Small Focal Field Volumetric Cone Beam Tomography: The New Standard of Care in Foundational Dentistry?

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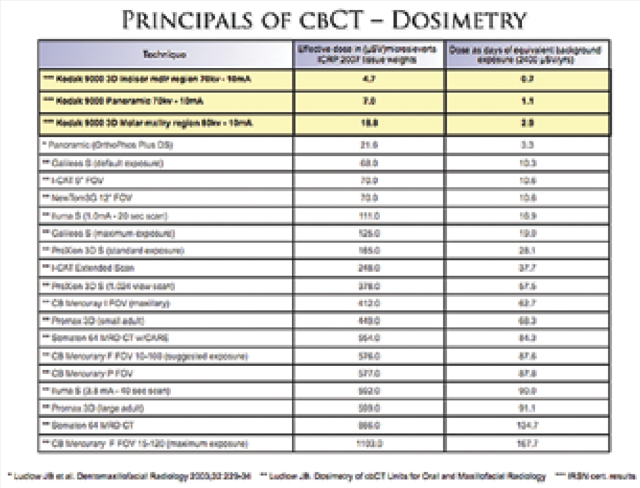
In 1895, Wilhelm Roentgen, a German physicist, discovered x-rays and in 1896, a New Orleans dentist, C. Edmond Kells, took the first diagnostic x-ray of a dental patient in the United States. In spite of this diagnostic breakthrough, for over the past one hundred years, the dental profession has seen three dimensional (3D) structures with two dimensional (2D) views; this is insufficient for more detailed analysis of the maxillo-facial region.[1]

By 1943, the modern era of endodontic research and therapeutics began with the formation of the American Association of Endodontics. In 1952, Per-Ingvar Branemark discovered osseointegration during a vital microscopy experiment on rabbits and in 1982, the Toronto conference on osseointegration recognized Dr. Branemark's implant methods and materials as one of the most significant scientific breakthroughs in dental history.

Dentistry is poised upon the launch pad of advancement once again as digital imaging and volume acquisition data enable three dimensional (3D) imaging to optimize diagnostics and treatment planning, thus facilitating the sophistication of foundational dental therapeutics. The American Academy of Oral and Maxillofacial Radiology, a professional organization representing oral and maxillofacial radiologists in the United States, has embraced the introduction of 3D cone beam computed tomography (cbCT) as a major iteration in the imaging armamentarium available to the dental profession. The AAOMR executive committee has formulated guidelines suggesting that dentists using cbCT be held to the same standards as board certified oral and maxillofacial radiologists in regard to interpretation, radiation standards, documentation and quality assurance, all very reasonable expectations.[2] Similar recommendations regarding implementation of appropriate radiographic practices (patient selection criteria, patient protective equipment, operator protection, film exposure and processing, infection control, quality assurance, image viewing, et al) were encouraged when panoramic radiography and digital panoramic radiography became mainstream diagnostic modalities.



PRINCIPALS OF CBCT – DOSIMETRY

Technique	Effective dose in (µSv) microsieverts ICRP 2007 tissue weights	Dose as days of equivalent background exposure (2400 µSv/yrs)
*** Kodak 9000 3D incisor mdl region 70kv - 10mA	4.7	0.7
*** Kodak 9000 Panoramic 70kv - 10mA	7.0	1.1
*** Kodak 9000 3D Molar maxilla region 80kv - 10mA	18.8	2.9
* Panoramic (OrthoPhos Plus DS)	21.6	3.3
** Galileos S (default exposure)	68.0	10.3
** I-CAT 9" FOV	70.0	10.6
** NewTom3G 12" FOV	70.0	10.6
** Iluma S (1.0mA - 20 sec scan)	111.0	16.9
** Galileos S (maximum exposure)	125.0	19.0
** ProXen 3D S (standard exposure)	185.0	28.1
** I-CAT Extended Scan	248.0	37.7
** ProXen 3D S (1,024 view scan)	378.0	57.5
** CB Mercuray I FOV (maxillary)	412.0	62.7
** Promax 3D (small adult)	449.0	68.3
** Somatom 64 MRD CT w/CARE	554.0	84.3
** CB Mercuray F FOV 10-100 (suggested exposure)	576.0	87.6
** CB Mercuray P FOV	577.0	87.8
** Iluma S (3.8 mA - 40 sec scan)	592.0	90.0
** Promax 3D (large adult)	599.0	91.1
** Somatom 64 MRD CT	860.0	124.7
** CB Mercuray F FOV 15-120 (maximum exposure)	1103.0	167.7

