBVT).

Although at least one manufacturer has previously shown vessels in the head and neck region in their CBVT machine brochure, dentists and oral radiologists will probably never do contrast procedures. Blood is not stationary, and to see the flow patterns, contrast nonionic agents such as Omnipaque (GE Healthcare, Piscataway, New Jersey) are used. Many of us have used these agents for sialography in the past, but this salivary gland investigative technique is labor intensive and has largely been replaced by conventional CT with contrast and MRI for salivary gland evaluation.

We are neither trained to perform these interventions, nor do we require any application for evaluation of head and neck problems with which we deal. Cerebral angiography is used to detect aneurysms, clots that have made their way to the brain giving rise to stroke and other vascular problems. The catheter is inserted into the femoral or carotid artery, and the injected contrast medium administered. The procedure takes hours to perform and must be done in a hospital setting by an interventional radiologist. We will never be trained or licensed to do these procedures. We cannot image vessels in the head and neck region with cone beam technology.

Another “head and neck” radiology task we will never perform is the interpretation of neurologic structures in the brain—at least with CBVT. The exposure factors and the image acquisition technique do not allow us

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to visualize “gray and white” matter of the brain. In fact, we wouldn’t want it to. Again, although many oral and maxillofacial radiologists are “familiar” with the features of disorders and disease affecting the brain such as multiple sclerosis and disseminated herpetic lesions, we are neither trained nor licensed to perform interpretation of these neural structures and problems. And, luckily for us, CBVT cannot image these types of problems. The CBVT machines and techniques are suitable for bone and some soft tissue imaging tasks we require but are vastly inferior to conventional CT for most medical problems.

Finally, it is my opinion that dentists and dental specialists will never completely replace some conventional imaging techniques such as intraoral and panoramic with CBVT.

These restrictions aside, CBVT has opened a new door for all of us in the dental profession. We can now perform limited imaging tasks, like our medical radiology colleagues, with software tools that rival theirs for visualization of anatomy and pathology specifically related to our desired applications. Let’s now see what the “future” might hold for us with all of the imaging techniques available. What follows is a series of questions we’ve been asked or ask ourselves, followed by my “predictions” of how and why oral and maxillofacial imaging techniques will evolve.

### **Predictions for intraoral, panoramic, and “advanced” imaging modalities**

#### ***Question #1: Will intraoral and panoramic imaging disappear or be replaced by CBVT?***

My response is a resounding, “NO!” Certainly the ability to “slice” through a patient’s dental anatomy at 0.15 mm thicknesses could uncover a carious lesion, right? The answer is “Yes” and “No.” Although we can see cavitations in some volumes more precisely (Fig. 1), in others the scatter artifact, running horizontally through the occlusal region, will obscure many lesions (Fig. 2). Besides, it is currently, and I think for many years to come, unjustified to use CBVT for caries detection [1,2]. Why you might ask?

First, as low as the x-ray doses are for CBVT machines, the x-ray dose is still too high for many dental imaging tasks. Second, the simpler, more conventional techniques to image interproximal cavities still have the highest resolution. In addition, certain panoramic machines can now provide high-resolution interproximal images, collimated to reduce dose and provide periapical information that may reduce the total number of intraoral images we require for treatment planning (Fig. 3). The large bitewing images below also could replace some posterior intraoral images from the cuspid posteriorly. Note how they even give a detailed view of the third molar region. This would leave only a few anterior views in an initial new patient examination. And, those are the images the auxiliary likes to do!

