Clinical Experience with Cone-beam Volumetric Imaging—Report of Findings in 381 Cases

a report by

Dale A Miles, BA, DDS, MS, FRCD(C)

Chief Executive Officer, Digital Radiographic Solutions

Dale A Miles, BA, DDS, MS, FRCD(C), is the CEO of Digital Radiographic Solutions, a company providing radiographic interpretation to colleagues and radiology laboratories using cone-beam computed tomography (CT) machines. He is a diplomate of the American Board of Oral and Maxillofacial Radiology and the American Board of Oral Medicine. Until recently, Dr Miles was Associate Dean for Clinical Affairs at the Arizona School of Dentistry and Oral Health. Dr Miles has consulted with many imaging and practice management companies. He earned his Master's degree at the University of Texas, San Antonio. He has a website for teaching dentists and auxiliaries about digital imaging at www.learndigital.net

No imaging modality in dentistry has made as great an impact on dental procedures in as short a time as cone-beam volumetric tomography (CBVT), cone-beam volumetric imaging (CBVI), or cone-beam computed tomography (CBCT).[1-7] Three-dimensional image capture and analysis had been absent in dentistry until its introduction in 1998 by Mozzo et al.[1] Now the interest and demand for 3-D imaging studies is accelerating faster than any previous image modality in our profession. The current applications appear to have impacted upon all dentists and dental specialists. This article summarizes the findings of 381 cases referred for CBVI and discusses the current status and future developments for this novel imaging modality. Several interesting cases are included to demonstrate the power of 3-D visualization of pathology.

Current Applications for CBVT

Table 1 lists the current applications for 2-D/3-D imaging of dental patients. Like Danforth and colleagues,[2] the author uses the term 'volumetric imaging', as in cone-beam volumetric imaging (CBVI), because the image acquisition for the data is unlike conventional medical computed tomography (CT) or multi-detector CT (MDCT). CBVI data is acquired during one 360º video acquisition, using either a flat panel detector or an image intensifier coupled to a solid-state detector or set of detectors like a charge-coupled device (CCD). There are no true gantry-like medical devices and the patient is not moved any distance to acquire a sequential slice (slice thickness). Spatial resolution is expressed in voxels (volume elements) rather than pixels (picture elements), and the volume array can range from 0.1mm to 0.4mm, depending on the machine and size of detector. Detector sizes vary greatly, from arrays as small as 4.0x4.0cm up to 22cm.

Table 1: Dental Applications for CBVI

- Assessment of impactions
- Inferior alveolar nerve and sinus floor location
- Pre-surgical implant site assessment
- Paranasal sinus evaluation
- Odontogenic lesion visualization
- Trauma evaluation
- Temporomandibular joint (TMJ) visualization
- Surgical guide fabrication
- Other CAD/CAM devices (3-D models)
- Craniofacial surgery assessment

In addition, the radiation doses from all CBVI machines are greatly reduced in this image capture, largely because of the low exposure parameters (typically around 70–120kV at 1–3mA). Doses reported are well

1. *Mozzo P, Procacci C, Tacconi A, et al., "A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results",* Eur Radiol *(1998);8: pp. 1,558–1,564.*
2. *Danforth R A, Du I and Mah J, "3-D volume imaging for dentistry: a new dimension",* J Calif Dent Assoc *(2003);31: pp. 817–823.*
3. *Ludlow J B, Davies-Ludlow L E, Brooks, S L, Howerton B, "Dosimetry of 3 CBCT units for oral and maxillofacial radiology", Abstract accepted for 15th International Congress of the International Association of Dento-Maxillo-Facial Radiology, Cape Town, South Africa, June 2005.*
4. *Aranyarachkul P, Caruso J, Gantes B, et al., "Bone density assessments of dental implant sites: 2. quantitative cone-beam computerized tomography",* Int J Oral Maxillofac Implants *(2005);20: pp. 416–424.*
5. *Cervidanes L H, Bailey L J, Tucker G R J R, et al., "Superimposition of 3-D cone-beam CT models of orthognathic surgery patients",* Dentomaxillofac Radiol *(2005);34: pp. 369–75.*
6. *Nakajima A, Sameshima G T, Arai Y, et al., "Two and three-dimensional orthodontic imaging using limited cone-beam computed tomography",* Angle Orthod *(2005);75: pp. 895–903.*
7. *Scarfe W C, Farman A G and Sukovic P, "Clinical applications of cone-beam computed tomography in dental practice",* J Can Dent Assoc *(2006);72: pp. 75–80.*