* Ludlow JB et al. Dentomaxillofacial Radiology 2003;32:229-34 ** Ludlow JB. Dosimetry of cbCT Units for Oral and Maxillofacial Radiology *** IRSN cert. results

FIGURE 1A—The sievert (Sv) is the standard international derived unit of dose equivalent. It attempts to reflect the biological effects of radiation as opposed to the physical aspects, which are characterised by the absorbed dose, measured in gray. It is named after Rolf Sievert, a Swedish medical physicist famous for work on radiation dosage measurement and research into the biological effects of radiation.

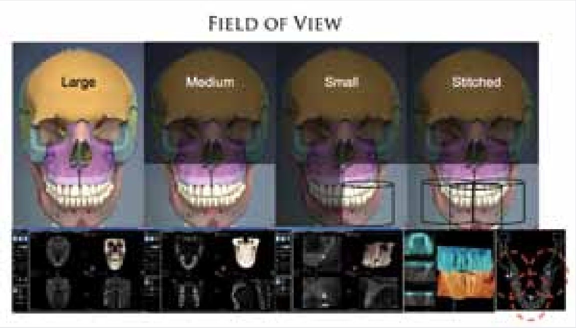


FIGURE 1C—cbCT incorporates a single 360° scan in which the x-ray source and a reciprocating area detector synchronously move around the patient's head. At certain degree intervals, single projection images, known as "basis" images, are acquired. This series of basis projection images is referred to as the projection data.

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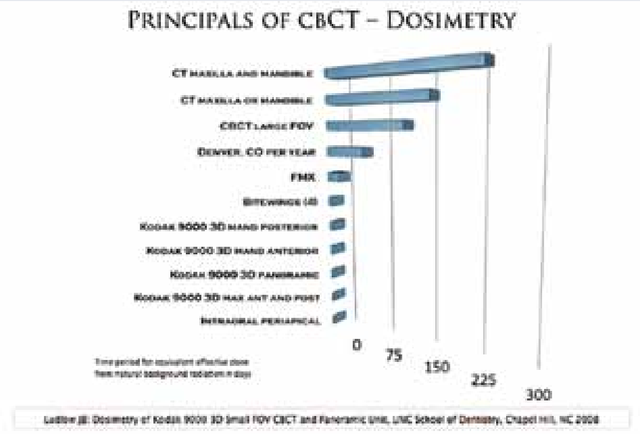

FIGURE 1B—Radiation dosimetry is the calculation of the absorbed dose in matter and tissue resulting from the exposure to indirectly and directly ionizing radiation. It is a scientific subspecialty in the fields of health physics and medical physics that is focused on the calculation of internal and external doses from ionizing radiation.

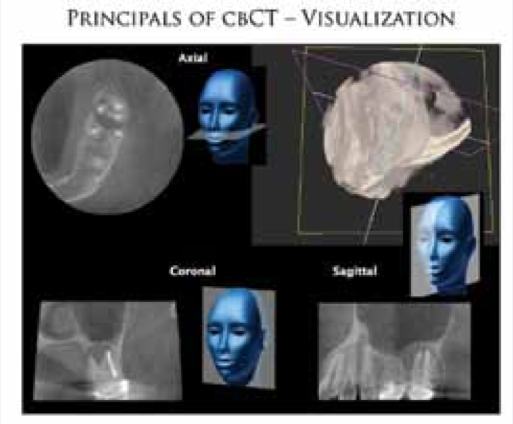

FIGURE 1D—Software programs incorporating sophisticated algorithms including back-filtered projection are applied to these image data to generate a 3D volumetric data set, which can be used to provide primary reconstruction images in 3 orthogonal planes (axial, sagittal and coronal).

