The Use of Cone-Beam Computed Tomography in Management of Patients Requiring Dental Implants: An American Academy of Periodontology Best Evidence Review

Hector F. Rios,* Wenche S. Borgnakke,* and Erika Benavides*

Background: Application of cone-beam computed tomography (CBCT) has grown exponentially across dentistry with a clear impact in implant dentistry. This review aims at providing the scientific context to understand if CBCT imaging should become the standard of care for patients requiring dental implants.

Methods: A literature search for CBCT applications in implant dentistry was performed using the PubMed database that included studies published between January 1, 2000, and June 24, 2017.

Results: Of 559 citations identified and manually screened, 161 were selected as suitable for the purpose of the review. The selected studies belonged to three distinct categories: 1) diagnosis and treatment outcome assessment, 2) implant treatment planning, and 3) anatomic characterization.

Conclusions: The current available literature reflects an increased optimization of emerging CBCT imaging protocols and further highlights its diverse applications for dental implant therapy. This technology continues to be considered an advanced point-of-care imaging modality and should be used selectively as an adjunct to two-dimensional dental radiography. As with other ionizing radiation imaging modalities, CBCT imaging should be used only when the potential benefits to the patient outweigh the risks. Dental health care professionals should consider CBCT imaging only when they expect the diagnostic information yielded will lead to better patient care, enhanced patient safety, and ultimately facilitate a more predictable, optimal treatment outcome. *J Periodontol 2017; 88:946-959.*

KEY WORDS

Cone-beam computed tomography; dental implants; diagnostic imaging; oral surgical procedures; sinus floor augmentation; surgery, computer-assisted.

* Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, MI.

This century, the application of cross-sectional imaging using cone-beam computed tomography (CBCT) in implant dentistry has rapidly grown as a popular tool, driven by continued scientific and technologic advances.[1] Apart from replacing teeth lost due to injury, disease, or developmental disorders, increased life expectancy and esthetic concerns have accelerated the widespread acceptance of dental implants and other associated surgical procedures.[2] In dentistry, CBCT has been positioned as the modality of choice for cross-sectional imaging as an application that certainly has tangible implications for implant therapy.[3] Generally speaking, CBCT technology is perceived as a radiographic tool with increased accuracy, higher resolution, lower radiation dose, and reduced cost for patients compared with other volumetric imaging modalities for the assessment of mineralized tissues.[4] This notion has driven a robust interest to adopt this technology for routine dental implantology.[5] Furthermore, the global adoption of this technology is reflected in the collective market value of US $407.5 million estimated in 2014 and primarily represented by North America, followed by Europe. Continued growth is anticipated to average 10.0% per year to

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reach US $960.8 million by 2023.[6] This rise in commercialization and advances in CBCT have fueled the industry efforts to improve accessibility and affordability and has created awareness of its diverse clinical value (Fig. 1).[6-8]

Undoubtedly, CBCT technology has empowered clinicians to overcome tangible limitations that often compromised a predictable clinical outcome. The three-dimensional (3D) information provided by CBCT can often lead to improved diagnostic acumen and subsequent treatment recommendations compared with two-dimensional (2D) radiographs.[9] However, routine or excessive use of CBCT would cause a substantial increase in the effective and cumulative patient radiation dosages, which is a risk that may not be justified in all cases. This risk is age-dependent, being highest for the young and lower for the elderly.[10] Nonetheless, published estimated risks usually represent averages for both sexes at all ages, even though risks for females are higher than those for males.[10] Therefore, creating awareness of the important responsibilities regarding patient safety when using this powerful resource becomes pivotal to providing proper justification and optimization of CBCT exposures.[1,4,11-27]

Marked improvements in hardware and software components have reduced the effective radiation dose to a patient.[3] However, great heterogeneity still remains among the different available CBCT units, which is reflected in the wide range of effective CBCT doses estimated for the more than 50 CBCT models available in today's market (Fig. 2). This is a shortcoming of many published reports that present values from outdated units that may differ substantially when using newer-generation machines.