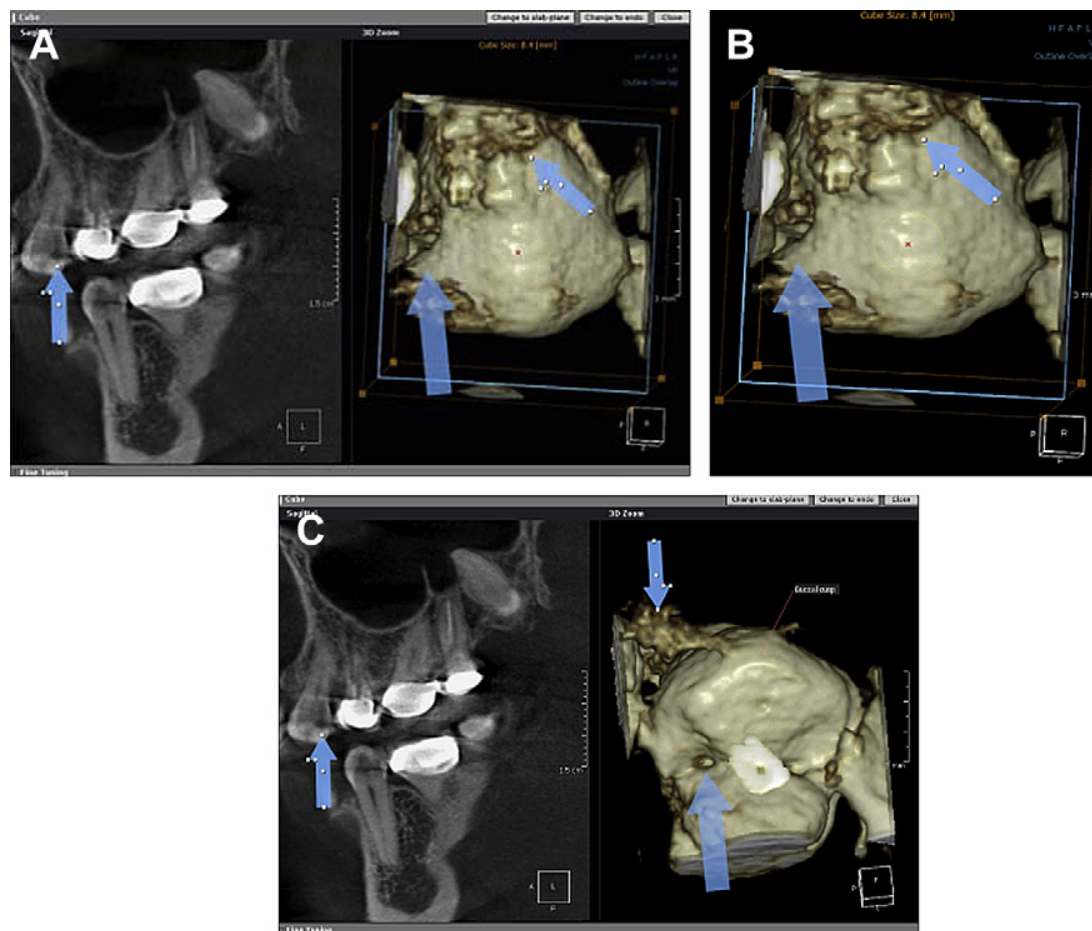


Fig. 1. (A) Interproximal carious lesion on the distal of tooth #12. There is some distortion of this area because of scatter artifact from the restorations. The 3D color reconstructions using N-Liten from PlanmecaUSA (Roselle, Illinois). The “Cube Tool” allows better visualization of the lesion in (B) (large blue arrows). However, the noise artifact created by these restorations is apparent (small blue arrows) in 3D views. (C) The lesion, although appearing “interproximal” may actually have developed as a “distal pit” lesion as seen in the 3D color view (large blue arrow). Noise is again distracting (small blue arrow). Case images in Planmeca N-Liten software.

### Prediction #1

*Although we may use fewer intraoral images, both bitewing and periapical, and even with advances in panoramic techniques and software that can replace some intraoral images, we still will need the higher resolution capability of film or digital intraoral images for high-risk “caries patients” to see the earliest lesions. Cone beam imaging will not replace intraoral or panoramic.*

### Question #2: Will tomography or panoramic imaging technique be replaced by CBVT?

My response to this question is a hearty “Yes”! Although tomography was considered “state-of-the-art” for implant planning, even with the best machines and tomographic programs that are available in some panoramic machines, the technique is “labor intensive” once again. Despite the acceptable quality that these images may have, they cannot be made thin enough to precisely locate the alveolar crest in many cases. The technique’s