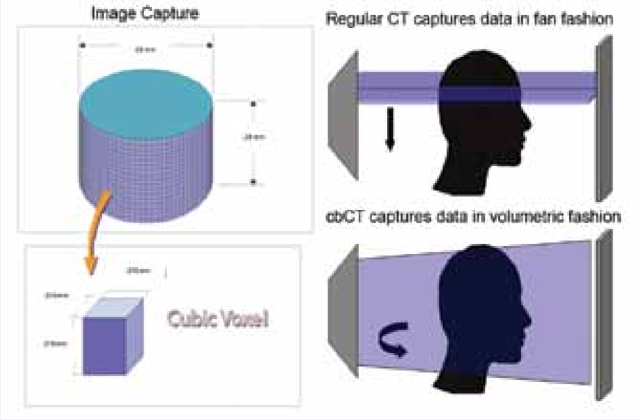

FIGURE 1E—The sensor in the Kodak 90003D (Carestream Health Inc, Atlanta GA) has a resolution of .076mm or 76 microns. This is the highest resolution of any cbCT unit available today and the primary reason it was chosen by the authors to obtain the images for this publication.

The primary reasons for taking panoramic radiographs determined from global survey samplings were as a "general screen" and as a "view for unerupted or impacted teeth". However, their value for caries detection, endodontic and periodontic pathology was assessed as questionable.[3,4] The potential for cbCT usage as the standard of care for diagnosis in dentistry is incalculable. In order to create a nexus between regulation and pervasive dissemination of this modality, organized dentistry will need to look beyond traditional educational delivery modes and consider the use of virtual faculty technologies to establish baseline standards, to foster continuing education in the truest sense of term, to evaluate its impact and to establish quality assurance standards that protect all.

This publication has a two-fold purpose; firstly, the authors wish to demonstrate the incomparable diagnostic acuity in evidence with cbCT, particularly small focal field of view (FOV) cbCT and secondly, to challenge locales with restrictive oversight and control by regulatory agencies in regard to the all-encompassing use of cbCT. No institution or organization can license or teach professionalism anymore than it can mandate ethics; thus concerns for abuse and malfeasance, while realistic, are impossible to control. Short classroom courses, regardless of how well structured, are finite in their immediate impact and even with follow-up reporting and assessment of mandated continuing education, there is no mechanism to ensure accuracy in interpretation or usage within conventional educational systems. There are however, evidence based alternatives.[5-9]

This publication will demonstrate the qualitative difference between 2 and 3 dimensional imaging in categories pertaining to foundational dentistry by providing the reader visual evidence of the distinction in diagnostic value of each format. The authors' area of expertise is endodontics. They have chosen a source for image acquisition that meets all conceivable criteria for foundational dentistry within the parameters of their discipline. The focus of this article is endodontic usage of cbCT; it will not address diagnosis and treatment planning for implant driven dentistry, however, it is the opinion of the authors that the use of cbCT for implant treatment planning and facilitation of stereo-lithographic surgical guides simply cannot be viewed in any other context than the default standard of care.

COMPLEX ANATOMY AND PATHOLOGY

Digital imaging, computed tomography (CT), magnetic resonance imaging ((MRI), positron emission tomography (PET) and cbCT provide unprecedented

FIGURE 2A—A circumscribed radiolucent lesion in the panoramic radiograph suggests anything from a juvenile to cemento-ossifying fibroma (fibrous dysplasia), to Stafne's idiopathic bone cavity to a giant-cell granuloma.