ESTIMATED MEAN EFFECTIVE DOSE OF DENTAL CBCT AND OTHER IMAGING MODALITIES

ADULT	Small FOV	5 - 652 uSv
	Medium FOV	9 - 560 uSv
	Large FOV	46 -1,073 uSv
CHILD	Small FOV	7- 521 uSv
	Medium - Large FOV	13 - 769 uSv

Background Radiation	4 Posterior Bitewings	Panoramic Radiograph	Full-Mouth Series	Multi-slice CT
~8 uSv/day	~5 uSv	~3 - 24 uSv	~34 uSv (Rectangular Collimator) ~170 uSv (Round Collimator)	~ 1,000 - 2,000 uSv

Figure 2.
Radiation and CBCT. The overall long-term risk to a patient from a procedure such as a CBCT scan is best estimated by calculating the effective dose associated with a particular scanning protocol and equipment. In dental CBCT, the effective dose varies considerably among machines. This table provides reported effective dose ranges in CBCT compared to other common sources of radiation. FOV = field of view; uSv = microsieverts.

The main variations are derived from differences in detector technology, scanning times, and available fields of view (FOV). The industry has shifted to having units with smaller FOV capabilities and dramatically reducing the effective radiation doses. These efforts to reduce the radiation dose to the patient by using the smallest field of view directly respond to the "as low as diagnostically acceptable" (ALADA) principle.[27] The concept of ALADA further highlights the critical balance between clinical value and safety, which is an effort that was less explicit and more vaguely portrayed by the former "as low as reasonably achievable" (ALARA) acronym. As a community, having guidelines, in the form of selection criteria, can provide the clinician with a helpful framework to tailor the use of CBCT to those scenarios where 2D radiography has failed to answer the question for which imaging was performed.

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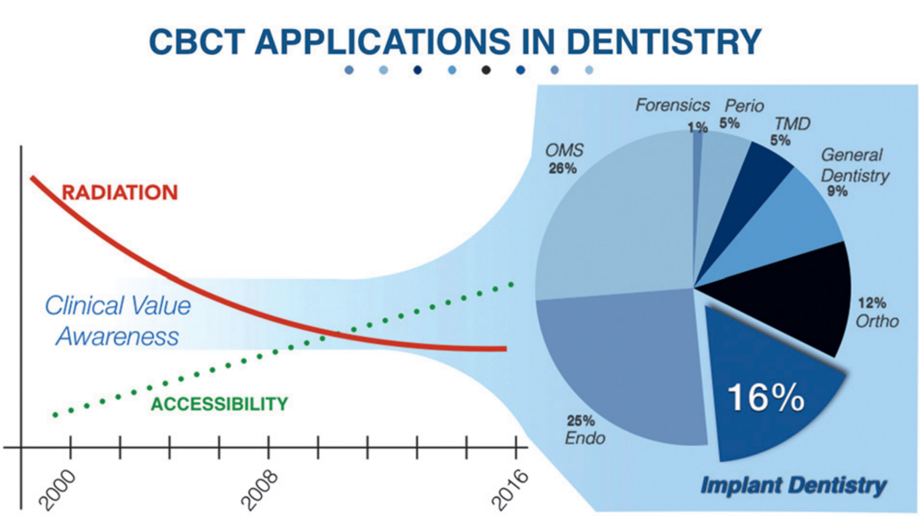

Figure 1.
CBCT availability in dentistry. General awareness of the diverse value and application of CBCT in dentistry has increased over time, driven by improvements in hardware and software technology in the field. Today, CBCT is perceived as a safe, valuable, and accessible resource with tangible benefits to clinical implant dentistry. OMS = oral and maxillofacial surgery; Perio = periodontology; TMD = temporomandibular disorders; Ortho = orthodontics; Endo = endodontology.

(AAOMR) as well as other organizations have already acknowledged the benefit of cross-sectional imaging for implant patients.[28-30] They emphasize that the decision to order a CBCT scan should be based strictly on the diagnostic and treatment planning needs with a conscious effort to minimize the patient's radiation dose, as also pointed out by Bornstein et al.[3] In other words, when acquiring a CBCT scan on an implant patient, it is important to limit the FOV to the implant site and the adjacent areas that require evaluation. Furthermore, high-resolution scans are generally not required for most implant treatment planning applications (e.g., bone dimensional assessment, general evaluation of bone quality, and visualization of adjacent structures). In fact, low-dose protocols would generally suffice. Additionally, the European guidelines by the Safety and Efficacy of a New and Emerging Dental X-ray Modality (SEDENTEXCT) further emphasize that since CBCT images often include structures that are not part of the diagnostic region of interest, the entire volume should be evaluated, not just the region of interest.[29]

It is indisputable that CBCT plays an important role in dental imaging and has the ability to improve treatment outcomes in many cases. However, the current available guidelines underscore the importance of looking beyond the novelty of attractive 3D images and encourage the clinician to have an objective perspective on the delicate risk versus benefit balance associated with the use of this imaging modality. Therefore, the intent of this review is to provide an overview of the currently available literature since the emergence of CBCT in dentistry and to offer a weighed perspective of its role in the context of implant dentistry.