Table 2: Clinical Findings of 381 CBVI reports

Site	CSP1	CSP2	Port1	ADB	LVI	Total Cases n=381
No. of Cases	253	43	17	66	2	381
Airway	13	1	2	1	0	17+
Bone	97	16	10	32	0	155*
Dental	20	3		3	0	26
Sinus	143	14	12	37	2	208
TMJ	39	10	5	13		67
Vertebral Bodies	26	1	1	4	0	32
Odontogenic lesion	20	1	1	5	0	27
Non-odontogenic lesion	4	0	0	0	0	4
Soft-tissue calcifications	1	1	1	1	0	4
Other	78	19	3	27	2	129#
Unremarkable	11	3		6		20
Total	**452**	**112**	**52**	**185**	**6**	**701**

CSP1 = ClearScan Property in Phoenix, AZ.
CSP2 = ClearScan Property in Peoria, AZ—lab service since closed.
Port1 = Portland, OR—lab service since closed.
ADB = Advanced Dental Board, an Internet-based radiology reporting service.
LVI = Las Vegas Institute
TMJ = temporomandibular joint.
"Bone": apical periodontitis, residual cysts, furcations, recent extraction site(s), impacted teeth, idiopathic osteosclerosis.
"Other": includes congenitally missing teeth; calcified, elongated stylohyoid process(es); calcified lymph nodes; retained root(s); metallic fragments; hypoplasias/hyperplasias (facial, teeth); medial sigmoid depression(s); dilacerated roots; tori; enostosis; SSGD (submandibular salivary gland depression); fibrous healing defect; and one possible case of Paget's disease of bone.
Several implants were reported impinging in anatomic spaces.
 # includes two pharyngeal masses.
+ includes two cases of blocked ostium.
Non-odontogenic lesions included several antral lesion (extrinsic), a neurolemmoma, and a fractured zygoma.
Vertebral changes included two surgical "repairs".
Two cleft palate cases, one surgical "non-union" case.
Note: gross caries and periodontal bone loss NOT tallied, but reported in the formal interpretive reports.

under 0.1mSv, with several machines as low as 0.007–0.05mSv, whereas MDCT doses range from 0.289–0.723mSv.[2] Others have expressed the dose from CBVI to MDCT in terms of "dose in days per capita background dose".[3] For cone-beam image acquisition, this ranges from 3–48 days, depending upon machine and volume detector size, compared to 103–243 days for maxillary or mandibular imaging performed with MDCT machines. Other differences between CBVI and MDCT are included in the discussion.

Clinical Studies

For one year, from February 2005 to February 2006, the clinical findings summarized in each of 381 reports were tabulated. The results from imaging centers in Phoenix and Peoria, Arizona, Portland, Oregon, several centers in California, and the Las Vegas Institute, Nevada, appear in *Table 2* above. The majority of the cases referred to the services were for pre-surgical implant assessment. An 'analytical report', complete with 1:1 measurements of proposed implant sites, hard copy images, a CD-ROM with images, and a DICOM (Digital Imaging and Communication in Medicine) viewer, was provided to the referring clinician, usually within 24 hours. An 'interpretive report', from which these clinical findings were summarized, was returned within 48 hours to that same clinician.