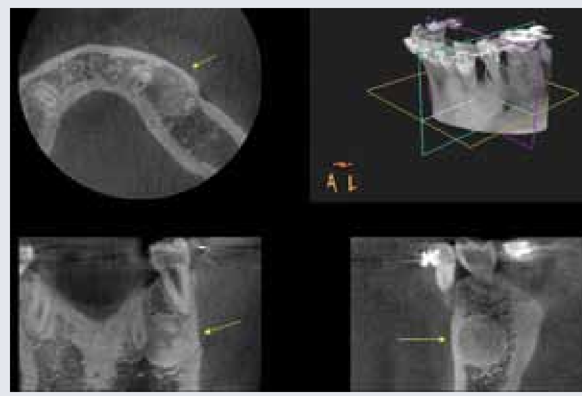

FIGURE 2B—It is the authors' contention, that restriction of cbCT usage to a select few is ill-conceived. These are digital images; as such, transmission for review and interpretation to an appropriate resource is mainstream communications technology. Perhaps the regulation required is mandating that all dental offices have connectivity, to ensure immediacy of communication for any and all needs.

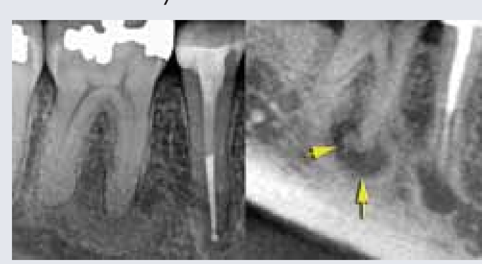

FIGURE 3A—It is intriguing that no lesion appears related to the mesial apex of tooth #4.6 (30) and yet, given that the patient presented with symptoms in the area, it would be reasonable to assume there was a lesion associated with the apex of the endodontically treated #4.5 (29).

FIGURE 3B—The incalculable diagnostic assist provided by small FOV cbCT speaks to itself as the size and location of the mental foramen and mental nerve canal are revealed.

TABLE 1
Cone Beam Computer Tomography Periapical Index Scores

SCORE	QUANTITATIVE BONE ALTERATIONS IN MINERAL STRUCTURES
0	Intact peripical bone structures
1	Diameter of periapical radiolucency > 0.5-1mm
2	Diameter of periapical radiolucency > 1-2mm
3	Diameter of periapical radiolucency > 2-4mm
4	Diameter of periapical radiolucency > 4-8mm
5	Diameter of periapical radiolucency > 8mm
Score (n) + E*	Expansion of periapical cortical bone
Score (n) + D*	Destruction of periapical cortical bone

* The variable E (expansion of cortical bone) or D (destruction of cortical bone) were added to each score, if either of these was detected in cbDT analysis

images that contribute to the sophistication and accuracy of diagnostic tasks of the maxillofacial region. Cone beam volumetric tomography, particularly small FOV cbCT, is revolutionizing dentistry with cross-sectional imaging that supersedes the anatomic noise and distortion of intraoral and panoramic radiographs. The information content in such examinations is high and the dose and costs are low.[10] As will be demonstrated, small FOV cbCT discloses occult pathology that cannot be detected with traditional flat field film or sensors. This is analogous to the ancillary use of magnetic resonance imaging by our medical colleagues to compliment computed tomography scans.[11] Figures 1a-e, provide the reader an introductory overview of cbCT technology.

cbCT has the potential to be an accurate, non-invasive, practical method to reliably determine osseous lesion size and volume. Further clinical validation will lead to a vast array of applications in oral and maxillofacial diagnosis.[12] Figs 2a and 2b show the difference between 2D and 3D imaging, panoramic radiography versus cbCT, in determination of the dimensions of a pathologic entity. Fig 3a demonstrates the apparent absence of apical pathology in flat field images in contrast to the evidence thereof in cbCT. Fig 3b shows coronal slices of the cbCT of this region which identifies the size and location of the mental foramen and mental nerve as it branches off the inferior alveolar nerve.