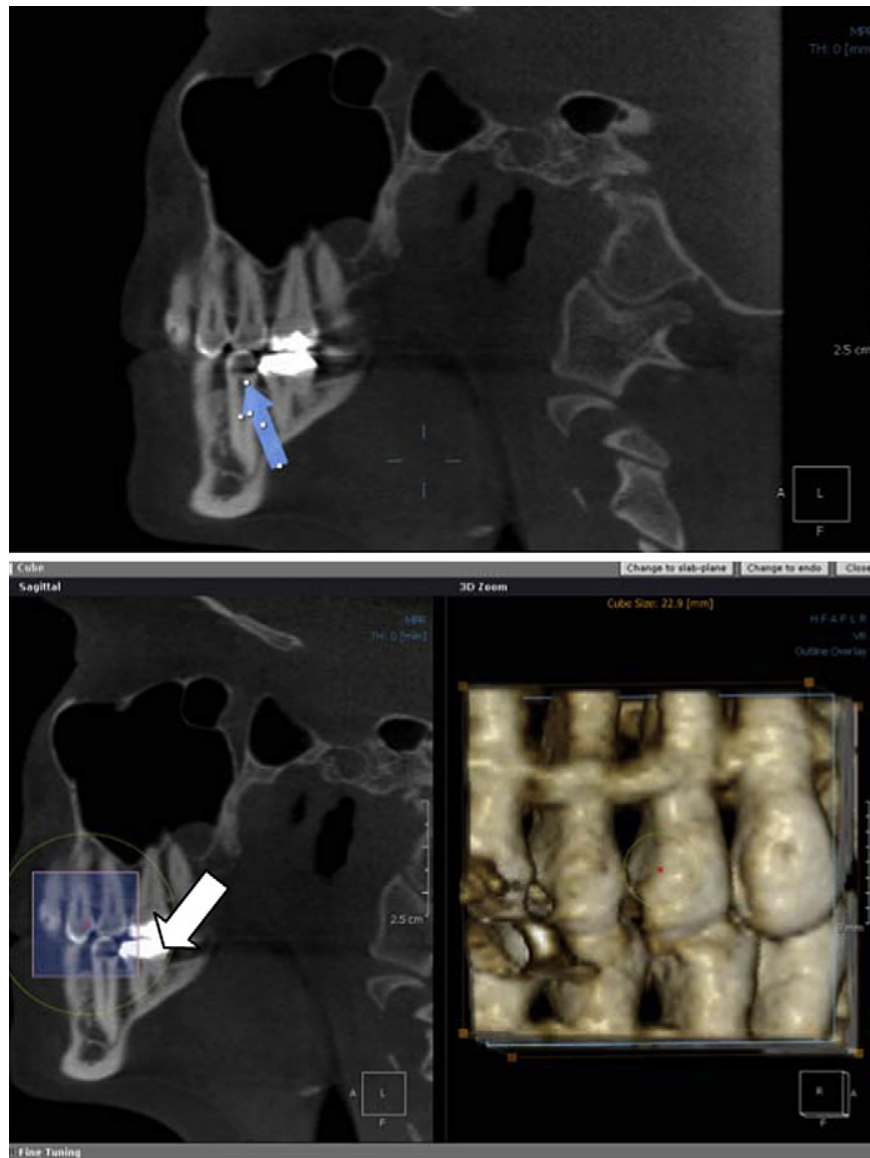


Fig. 2. This volume from an Imaging Sciences i-CAT also shows how even minor scatter artifact from restorations can obscure caries detection. Volume was imaged in OnDemand3D, (CyberMed International, Seoul, Korea).

magnification factors with either dedicated tomography or panoramic tomography programs must always be considered. Clinicians still have to factor in these technique parameters and leave the traditional 2 mm of “safety margin.” With CBVT the measurements are accurate to within 1/10 mm in most software. And, all structures are rendered in a 1:1 ratio in the image reconstruction software. The margin of error is more precise with CBVT. You can “recapture” 1 to 1.5 mm of space that might mean the difference between being able to place a fixture and not being able.

As an aside, many clinicians first encountering CBVT images, and stuck in their conventional imaging techniques, confuse the term 1:1 ratio with their perception of “life size!” If the structures are rendered in a precise 1:1 ratio, we can make the image of an implant site into an 8- × 11-inch glossy print. And if the measured length says 12.2 mm, it IS 12.2 mm to



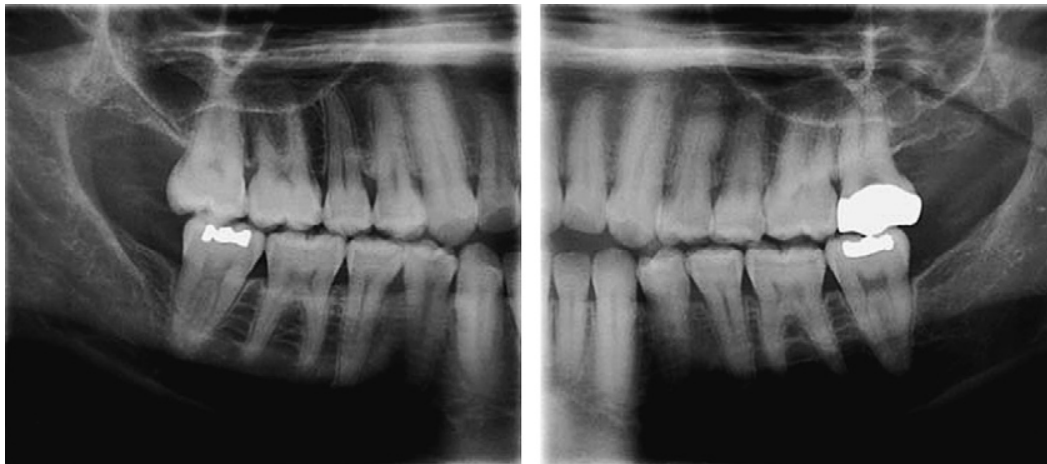


Fig. 3. A bitewing image from a panoramic image capture. Almost all contacts are “open” making caries detection in the bicuspid region possible. This can only be accomplished because of a C-arm on the top of the ProMax (PlanmecaUSA, Roselle, Illinois) panoramic machine, which allows the device to start from a different location and “open” the bicuspid contacts. Currently, in all other panoramic machines these contacts are overlapped and cannot be used for detecting carious lesions interproximally.

within 1/10 of a millimeter! You do not have to use tiny little transparency overlays with implant icon fixtures over a tiny little image of the mandible or maxilla. Those days are gone! That is not the “state-of-the-art” any longer. Images like that in Fig. 4 illustrate this point.