MATERIALS AND METHODS

A PubMed search conducted of the available literature regarding CBCT and implant dentistry identified reports published between January 1, 2000, and June 24, 2017. Eligible studies were limited to those that presented illustrative ex-vivo or clinical evidence related to the use of CBCT in dental implant therapy. Of the 559 citations initially identified and manually screened, 176 were selected as relevant for the purpose of this review. Since this report is a narrative review that aims to broadly illustrate various aspects of CBCT application in implant dentistry, there was no formal evaluation of the strength of the evidence included. Among the relevant studies, three main categories emerged: 1) use of CBCT for diagnosis and treatment outcome assessment; 2) use of CBCT for implant treatment planning; and 3) use of CBCT for anatomic characterization (Fig. 3).

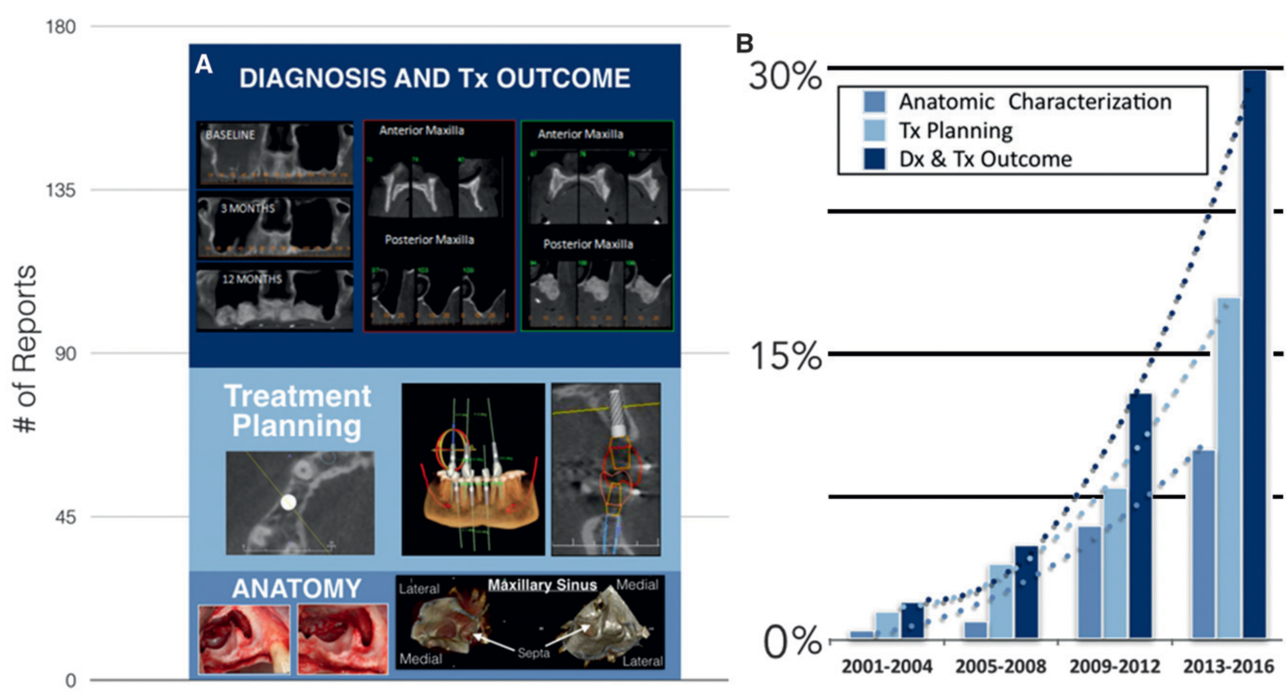

Figure 3.
Emerging evidence for clinical applications of CBCT. ***A)*** *The available dental implant literature clearly reflects an increased interest in the use of volumetric advanced imaging modalities such as CBCT for diagnostic (Dx), treatment (Tx) planning, and outcome assessment applications.* ***B)*** *This graph illustrates the available evidence, consisting of 176 papers published during the most recent full 16 years, distributed by the three most common dental implant-related applications and stratified by 4-year periods.*