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APICAL PERIODONTITIS

One of the most distressing clinical situations a practitioner confronts occurs when a symptomatic patient presents and the 2 dimensional flat field periapical image shows no pathosis and clinical testing is equivocal. The periapical index (PAI) is a scoring system for radiographic assessment of apical periodontitis (AP). The PAI represents an ordinal scale of

TABLE 2
Prevalence of apical periodontitis in endodontically treated teeth as determined by periapical radiography and cbCT using cbDTPAI (n=1014)

	PERIAPICAL RADIOGRAPHY	cbT	P VALUE X^{2}test
Presence of AP	401 (39.5%)	618 (60.9%)	P<.001
Absence of AP	613 (60.5%)	396 (39.1%)	

5 scores ranging from no disease to severe periodontitis with exacerbating features and is based on reference radiographs with confirmed histologic diagnosis originally published by Brynolf.[13] ÿrstavik et al.[14] applied the PAI to both clinical trials and epidemiologic surveys; however, as the index relied on flat field films, it was vulnerable to subjective evaluation.

Estrela et al proposed a cbCT-PAI based on criteria established from measurements corresponding to periapical radiolucencies on cbCT scans. A total of 1014 images (periapical radiographs and cbCT scans) originally taken from 596 patients were evaluated by 3 observers using the new cbCT-PAI criteria. Apical periodontitis was identified in 39.5% and 60.9% of cases by radiography and cbCT, respectively (P <.01). They concluded cbCT-PAI offers an accurate diagnostic method for use with high-resolution images, which can reduce the incidence of false negative diagnosis, minimize observer bias, and increase the reliability of epidemiologic studies, especially those referring to AP prevalence and severity[15] [Fig 4] [Tables I and II].

Figures 5 and 6 both demonstrate how truly deceptive 2D images can be. Lesions as shown, if the clinician chooses not to reengineer the prior procedure, are routinely treated with endodontic surgery based on the presumption of limited size and extent; the disparity between appearance and clinical reality can result in serious complications. Surgical guidance, which uses computed tomography and computer-aided design and computer-aided manufacturing processing, has been utilized in dentistry, but not in endodontics. A recent in vitro study designed to obviate the risk factors of iatrogenic misadventure showed that greater accuracy and consistency can be achieved during endodontic surgery with surgical guidance as a function of pre-surgical visualization in three dimensions.[16]

ENDODONTIC RETREATMENT

The American Academy of Implant Dentistry (AAID) has recently published a report stating that endodontic treatments are not as successful as single-tooth implants. "There is really no justification for undergoing multiple endodontic or periodontic procedures and enduring the pain and financial burden to save diseased teeth," said John Minichetti, DDS, speaking on behalf of the AAID. "The days are over for saving teeth till they fall out. Preserving questionable teeth is not the best option for both oral

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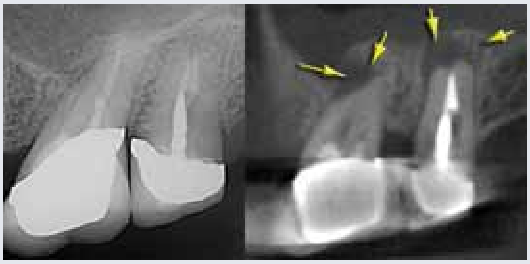

FIGURE 4—Occasionally, apical periodontitis will not penetrate the antral floor, but will displace the periosteum, which deposits new bone producing a periapical osteoperiostitis or "halo".

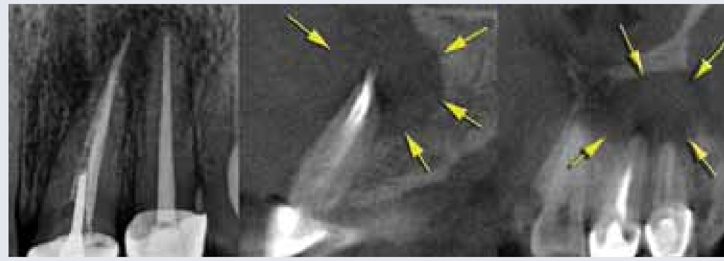

FIGURE 5—Anatomical structures of importance in planning for endodontic surgery include the neurovascular bundle associated with the greater palatine foramen, the mandibular canal, the mental foramen, the floor of the nose and the maxillary sinus among others. In the absence of 3D imagery, the potential for iatrogenic misadventure is increased.