Clinical Case Studies

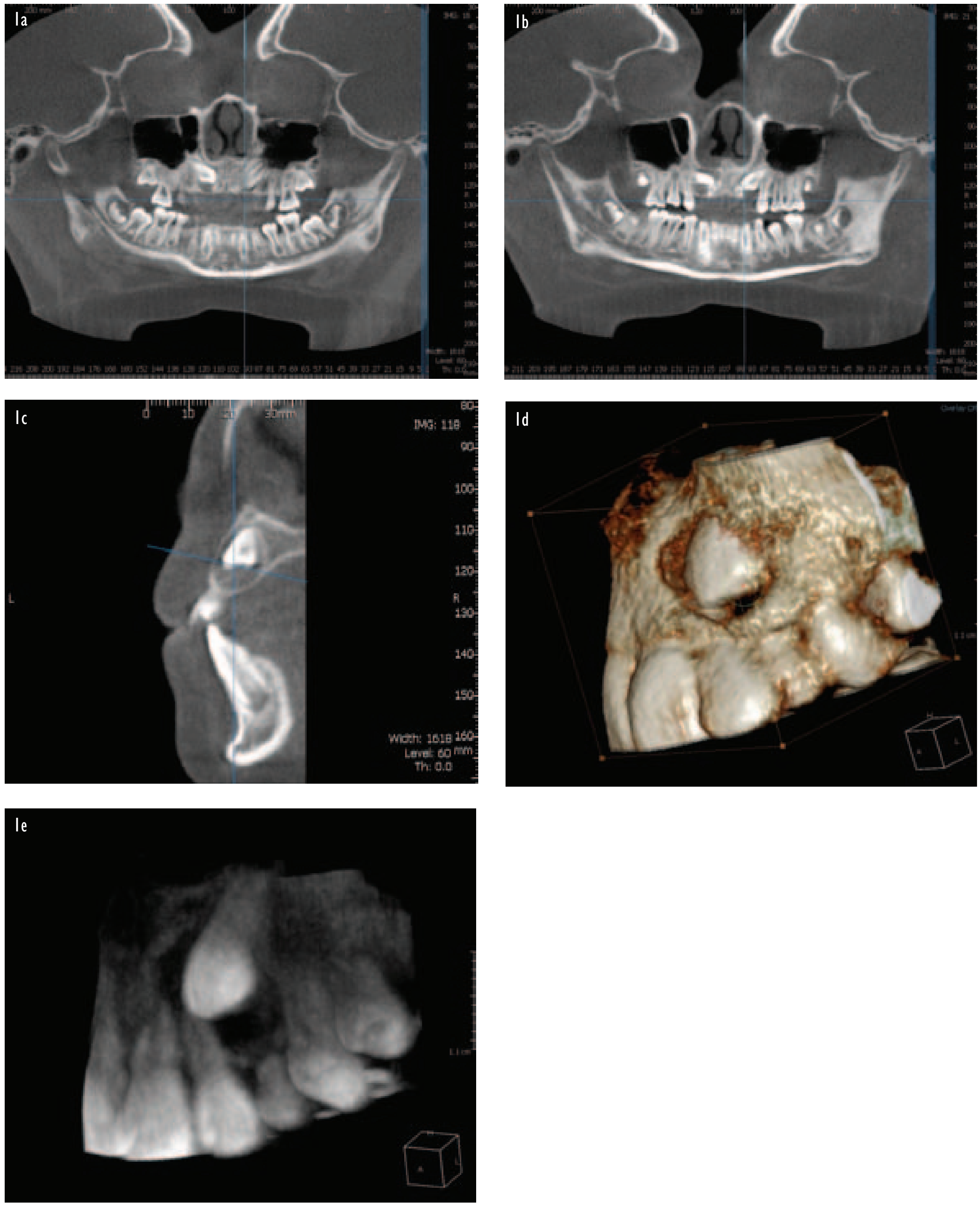
Case Study 1

A 12-year-old white male was referred to the University of California, San Francisco (UCSF) orthodontic clinic for evaluation of impacted maxillary permanent cuspids. CBVI was performed using a Hitachi CB MercuRay X-ray device. Image reconstruction was performed and the volume data analyzed. Two-dimensional and 3-D images were returned to the referring clinician with a diagnosis of impacted maxillary canines and cystic transformation of the follicle of tooth #6 (see *Figure 1*).

Case Study 2

A 35-year-old Asian female was referred to the University of Southern California (USC) orthodontic