Of the 176 studies, the majority (51%) were relevant to diagnosis and treatment outcome assessment with a main focus on: 1) ridge dimensional changes; 2) artifacts; 3) peri-implantitis/implant fate; 4) pathology; and 5) incidental findings (Fig. 3). The second most abundant category comprised articles related to implant treatment planning, which accounted for 32% with a primary focus on guided implant surgery and accuracy of measurements. The remaining 17% consisted of articles related to anatomic characterization relevant to implant dentistry, such as: 1) neurovascular canals and foramina; 2) maxillary sinus; 3) buccal cortical bone anatomy; and 4) bone density. Upon further scrutiny and elimination of redundancy, a total of 161 reports were included in this report.

RESULTS

Use of CBCT for Diagnosis and Treatment Outcome Assessment

This category includes studies that assessed the usefulness of CBCT as a diagnostic imaging modality before and after dental implant therapy. For this review pre-implant diagnosis refers to the evaluation of the proposed implant site prior to implant therapy to rule out the presence of occult pathology, foreign bodies, and/or defects and to determine the suitability of the site in terms of 3D morphology and proximity to vital anatomic structures. In terms of treatment outcome assessment related to the use of CBCT after implant site development or implant placement, it should be noted that comparing digital treatment plans to post-treatment digital impressions is a radiation-free alternative to CBCT for assessing treatment outcomes.[31]

Pathology/incidental findings. Studies in this category underscore the need to thoroughly examine all CBCT volumes for clinically significant findings within and beyond the region of interest and highlight the high prevalence of incidental findings in CBCT scans.[32,33] Such incidental findings may include, but are not limited to: 1) osseous or sinus pathology; 2) intracranial or vascular calcifications; and 3) airway asymmetry. One study[32] reported airway narrowing and asymmetry as the most prevalent incidental finding (35%), followed by soft tissue calcifications (20%), bone pathology (17.5%), degenerative changes of the temporomandibular joint (15.4%), endodontic lesions (11.3%), dental developmental anomalies (0.7%), and other pathology (0.1%). Of these findings, 16.1% required intervention/referral, 15.6% required monitoring, and the remainder (68.3%) required neither.[32]

Another study found 76 different incidental findings within or outside the region of interest in 943 of 1,000 scans reviewed and indicated that most scans had incidental findings in more than one area.[34]

Most reports regarding findings unrelated to the reason the CBCT was indicated agree that the prevalence of incidental findings is greater than 90%, and therefore it is essential to have each scan comprehensively reviewed by someone with advanced training in radiographic interpretation.[32-37]

Peri-implantitis/implant fate. This section includes studies where implant fate evaluation was the main goal. Within this scope, understanding whether CBCT will detect these defects earlier than other imaging modalities and if these early detections will have an effect on the overall prognosis of the implants is a matter of current investigation.[38-43]

Monitoring the bone and tissue condition around dental implants is essential not only during follow-up evaluation under functional loading but also during the assessment of strategies for regenerating peri-implant bone.[39] However, the use of CBCT for this particular application remains questionable as it is known that periapical radiographs with a strict projection protocol can assess mesial and distal peri-implant bone levels almost as accurately as histologic studies, assuming that the projected level of peri-implant bone is located in the sectioning plane of the implant or is of uniform height around the implant.[3] Moreover, the visualization of buccal or lingual bone defects with CBCT is also limited, as it is with periapical radiographs, but for different reasons.[44] The presence of inherent imaging artifacts such as beam hardening and partial volume averaging artifacts caused by titanium implants significantly decreases the visualization of the bone-implant interface.[45] However, scattering artifacts caused by metal are significantly less with CBCT as compared with medical CT. Naitoh et al.[46] evaluated the rate of bone-to-implant contact in a clinical study and reported that the bone configuration surrounding anterior dental implants with and without bone grafting can be adequately assessed using CBCT. Similar findings have also been obtained in human skulls.[47] However, controversial results are also found in the literature using other animal models where the evaluation of peri-implant bone defect regeneration by means of CBCT was not accurate for sites providing bone width of <0.5 mm.[39] Research to reduce artifacts caused by titanium implants in CBCT images is emerging.[45,48]