The true extent of inflammatory and external cervical resorptive lesions cannot always be estimated from conventional radiographs

FIGURE 6—Lesions heal, regardless of size, provided the biologic imperative of the treatment procedure executed is met.

health and cosmetic perspectives".[17] It is not within the scope of this article to discuss such rhetoric; rather the reader is directed to previous publications in this periodical, The Endodontic Implant Algorithm: Parts I and II (Nov 2009, Feb 2010) for counterpoint.

Friedman, in his landmark article on post-treatment endodontic disease (treatment failure), noted that root canal intra-radicular infection is far more common than exclusive extra-radicular infection, and it should be considered as representing the majority of teeth associated with post-treatment disease. Therefore, it is appropriate to consider that generally the benefits of retreatment, the procedure that best curtails root canal infection, outweigh those of apical surgery. When clinical evidence or case history supports the diagnosis of extra-radicular infection, the benefits of apical surgery outweigh those of retreatment.[18] As evidenced in Figs 7a and 7b, the orthograde primary endodontic treatment and the retrograde endodontic retreatment were unsuccessful as each procedure failed to address the entirety of the root canal system.

Far too often, the procedure is castigated for the treatment failure; we ignore the obvious biology and physiology of the host response. Additionally, it may be the operator's level of technical competency that fails. With the advent of small FOV cbCT in endodontics, it is hoped that editorials such as the one referenced previously will fade into obscurity as 3D imaging returns a level of humility to the profession and the natural state returns to its rightful position of dominance. Biomimetics is an adjunct, not the defining standard for optimal oral health.

FRACTURE

Numerous studies[19,20,21,22] have shown that cbCT scans are superior to periapical radiographs (PR) in detecting longitudinal root fractures. The three-dimensional nature of cbCT scans allows visualizing the fracture line from multiple angles and different orientations at very thin slices and at a very high contrast. Conversely, the 2D nature of PR's obscured the visibility of the fracture line because of the inherent superimposition artifact, which may explain the low sensitivity of PRs in detecting vertical root fractures (Figs 8a, 8b).

FIGURE 7A—There is simply never an end to the number of times it needs to be said, "Biology works". Failure to address the entirety of the pathologic process and its eradication is simply not standard of care. Endodontic surgery cannot correct and ill-treated orthograde primary procedure.

FIGURE 7B—The arguments about cost and radiation exposure will abound in regard to cbCT usage. They can be controlled. The counterpoint is the need to provide an optimal standard of care. The balance between the two needs is a temporal imperative for organized dentistry.

FIGURE 8A—The 2D nature of periapical radiographs (PRs) obscures the visibility of a fracture line because of the inherent superimposition artifact, which may explain the low sensitivity of PRs in detecting vertical root fractures.

FIGURE 8B—The 3D nature of cbCT scans allows visualizing the fracture line from multiple angles and different orientations at very thin slices and at a very high contrast.

FIGURE 9A—There are radiographic "suggestions" of the result of the traumatic injury sustained by the teeth and alveolus; however, nothing that would suggest the damaged evident in the accompanying cbCT image.

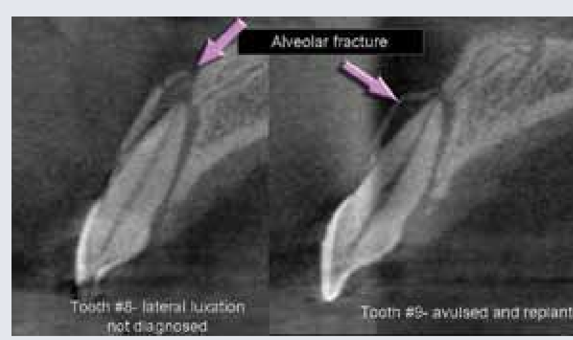

FIGURE 9B—cbCT has significantly improved the ability to accurately diagnose traumatic injuries with the potential to overcome most of the technical limitations of the plain film projection.