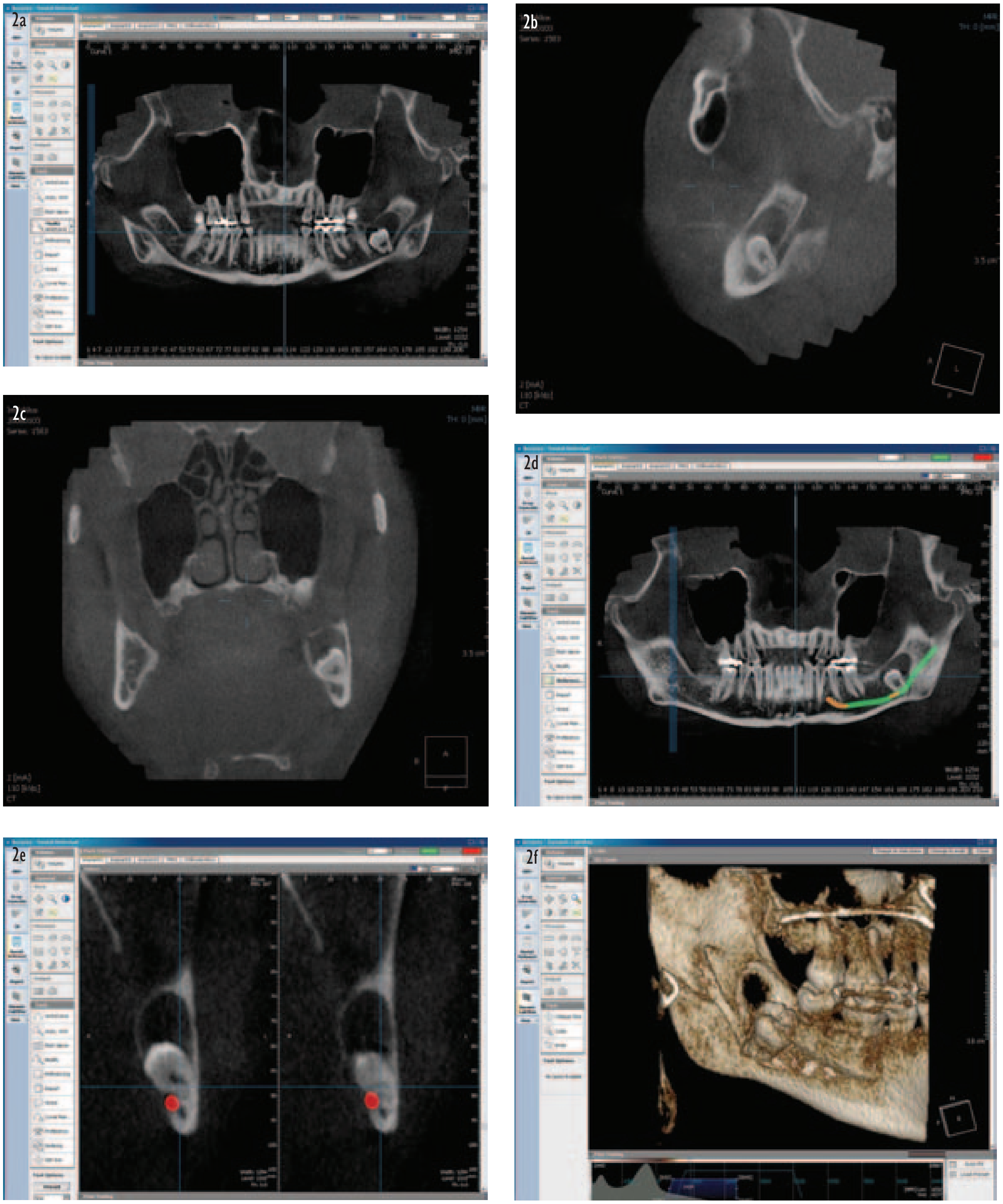
Figure 1: Case Study 1—Impacted Maxillary Permanent Cuspids



Figures 1a and 1b show thin pseudo-panoramic 1mm slices revealing loss of anatomic shape of the follicle and follicular attachment extension well past the cemento-enamel junction (CEJ), two classic radiographic features of 'cystic transformation of the tooth follicle'. 1c is a sagittal slice showing expansion of the suspected lesion. 1d is a 3-D reconstructed image showing perforation of buccal cortex. 1e is an MIP (maximum intensity profile) image rendered to look 'X-ray like' to show the loss of anatomic shape.

department's Redmond Imaging Center for implant evaluation. A radiographic interpretation report was requested secondary to the implant site evaluation. One of the more significant findings was a large, well-defined pericoronal radiolucency associated with the impacted tooth #17. Images were created using Accurex software (CyberMed International, Seoul, Korea) which characterized the changes and illustrated the intimate proximity of the inferior alveolar nerve and canal to this impaction (see *Figure 2*). Significant perforation of the lateral wall of the ascending ramus was noted and a differential diagnosis based on the radiographic appearance was given to the clinician to facilitate lesion management. The differential diagnosis

Figure 2: Case Study 2—Implant Evaluation



Figures 2a and 2d area pseudo-panoramic slices revealing the lesion. Figure 2d shows the inferior alveolar nerve/canal track after marking the canal. Figures 2b (sagittal slice) and 2c (coronal slice) show features of size, canal proximity and expansion. Figure 2e is the appearance of the canal in a coronal slicing revealing the canal in red to help visualize the proximity of the anatomic structure to the impaction. Figure 2f is a 3-D reconstruction showing the canal location with respect to the tooth and a cratering effect of the lesion with ramus perforation.

included a) dentigerous cyst, b) odontogenic keratocyst and c) ameloblastoma (doubtful).