Kühl et al.[42] reported high sensitivity of the CBCT scans when evaluating 1- and 3-mm defects. However, the specificity of CBCT is lower than that found when intraoral periapical radiographs are used. Although CBCT may represent an accurate diagnostic tool to estimate the histologic extent of advanced peri-implantitis defects in some cases, intraoral radiography is still recommended as a favorable method of evaluating bone loss around dental implants.[3,42]

Alveolar ridge dimensional changes. Successful implant esthetics following tooth extraction requires a detailed understanding of tissue biology and the associated volumetric and facial contour changes in bone architecture.[29] 3D CBCT assessment has been clinically validated for the characterization of dimensional alterations of the facial bone following extractions or bone grafting procedures.[49-51] Different longitudinal and retrospective studies illustrate the application of CBCT for both linear and 3D analyses.[52,53] The reviewed studies exemplify the potential clinical applications in common therapeutic scenarios such as immediate implant placement, ridge preservation, volume stability associated with maxillary sinus advanced grafting procedures, and regenerative outcomes associated with flapless procedures.[52,54]

Artifacts. The artifacts produced by dental implants can cause significant interference when images are reviewed to assess implant placement and performance.[44,45,55-57] Noise and beam hardening are the most prominent artifacts induced by high-density objects in the path of the x-ray beam.[44] For many high-density dental filling materials, such as amalgam or gold, the complete absorption of the beam leads to extinction artifacts rather than to beam-hardening artifacts.[58] Even though dental implants are commonly made of titanium, which is a light metal with the atomic number of 22, massive beam-hardening artifacts are often associated with the typical diameter of implants and the typical beam energies used by CBCT machines. Decreasing the severity of implant-related beam-hardening artifacts in CBCT scans will require more sophisticated post-image processing mathematical algorithms.[56] Research aimed at reducing the number of artifacts caused by titanium implants in CBCT images is currently underway.[59]

Use of CBCT for Implant Treatment Planning

CBCT data interaction is a valuable resource for today's practitioner as it enhances treatment planning assessment based on information such as linear measurements, relative bone quality, 3D evaluation of ridge topography, and proximity to vital anatomic structures.[30] CBCT-aided implant surgery can be accomplished with or without third-party interactive treatment planning software.[30]

Accuracy of CBCT measurements. CBCT posterior-anterior cephalograms are shown to be more accurate than conventionally obtained extraoral cephalograms, in which transverse measurements may be impacted by changes in head position and head movements.[60] In dental implant treatment planning, one of the most frequently reported applications of CBCT is the ability to obtain height and width linear measurements of the alveolar ridge.[61-75]

CBCT images have been found to provide reliable bone quantity information for preoperative implant planning in different areas of the maxilla and mandible both in clinical and experimental studies.[47,62,76-78]

Guided implant surgery. CBCT-aided implant treatment planning includes the use of CBCT data imported into third-party interactive software platforms that simulate virtual implant placement as a precursor to the fabrication of guides that will be used at the time of surgery.[79] A scanning template made in a radiopaque material may be needed during patient scanning to enhance the registration of 3D surface data for dental implant planning,[80] depending on the software application protocol. In other situations and with certain software applications, scanning templates can be avoided, and dental implant planning can be accomplished fully virtually.[81] Placing the implant virtually prior to the surgery can help determine the most appropriate location and orientation of the proposed implant.[76,82] Moreover, the use of surgical guides facilitates flapless implant placement.[83,84] Use of CBCT-derived surgical guides has been enhanced to allow for implants to be placed directly through the surgical template with manufacturer-specific hardware to control depth and rotation of the implants. Therefore, extra equipment and related costs are associated with these protocols. CBCT-generated surgical guides and the integration of computer-aided design/computer-assisted manufacturing and CBCT to determine the appropriate restorative modality have been found to be precise[76,85,86] and will continue to evolve as a link between the treatment planning and restorative processes.