TRAUMA

Traumatized teeth present a clinical challenge with regard to their diagnosis, treatment plan, and prognosis. Unfortunately, film-based intraoral radiography provides poor sensitivity in the detection of minimal tooth displacements, root, and alveolar fractures. This limitation is due to the projection geometry, superimposition of anatomic structures, and processing errors. cbCT has significantly improved the ability to accurately diagnose traumatic injuries with the potential to overcome most of the technical limitations of the plain film projection and the capability of providing a 3-D representation of the maxillofacial tissues in a

FIGURE 10B—In regard to the question posed, 'would detection of an incipient resorptive area with a cbCT scan have prevented the loss of this buttressing tooth?' Technology is an evolutionary process and the transitional timeline is occurring with heretofore unprecedented speed. Today's question is tomorrow's answer.

FIGURE 10A—The resorptive defect associated with tooth #1.3 (6) in this instance is readily visible with a 2D image. The question to be posed is, 'in lieu of panoramic surveys, would a cbCT scan, particularly with the advent of stitching software, prove to be a more efficacious diagnostic survey of potential concerns, recognizing all variables of radiation hygiene, quality assurance, et al?'

cost- and dose-efficient manner.[23] [Figs 9a, 9b].

RESORPTION

The true extent of inflammatory and external cervical resorptive lesions cannot always be estimated from conventional radiographs. cbCT can be a useful diagnostic tool in the early diagnosis and management of such lesions.[24,25] [Figs 10a, 10b].

INTRA-OPERATIVE CONSIDERATIONS

cbCT has been used for implant placement, third molar removal and accessing the palatal root of maxillary molars using a vestibular or trans-antral approach to optimize root end surgery.[26] Figures 11a and 11b demonstrate its use in non-surgical orthograde endodontics to address morphologic complexities.

MAXILLARY SINUSITIS OF DENTAL ORIGIN (MSDO)

Although sinusitis is a common condition, its pathogenesis is not clearly understood and there is lack of consensus concerning its treatment and prevention. Sinusitis is regarded as being primarily rhinogenous in origin, and oral/dental infections are considered to be predisposing factors. A review of the literature suggests that many cases of recurrent acute sinusitis are due to secondary rhinogenous bacterial colonization of antral mucosa that have been weakened and degenerated by chronic dental infection/inflammation.[27] [Fig 12].

> It is evident that inflammatory or tumorous lesions cannot be visualized if they are confined within the cancellous bone

In a study by Melen et al conducted over a 5-year period, 198 patients with 244 affected sinuses, a dental cause was found in 40.6% of the sinuses. The dental cause could be confirmed by routine dental examination in only 43 of 99 cases, while an extended maxillo-dental examination was conclusive in the other cases (56/99). Marginal periodontitis was found as frequently as apical periodontitis and together they constituted 83% of all dental causes. Every sixth patient was found to have nasal polyposis. When related to the number of affected sinuses, the incidence of nasal polyposis was 13.1% in sinusitis of dental origin and 23.4% in that of rhinogenous origin. The importance of close cooperation between the ENT specialist and the dentist was stressed.[28]

CONCLUSION

A search of the dental literature uncovers the science upon which to base a hypothesis to be studied or a review to be conducted and the means by which the results can be analyzed and conclusions derived. It is also a wondrous voyage through the history of our profession and a visit with the minds who inspired us; as Isaac Newton so eloquently stated, "If I see further, it is because I stand on the shoulders of giants."

It is fascinating to read the work of the Seltzer and Bender from 1961 on radiographic diagnosis; "to simulate periodontal and periapical lesions, bone cuts were made in mandibles from human cadavers, and the roentgenographic and visual appearances of the bone were compared. It is evident that inflammatory or tumorous lesions cannot be visualized if they are confined within the cancellous bone.[29] However, if the lesions erode the junction area of the cortex and cancellous bone or perforate the cortex, they can be distinguished roentgenographically. Early stages of bone disease cannot be detected by means of routine roentgenograms, nor can the size of a rarefied area on the roentgenogram be correlated with the amount of tissue destruction."