Case Study 3

The patient was referred for a CBCT dental imaging series, which was performed at the Case Western Reserve University in Cleveland, Ohio. A radiographic interpretive report was generated, which included findings of impacted lower third molars and an occult pericoronal radiolucency about tooth #32. Incidental findings in this case also included a calcified lymph node (*Figures 3c, 3d*) and chronic inflammatory changes in the patient's right maxillary sinus (*Figure 3h*).

Figure 3: Case Study 3—CBCT Dental Imaging Series

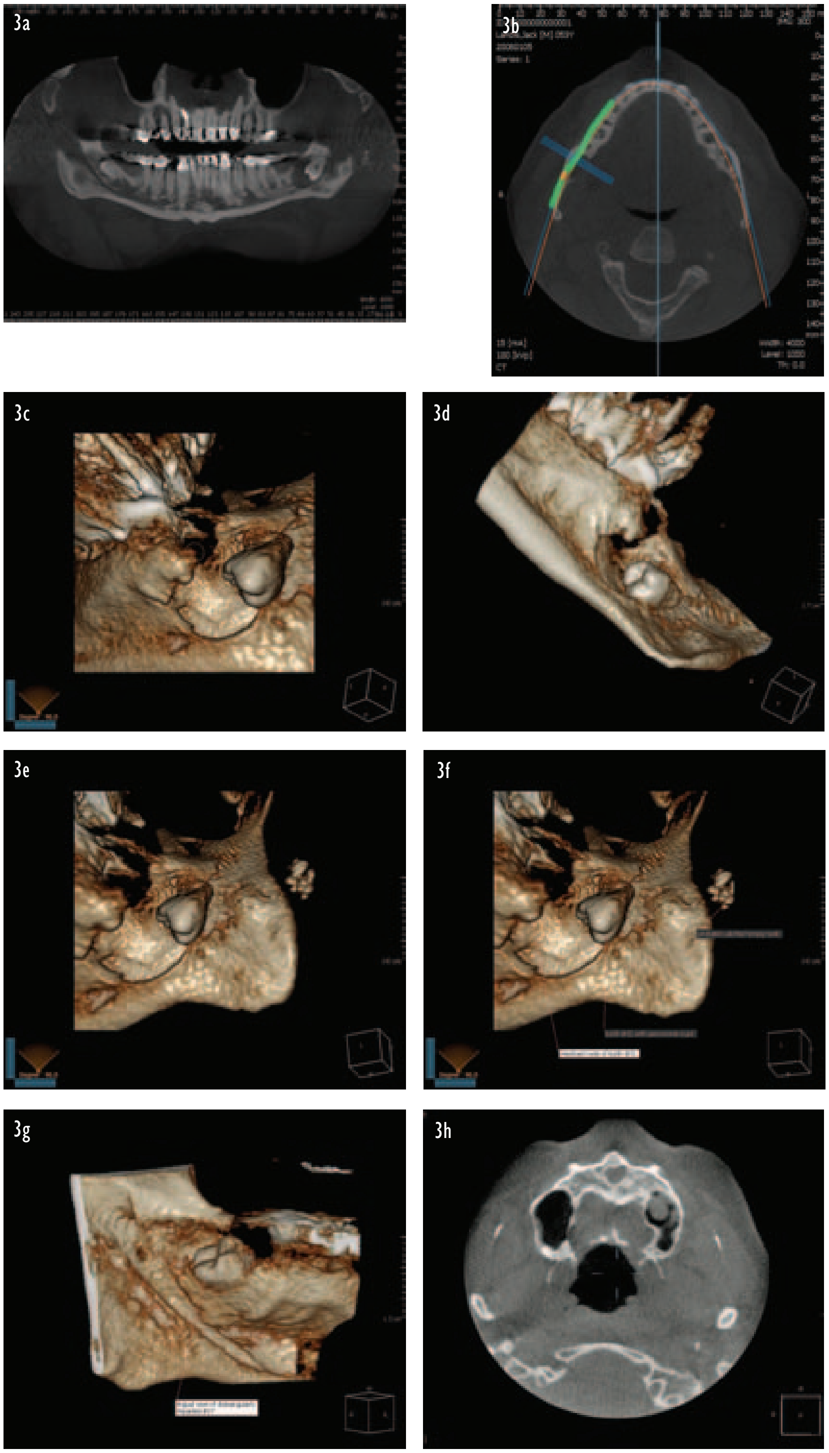


Figure 3a shows a large, well-defined pericoronal raidolucency about tooth #32. Figure 3b shows nerve localization and referencing markers to identify slices to view sagittally. Figures 3c and 3d show severe, linear root resorption, suggestive of an odontogenic keratocyst or ameloblastoma. Figure 3d shows occlusal anatomy in remarkable detail. Remember that this tooth is impacted in bone. Figure 3e shows incidental calcification suspected of being a calcified lymph node. 3f shows how these findings can be labeled. Figure 3g is a 3-D reconstruction of the impacted tooth #17. Figure 3h is an axial slice at the level of the mid-palate or top of condylar head, showing left antral change.

Discussion

There are many differences between MDCT and CBVI. *Table 3* cites most of them. The most significant difference, in the author's opinion, is that the image acquisition does not allow separation of soft tissue of the brain; that is, one cannot see gray and white matter. For the dentist and oral radiologist, this is significant, because, although studied, neither practitioner is trained to read neuroanatomy or neural lesions. The cone-beam images acquired are excellent at displaying bony anatomy and skull spaces, but soft tissues are only seen in the cervical and external surfaces (see *Figure 1*). CBVI scans evaluated for the referring dentist or dental specialist by the oral and maxillofacial radiologist are of the airway, paranasal sinuses and nasal cavity, temporomandibular joints structures, osseous structure, and dental structures. Our clinical studies demonstrated almost two 'reportable findings' per scan, many of which led to referrals to other dental specialists, rhematologists and otolaryngologists. In addition, because of the unique 3-D and slice rendering, even periapical lesions, missed during conventional intra-oral and panoramic examination, were found on CBVI images and recommended for treatment and follow-up. *Table 4* lists currently available CBVI machines.