As for panoramic imaging remaining a “standard of care,” I can state this. In my opinion it really was never a standard of care. Clinicians, including oral and maxillofacial surgeons, were placing themselves at some risk for using a panoramic image as the sole radiographic means of implant site assessment. Some still do. Now that CBVT has become so widely available, the use of a panoramic image, with the myriad of positioning errors made and the lack of the cross-sectional information cannot be justified. Anyone who persists using this image as their only image for implant site

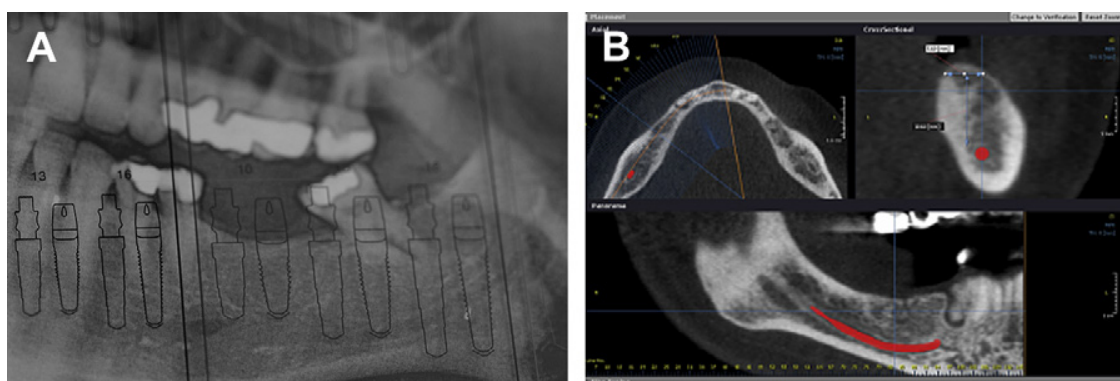


Fig. 4. (A) A panoramic image with a “transparency overlay” of generic implant icons. (Courtesy of Ronald Shelley, DMD, Glendale, AZ). (B) A typical cross-sectional display with nerve marked in red and precise measurements labeled on the proposed implant site for tooth #30 (implant image #83). If needed, an icon can be overlaid to better visualize the proposed site.

evaluation will have a serious liability issue in my opinion. Fig. 5A–D show the improved information available with CBVT technique software.

**Prediction #2**

*CBVT will replace conventional tomography as the “standard of care,” and should now be used in place of panoramic imaging to assess any implant site.*

**Question #3: Will CBVT replace conventional CT as the “state-of-the-art” or the “standard of care” for presurgical implant site evaluation?**

Yes. Period! With the substantially reduced patient x-ray dose [3], the “implant-specific” software, the smaller voxel size, the wider “availability” and the reduced cost, CBVT will become the standard of care within the foreseeable future. This is obvious from the images seen above.

**Prediction #3**

*CBVT will replace conventional CT as the standard of care for implant assessment.*

**Question #4: Will the “cephalometric” image reconstructed from a CBVT data volume replace the conventional cephalometric image for cephalometric analysis?**

My answer today is “not yet.” Since the 1940s when the cephalometric techniques were introduced, orthodontists have developed many ways of