It is equally as intriguing to read the work of Branemark and Breine from 1980 as they began the era of implant driven treatment procedures; "In edentulousness, which cannot be adequately compensated for by a denture but causes considerable oral dysfunction, the treatment of choice is a bridge construction on osseointegrated titanium fixtures. In those cases, where the quantity or quality of the alveolar ridge-as a consequence of progressing resorption-does not provide enough bone tissue for lasting implant anchorage, restoration of jaw bone anatomy is required."[30]

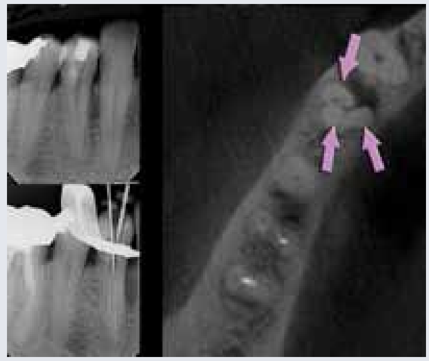

FIGURE 11A—Published studies cite the anatomy and morphology of the mandibular second premolar tooth for more than 7700 teeth. The incidence of 2 roots (0.3%) and 3 roots (0.1%) was extremely rare.

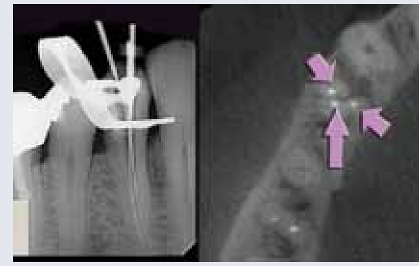

FIGURE 11B—Data derived from B. Cleghorn, W. Christie, C. Dong. The Root and Root Canal Morphology of the Human Mandibular Second Premolar: A Literature Review J Endo 2007;33(9):1031-1037.

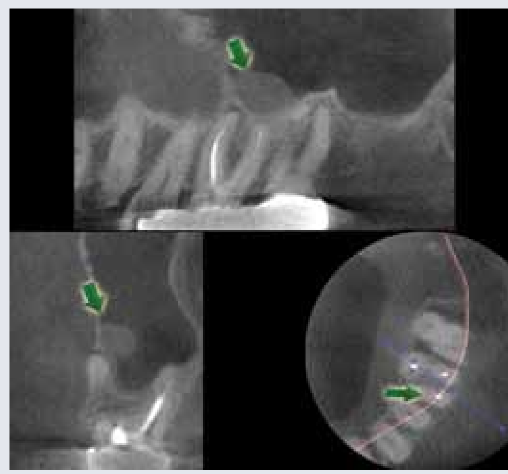

FIGURE 12—An odontogenic source should be considered in patients with symptoms of maxillary sinusitis who give a history positive for odontogenic infection or dentoalveolar surgery or who are resistant to standard sinusitis therapy.

The counterpoint to the AAOMR executive committee guidelines referenced at the outset is to be found in a developed a set of basic principles on the use of cbCT in Febuary of 2009 by The European Academy of Dental and MaxilloFacial Radiology. The 19th principle states that for dental and maxillofacial cbCT images of the teeth, their supporting structures, the mandible (including the TMJ) and the maxilla up to the floor of nose (e.g. 8 cm 68 cm or smaller fields of view) clinical evaluation ("radiological report") should be made by an adequately trained general dental practitioner or by a specially trained dentomaxillo-facial (DMF) radiologist.

Medical schools around the world are rushing to include network-based electronic learning resources in their arsenal of teaching aids. They seem to understand the words of Samuel Johnson; "Knowledge is of two kinds: we know a subject ourselves, or we know where we can find information upon it". Organized dentistry must encourage the creation of a thoughtfully conceived nexus of association and institutional websites that will facilitate an educational social network to move yardsticks to accelerate generational changes in dental knowledge from decades to months. OH

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Drs. Barnett and Serota have administered the discussion forum ROOTS for the past decade (www.rxroots.com). Its over three thousand members "share and care" their endodontic experiences and knowledge on a daily basis and meet one time per year around the globe in a three day real time event know as the ROOTS SUMMIT. This year's SUMMIT is in Barcelona, Spain, June 3rd to 5th.

Oral Health welcomes this original article.

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