Future Developments

Several other manufacturers are planning to introduce cone-beam imaging devices to the dental market in North America in the next year. Among these are Sirona (Bensheim, Germany), and Planmeca (Helsinki, Finland), two companies in the process of finishing development of a CBCT device.

Planmeca's CBCT machine, the ProMax 3D, is unique in the industry because it consists of an upgrade of its existing ProMax digital panoramic machine. This means that existing ProMax owners will have a substantially less expensive upgrade path to 3-D imaging capability. Planmeca is the only company to plan a device based on an existing dental X-ray machine.

Sirona's CBCT device is called Galileos. Sirona will offer a 3-D imaging software program called Galaxis 3D with their device.

There is no doubt that cone-beam volumetric imaging will change the way dentists approach many procedures. Three-dimensional data appear superior for visualization of anatomy and many aspects of pre-surgical implant and orthognathic surgery, as well as orthodontic planning. Even specialties like endodontics are looking to CBVI to assist decision-making in complex or failed cases. With the excellent hardware devices listed here, and in progress, and the amazing software tools now available to clinicians, patient management will improve, surgical risk will be reduced, and complex dental procedures such as implant surgery will be vastly simplified. All of these developments and tools will ultimately improve patient dental care, the major goal of all of our profession. ■

Table 3: CBVI Versus MDCT

Parameter	CBVI	MDCT
Image acquisition speed	Fastest (10—20s)*	Slow—several minutes
Absorbed X-ray dose least	(Average .025mSv)*	High (average about .500mSv)
Hardware expense	Moderate ($180K)*	High (approx. $1M)
Cost of dental examination	Inexpensive (<$400)*	Expensive ($700—1500)
Dentally specific software	Yes, readily available*	Limited
Dental 'reporting' software	Yes*	None
Convenience	Very convenient (day)*	May require evening appt.

CBVI = cone-beam volumetric imaging, MDCT = multi-detector computed tomography.
* advantage cone-beam volumetric imaging

Table 4: Companies Currently Providing Cone-beam CT (CBCT) Systems

Aperio Services: NewTom 3G
J Morita: Accuitomo
Hitachi Medical Systems: CB MercuRay
Imaging Sciences: i-CAT
Imtec: Iluma