As expected, freehand implant placement by even experienced surgeons was significantly less accurate than when aided by a 3D fabricated guide in a study of 80 implants placed in the maxillary anterior region.[87]

Angular accuracy of guided surgery. A 2017 systematic review and meta-analysis of clinical studies by Raico Gallardo et al.[88] assessed the accuracy of guided dental implant surgery by type of tissue support. With tooth support, the angle deviations were reported as 3.39°, 3.5°, and 4.4° in the three prospective studies and 2.91° and 4.88°, in the two retrospective studies included in the meta-analysis. The corresponding figures with bone support were 4.73°, 5°, and 5.1°; and 4.63° and 9.31°, respectively, hence favoring tooth support.[88]

In an ex vivo study of 80 anterior maxillary implants placed by 10 experienced surgeons, the deviation between the virtually planned and the actually attained implant positions were measured based on CBCT scans.[87] The angular deviation was on average 2.19° following guided versus 7.63° freehand implant placement.[87] Another research team reported a mean angle deviation of 0.25° with 3D dental drill guides.[89]

Linear accuracy of guided surgery. It has been shown that magnification of CBCT-obtained linear measurements does not occur, and measurements were found to be more accurate than those obtained with medical CT.[61,90]

Raico Gallardo et al.'s systematic review[88] found that with tooth support, the mean deviations at the entry point were 0.81, 1.1, and 1.31 mm in the three prospective studies and 0.87 and 2.08 mm in the two retrospective studies. The corresponding figures with bone support were 1.3, 1.56, and 1.7 mm and 1.28 and 1.84 mm, respectively, hence favoring tooth support. The corresponding mean deviations at the apical level were for tooth support 1.01, 1.3, and 1.62 mm and 0.6 and 1.81 mm, respectively, and for bone support 1.6, 1.86, and 1.99 mm and 1.57 and 2.26 mm, respectively, also favoring tooth support.[88]

In the 2017 study by Vermeulen,[87] the mean lateral deviation at the implant coronal level was 0.42 mm with guided and 1.27 mm with freehand implant placement, versus 0.52 and 1.28 mm apically. The respective depth deviations were 0.54 versus 0.78 mm coronally and 0.54 versus 0.73 mm at the apical level.

Importantly, when comparing linear measurements while using different FOV sizes at varying voxel sizes[75] or different voxel sizes with the same FOV,[91] there were no significant differences in their linear accuracy. Therefore, the smallest possible FOV should be used, as recommended by the International Congress of Oral Implantologists.[30] Notably, dental metallic artifacts do not alter the accuracy of linear measurements obtained with CBCT.[92]

Navigational surgery. Fully active CBCT-aided implant surgery refers to the use of CBCT data in surgical navigation systems to perform fully computer-guided implant placement. The accuracy of navigation systems has been tested in some studies and clearly represents an emerging area with great potential. However, more research is still needed in this field.[93]

It is important to further highlight that even with CBCT and guided surgery, there is an expected apical position error ranging from 1.0 to 2.3 mm, and care needs to be taken to avoid structures of anatomic significance.

Use of CBCT for Anatomic Characterization

Another important advantage of CBCT is the ability to evaluate the ridge topography and proximity to vital anatomic structures three-dimensionally to determine if advanced grafting is necessary for appropriate implant site development. CBCT images have proven to be superior in this regard compared with other 2D imaging modalities.[94-97] CBCT can accurately assess the thickness of cortical bone such as the buccal/facial and lingual/palatal cortical plates, the floor of the nasal cavity, and the medial and lateral walls of the maxillary sinuses.

CBCT-enhanced neurovascular anatomic characterization. Different studies have reported the importance of various neurovascular anatomic structures identified on cross-sectional imaging, including: 1) inferior alveolar (mandibular) canal; 2) anterior loop and mandibular incisive canal; 3) mental foramen; 4) lingual canal; and 5) maxillary incisive/nasopalatine canal, and highlight the variability of imaging identification and characteristics of these structures in relation to implant placement.[98-109] Hence, efforts are underway to automate identification of the mandibular canal.[110]