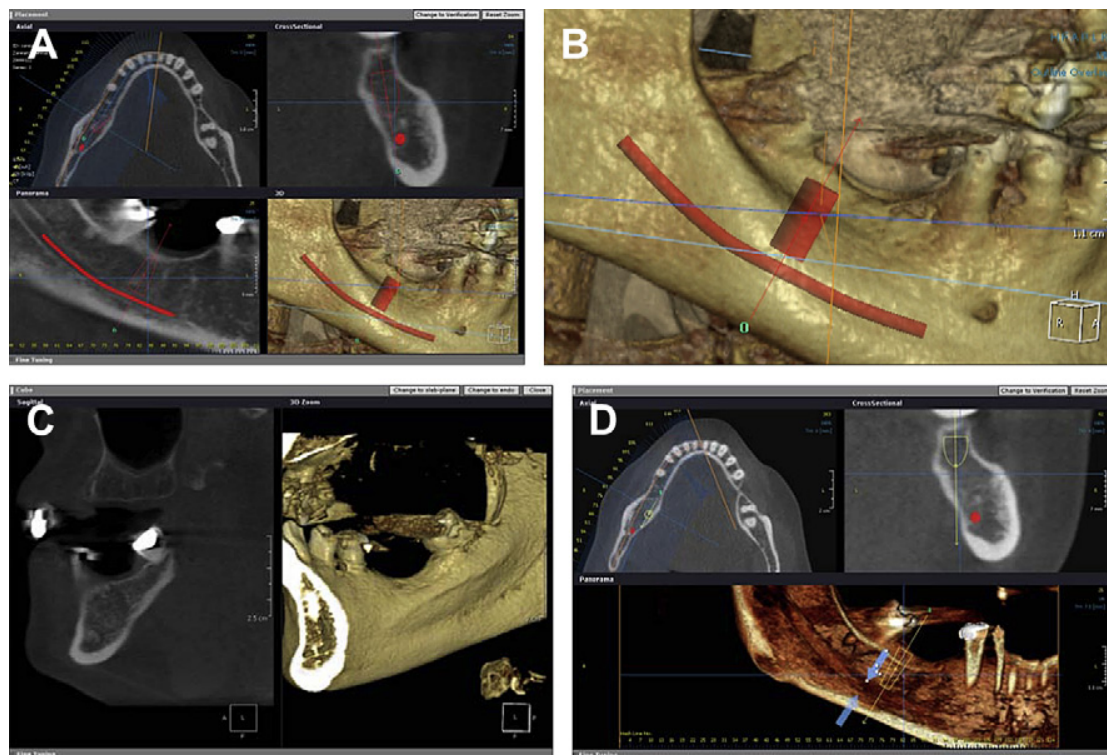


Fig. 5. (A) Typical implant planning image set shows a “generic” implant fixture orientation in relation to the inferior alveolar nerve. (B) A close-up image of the case above isolating the 3D color volume and proposed implant placement visualization. (C) A 3D colorized view to show the submandibular fossa in relation to the implant site. (D) A colorized “slab” rendering allows the clinician to actually see the canal and the desired position of the intended implant fixture. Precise measurements can now be made.

performing an “analysis” of the conventional cephalometric image to predict final tooth position and have been using these “analyses” for more than 60 years. Today, in the dental profession, just because a technology is available in the marketplace does not mean it can immediately replace the current “standard.” This was obvious from the discussion above. However, in orthodontics, this is especially true. As dentistry’s first specialty, orthodontics has had a long history of examining and developing the “clinical science” behind their orthodontic analyses. In my opinion, here’s what will and should happen before CBVT completely replaces conventional cephalometric techniques.

With the push in dentistry for evidence-based dentistry, multipatient, multitrail research will need to be completed. Possibly 50 patients at each of 10 dental schools or other sites will need to have their traditional cephalometric analyses performed on conventional “cephs” compared with a matching number of patients at each site whose cephalometric image(s) are reconstructed by CBVT software. Then these patients will need to be followed up for 5 years to see if the CBVT technique is more precise than the conventional technique for predicting final tooth position. My gut feeling is that CBVT will outperform conventional cephalometric measurement. Why? The main reason is the fact that, the image data, as stated earlier, is reconstructed at a precise 1:1 ratio. As a result, the magnification artifact(s) inherent in conventional cephalometric x-ray techniques are eliminated. Thus, the localization of the typical landmarks used in the analyses will be more precise, reduced operator error. So, the adoption of CBVT for orthodontic cephalometric analyses is inevitable. Software manufacturers are just now beginning to create the software to perform these analyses. I do not believe orthodontists are ready to “give up” their traditional analyses just yet.

#### ***Prediction #4***

***CBVT will replace conventional cephalometric x-ray technique as the standard of care within 7 to 10 years after the “science” has been completed.***

#### ***Question #5: Will CBVT imaging replace panoramic imaging for third molar extraction?***

In my opinion, my answer would be “not completely.” Not every impacted third molar is located close to anatomic entities that could cause problems like the inferior alveolar nerve (IAN) or the maxillary antra. Some are; some are not (Fig. 6). If an oral and maxillofacial surgeon can obtain the initial information on a panoramic image, film, or digital image, and if the teeth to be removed are in locations that do not approximate the sinuses or IANs, then the clinical treatment decision is simple, the panoramic image provides the necessary data by itself, and CBVT may not be required. They may not even require a “large-volume” machine. If the machine is capable of capturing both the panoramic image alone (low dose to patient) and CBVT data (higher dose to patient), then the decision making