In addition, the use of CBCT has been found to be effective in locating blood vessels in the lateral wall of the maxillary sinus, which should be appreciated prior to sinus augmentation procedures.[111] Relevant vascular anatomy that characterizes the mandibular symphysis region should be recognized and considered when planning for implant therapy in the mandibular anterior region.[100] CBCT can aid clinicians in identifying these important anatomic features to avoid potential serious complications. In fact, CBCT preoperative imaging has been associated with only 10% adverse events involving any of the abovementioned structures, whereas the risk of injury when other imaging modalities are used ranges from 30% to 50%.[30]

CBCT-enhanced buccal/lingual bone characterization. It is known that due to naturally occurring biologic events, the thin facial bone plate is prone to resorption, which can lead to fenestration and dehiscence following tooth extraction. The accuracy of buccal and lingual bone plate thickness measurements prior to implant placement using CBCT images has been demonstrated in several studies.[112-114]

However, the accuracy decreases significantly for post-implant buccal and lingual plate thickness assessment mainly due to the presence of the implant-related artifacts described above.[44] Nevertheless, considering the submillimeter differences in CBCT measurements compared with histologic measurements, this non-invasive imaging method provides limited yet useful information on bone-level measurements of dental implants.[113]

CBCT-enhanced maxillary sinus characterization. Preoperative assessment of the maxillary sinuses using CBCT imaging is important for patients undergoing implant-supported restorations in the posterior maxilla since panoramic radiographs fail to accurately detect a significant number of anatomic and pathologic variations in the maxillary sinus.[115-127]

The most common anatomic variations include increased thickness of the sinus membrane, the presence of sinus septa, and sinus pneumatization.[127,128] The clinical significance of the presence of mucosal thickening within the sinus prior to sinus augmentation and subsequent implant placement in the posterior edentulous maxilla remains controversial since a clear classification associating mucosal findings to active sinus pathology is lacking.[125]

The reported frequency of sinus pathology varies widely, ranging from 14.3% to 82%.[125] There is a wide range in reported prevalence of mucosal thickening related to apical pathology, the degree of lumenal opacification, features of sinusitis, and the presence of mucous retention pseudocysts and polyps.[129] Of these, mucous retention pseudocyst and mucosal thickening appear to be the most commonly seen sinus abnormalities. The medial wall and sinus floor are most frequently affected, and pathologic findings in the maxillary sinus are more commonly reported in men than in women.[129]

The prevalence of maxillary sinus septation has been reported to be 59.7%, with most sinuses having either one or two septa,[127,128] most commonly in the transverse direction.[127] About 60% of the septa were located in the anterior maxillary sinus, with 21% in the middle and 20% posteriorly in a study of 198 persons/396 sinuses that also found the posterior superior alveolar artery located extraosseously below the membrane in one-fifth (21%).[128] Due to the high prevalence of antral septa and sinus pathology, a preoperative CBCT scan is helpful in uncovering potential anatomic issues and minimizing complications during sinus augmentation procedures for dental implant therapy since 3D evaluation of the sinus with CBCT has been found to be significantly more reliable in detecting pathology than panoramic imaging.[127]

In some patients, especially those with chronic sinusitis, the maxillary sinus ostium is not patent, compromising normal maxillary sinus drainage. Such cases can lead to postoperative complications such as infection and insufficient bone formation if sinus augmentation is performed. CBCT could potentially be used to ensure the ostiomeatal complex (or unit) is healthy prior to performing sinus bone graft surgery.[130] CBCT evaluations showing sinusitis issues or pathology may be considered for referral to a otolaryngologist for further clinical and radiographic evaluation. However, such imaging is not currently recommended for general use, although it might be used in patients with chronic sinusitis.[131] The literature is scant regarding CBCT application for diagnosis of any pathology in the ostiomeatal complex. A study among patients suffering from reversible contraindications to sinus elevation reports on this use.[130] Otherwise, such studies seem to mostly concern dental implants accidentally displaced to the ostiomeatal complex region[132,133] and cases in which the Schneiderian membrane is damaged or infected by sinus augmentation in preparation for implant placement.[131]

CBCT-enhanced bone density characterization. Beyond linear and volumetric measurements, the accuracy of CBCT to evaluate bone mineral density has also been assessed.[134-154] Evaluation of bone density using CBCT is an area of increasing interest and lingering controversy since Hounsfield units (HU) are not directly applicable for CBCT.[149] In some studies, the gray values from CBCT images have been found to be positively correlated with the known density of reference materials, including bone.[155] In an in vitro study using a water phantom, Nomura et al.[146] found high correlation between the voxel values of CBCT and CT. However, Hua et al.[156] reported that voxel values of CBCT seemed inappropriate for evaluating bone mineral density.

Because of the volumetric acquisition and reconstruction of CBCT data, linear attenuation coefficients and HU, which can be readily obtained from multislice CT scans, are challenging to calculate from CBCT scans. To date, only relative bone quality information can be acquired. However, there is significant interest in assessing the reliability of bone density measurements obtained with CBCT in an effort to overcome this limitation and provide a method to standardize imaging variables to better estimate true tissue density.[157] Some studies have found that CBCT might hold potential with regard to the structural analysis of trabecular bone and that bone quality evaluated by CBCT shows a high correlation with the primary stability of dental implants.[140,144,152,158]

Furthermore, the use of the quantitative CBCT method holds promise as an alternative diagnostic tool for preoperative bone density evaluation.[134] When the same CBCT scanner is used, the gray value of scanned bone can be directly converted to the corresponding bone mineral density value using a calibration curve. However, imaging errors during processing should be addressed when CBCT images obtained under different conditions are used to determine bone mineral density. Using human jaws, Parsa et al.[159] compared microcomputed tomography (micro-CT) and multislice CT (MSCT) in evaluating the accuracy of CBCT for determining trabecular bone density. Their results showed a strong correlation between CBCT and MSCT, suggesting that CBCT can be used to assess bone mineral density at the implant site. Monje et al.[143] studied the relationship between bone density as determined by CBCT and morphologic parameters of bone as determined by micro-CT. The identified correlation between radiographic and tomographic measures supported the potential use of CBCT for assessing bone mineral density. However, additional studies are necessary to provide clinicians with better tools for such assessment. Although CBCT does not possess the bone density accuracy of conventional CT, it emits a much lower radiation dosage and can clearly provide qualitative assistance to the clinician evaluating the bone density for potential implant sites when used in addition to 2D radiographs.

CONCLUSIONS

CBCT is a useful and widely available tool in implant dentistry that has the potential to improve today's standard of care. Notably, the collected data/images are in digital form and hence are easily transferable between care providers. Its responsible use is based on a case-by-case selection of patients whose treatment plans will be significantly impacted by the additional 3D information. The full potential of this modality is further exploited by emerging software applications with optimized algorithms for enhanced user-friendly interaction with the volumetric data acquired to be used as a virtual treatment planning platform to simulate the ideal implant placement by factoring in important surgical and prosthetic considerations.

The available literature supports and, in many cases, validates the accuracy of CBCT for the evaluation of the following parameters: 1) linear measurements of the available ridge height, width, and relative bone quality; 2) assessment of 3D surface alveolar ridge topography; 3) characterization of vital anatomic structures relevant to the implant site; and 4) recognition of incidental pathology.

Furthermore, digital information recorded via CBCT facilitates communication among the implant team members regarding the diagnosis and treatment plan and the fabrication of CBCT-derived implant surgical guides. More generally, such electronic CBCT data expedite a digital workflow from simple to complex interdisciplinary care provision.

Despite the great potential benefits of CBCT, it should be borne in mind that CBCT is a recent, advanced modality that is steadily being improved but requires increasingly sophisticated operator skills.

It is imperative to recognize that every effort must be made to reduce the effective radiation dose to the patient. This can be accomplished by using the smallest possible FOV, the lowest mA setting, the shortest exposure time, and a pulsed exposure mode of acquisition consistent with the information needed.[160] If visualization of structures beyond the region of interest for implant placement is required, imaging using the appropriate larger FOV protocol should be selected on a case-by-case basis.

Last, but not least, it is important to emphasize that practitioners ordering CBCT scans are responsible for interpreting the entire image volume for potentially significant incidental findings that may require medical consultation.[161]

In summary, CBCT offers numerous tangible clinical benefits to implant dentistry and allows the periodontist to further enhance clinical outcomes and ultimately patient satisfaction and improved quality of life.

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Correspondence: Prof. Hector F. Rios, Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, 1101 N. University Ave., Ann Arbor, MI 48109-1078. Fax: 734/763-5503; email: hrios@umich.edu.

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