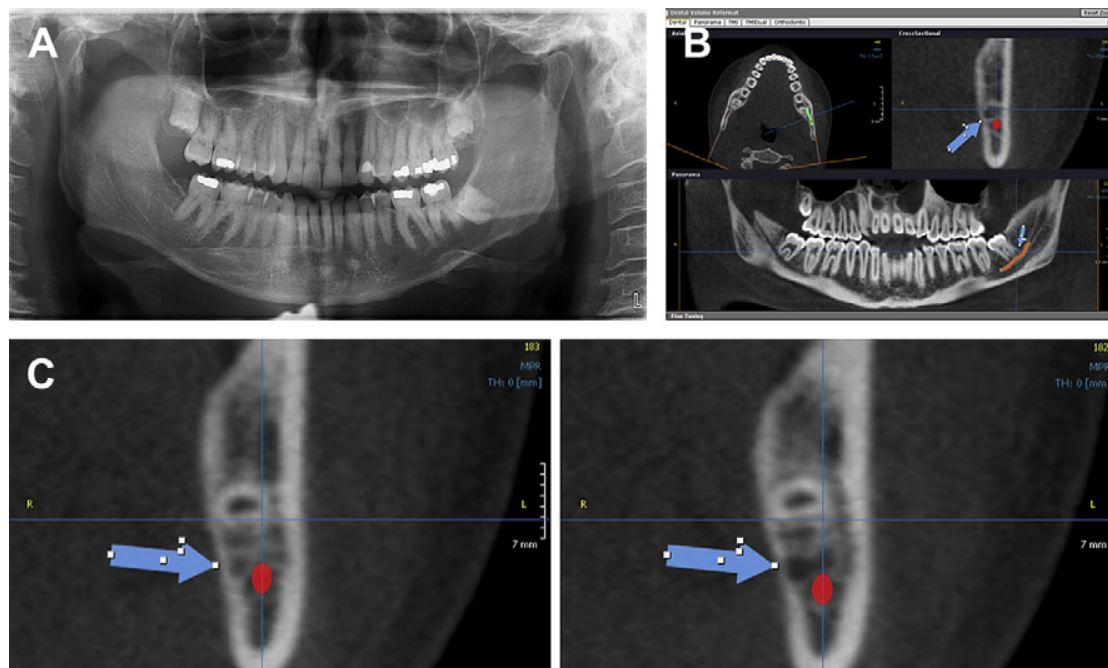


Fig. 6. (A) This excellent digital panoramic reveals 3 impacted molars. If only the upper molars were impacted, a CBVT volume may not be necessary. However, the lower left third molar does appear to be in close proximity to the IAN, so a CBVT should be ordered. Some machines like the ProMax3D can do both using CBVT volume only when needed. (B) This “pseudopanoramic” from an i-CAT volume has the nerve colorized and shows the developing apex of tooth #17 touching the IAN. (C) These cross-sectional images of tooth #17 show the proximity of the IAN to additional root areas of the tooth touching the IAN.

is improved as well as the productivity. In an oral and maxillofacial surgeon's office, time is money, and surgical removal of third molars is the primary procedure. Many oral and maxillofacial surgeons do not want to wait for image reconstruction from CBVT machines (as quick as they may have become) to see a panoramic view in a simple case.

#### **Prediction #5**

***CBVT will replace conventional panoramic images as the standard of care only for difficult third molar extraction cases.***

### **Future considerations for cone beam volumetric tomography imaging**

This is perhaps the most difficult area to make any predictions about because of the ingenuity and creativity of the dental software companies. New, innovative software technology is introduced constantly to our profession. Dentists are more and more computer literate and find processes and tasks in their own offices they wish to simplify or streamline.

Here are the primary areas for growth and thus predictions for dental imaging in the future. Most future uses, obviously, are related to CBVT.

- Software improvement
- Image-to-device processes

- Picture archiving and communication systems (PACS)/ radiographic information systems (RIS)

### Software improvement(s)

Software from the machine manufacturers is already good. They could not have introduced their hardware without accompanying software and be successful. However, some of the manufacturers have proprietary software. Examples are Imaging Sciences International (i-CAT, Hatfield, Pennsylvania) and AFP Imaging (NewTom 3G and VG, Elmsford, New York). Although both these machines—as all other CBCT machines—can export their volume data to third party software, DICOM (digital imaging and communication in medicine) data cannot be imported into the manufacturer's software for use with their templates and reporting tools. Although not a serious drawback, it is a point to consider when purchasing or using these machines. Third-party software is the biggest area of “growth” and is discussed below.

The most robust type of three-dimensional (3D) color software would include several parameters to assign to the voxel information. Every manufacturer and third-party software can handle the two-dimensional (2D) grayscale assignment to the voxel. Some even have algorithms to approximate Hounsfield units. Some third-party software can also perform surface rendering of the voxel units assigning a color to the voxel. You have seen many examples of gold, green, and even purple mandibles in implant planning software programs. A few vendors, for example Planmeca (Romexis, Helsinki, Finland) and Imaging Sciences (3DVR, Hatfield, Pennsylvania) and can assign a transparency value to each voxel to make a seemingly “transparent” image. A third-party company, Anatomage (San Jose, California) has this type of software and has created products for cephalometric landmark AnatoCeph tracing and implant planning (In Vivo Dental software, Anatomage, Inc., San Jose, California). Fig. 7 shows some of these products.

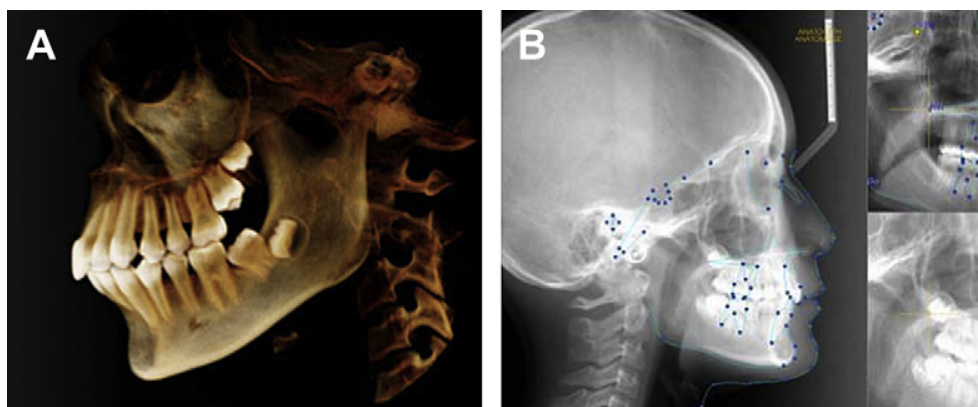


Fig. 7. (A) Typical 3D color reconstruction software with color and transparency shows course of IAN canal through the mandible. (B) Cephalometric tracing. (Courtesy of Anatomage, San Jose, CA. Available at: <http://www.anatomage.com>. Accessed June 27, 2008; with permission.)

The highest level of software treatment is able to assign color, transparency, and opacity values to the CBVT voxel information. To date, only OnDemand3D (CyberMed International, Seoul, Korea) can perform these tasks (Fig. 8).

Table 1 shows some of these third-party companies' products and capability.

### Useful software improvements

1. All software will be able to assign all 3 attributes—color, transparency, and opacity
2. Improved “scatter rejection” algorithms
3. All software completely DICOM compliant
4. Software in four dimensions to create the “Virtual Articulator”
5. Online, Internet “portal” software to speed surgical guide construction and delivery as well as interpretive reports and analytic images (eg, measured implant sites)
6. PACS/RIS systems for dentistry (see discussion below)

### Picture archiving and communication systems/radiographic information system radiographic information delivery

PACS have been developed and used in medicine for many years. The ability to store, retrieve, and share image information between medical specialists, including radiologists payers, administrators, and others, has

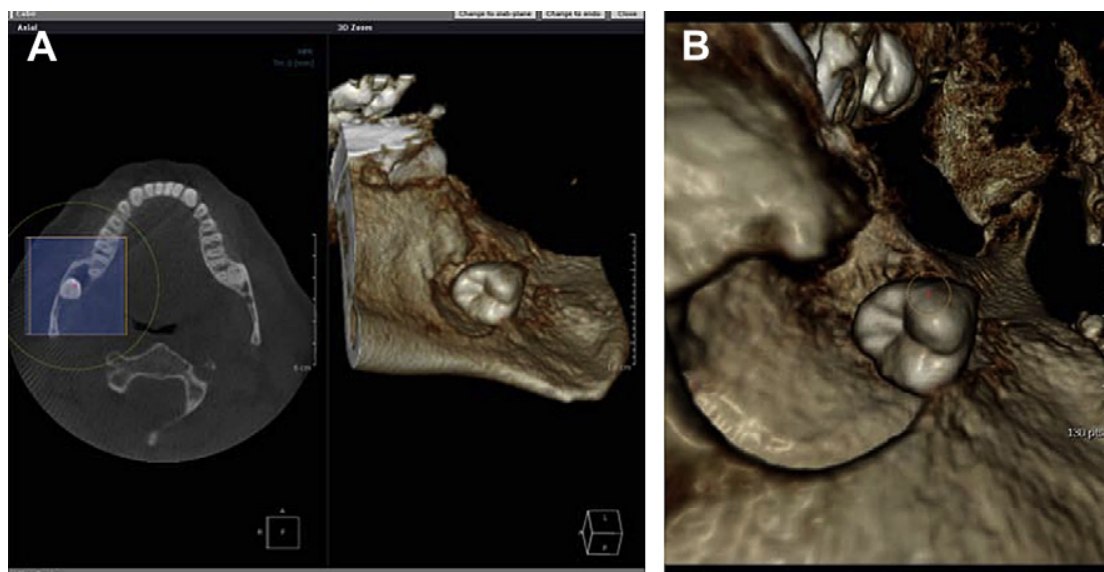


Fig. 8. (A) A 3D color reconstruction using transparency and opacity to show the occlusal surface of the third molar impacted in the bone! (Image created with OnDemand3D “Cube” tool, CyberMed, Seoul, Korea). (B) Same tooth as shown above but imaged with CyberMed’s “endoscopy” tool. Note the cuspal and developmental groove anatomy.

Table 1  
Oral and maxillofacial products and manufacturers

Manufacturer	Product name	Web site URL	Primary software task(s)
3dMD	3dMDFace 3DMD Cranial	<a href="http://www.3dmd.com/home.asp">http://www.3dmd.com/home.asp</a>	Orthodontics
Anatomage	In Vivo Dental AnatoCeph	<a href="http://www.anatamage.com/home.htm">http://www.anatamage.com/home.htm</a>	Implant, ortho
CyberMed	OnDemand3D Vworks Vceph	<a href="http://www.cybermed.co.kr/eindex.php">http://www.cybermed.co.kr/eindex.php</a>	Multiple
Dolphin	Dolphin 3D (OEM from Anatomage)	<a href="http://www.dolphinimaging.com/new_site/home.html">http://www.dolphinimaging.com/ new_site/home.html</a>	Orthodontics
NobelBioCare	NobelGuide	<a href="http://www.nobelbiocare.com/global/en/">http://www.nobelbiocare.com/global/en/</a>	Implant
Materialise Dental	SimPlant	<a href="http://www.materialise.com/materialise/view/en/84113-Dental+homepage.html">http://www.materialise.com/materialise/ view/en/84113-Dental+homepage.html</a>	Implant

grown an entire industry for these tasks. Until now, dentistry had only a couple of such products, and they were not widely used. Indeed, in the best of worlds, medical and dental records could be shared and distributed using PACS systems.

RIS is really just the information highway to deliver the radiologist's report to the referring hospital, clinician, or colleague. The two systems or products really go hand in hand.

Now there is a PACS/RIS product specifically for dentistry. CyberMed's OnDemand PACS/RIS was designed to handle the necessary data volumes, deliver reports, and analyses and archive client data off-site, one of the many, necessary Health Insurance Portability and Accountability Act (HIPAA) regulations. To date, it is the only HIPAA-compliant product I know of to use with our CBVT volumes. Remember that each patient case is 60 to 250 MB, depending on machine manufacturer. These large files must be moved quickly, safely, and efficiently without corruption. Dentistry has truly "made it to the big time" with this capability.

The PACS/RIS also does a lot more. Think of it as a "Practice Management System" for the office or laboratory. All dentists using cone beam, cone beam imaging laboratories, and single cone beam will use a PACS/RIS within 5 years.

### *Image-to-device processes*

Perhaps the most exciting area of dental and maxillofacial imaging will come in the area of device manufacture from 3D data using an "Online Distributive Network." Dentists want to be able to request or order



radiographic stents, surgical guides, study and orthodontic models, and other devices directly from their office computers.

Companies currently are raising venture capital to deliver these appliances and devices electronically. The Cone Beam image data makes this possible. Already we can see the patient's 3D color dentition. Many clinicians are sending their patient's data for surgical guide construction through companies like NobelBiocare. Larger surgical guides, requiring temporary horizontal "anchorage" to place multiple fixtures for overdentures can be received by mail or courier delivery. But, many more services, including faster, simpler delivery for single implant cases, will soon be offered through "Internet Portals" or distributive networks because of CBVT imaging. There are many more simple cases than complex cases.

## Summary

In summary, CBVT, as good as it is and will be, is a complementary technique to other more conventional imaging technologies. It offers our profession a substantial improvement for some but not all of our imaging tasks or need. For some procedures, it will become the standard of care.

Improvements in software removal of scatter artifacts; reduced x-ray dose; and delivery of interpretive reports, analyses, appliances, and images will continue, and use of CBVT will increase. Distributive networks will be introduced to simplify all of these tasks. Virtual articulators, computer assisted design and computer assisted manufacturing devices will improve, and online delivery of some of these services will increase concomitantly. In all, dentistry will improve and, along with it, patient care.

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