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Editorial

Applications of Cone Beam Computed Tomography (CBCT) in Implant Treatment Planning

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Abstract

The objective of this article is to review the literature which describes the evolving role of cone-beam computed tomography in dental implant treatment planning. The literature supports the use of CBCT in dental implant treatment planning particularly in regards to linear measurements, three-dimensional evaluation of alveolar ridge topography, proximity to vital anatomical structures, and fabrication of surgical guides. Despite inherent limitations associated with conventional two-dimensional (2D) radiographs, these continue as the mainstay for assessments of anatomical landmarks and implant site evaluation, CBCT should be considered as an imaging alternative in cases where the projected implant receptor or bone augmentation site(s) are suspect, and conventional radiography may not be able to assess the true regional three-dimensional anatomical presentation. This article has specific aim of describing critical anatomic landmark assessment based on four functional implant zones using CBCT.

SELECTIVE

Dental implant placement has become an integral part of comprehensive treatment plans for dental rehabilitation for edentulous patients. A thorough patient assessment is a pre-requisite for adequate treatment planning and placement of dental implants. Dental imaging is an important tool to accomplish this task. Traditional radiographs like periapical and panoramic radiography provide adequate information about proposed implant sites along with information about the neighboring vital structures that must not be violated [1]. However, these radiographic modalities provide a two-dimensional (2D) representation of three-dimensional (3D) structures. Their limited film size, image distortion, magnification, and 2-D view restrict their use in some cases. In an effort to overcome this limitation, the use of medical computed tomography (CT) for dental implant applications became available in the mid- 1980s; however, this practice received some criticism due to the level of radiation exposure during image acquisition. Recently, cone-beam computed tomography (CBCT) systems have become available for 3D visualization of the craniofacial complex. CBCT produces views and volumetric reconstructions of craniofacial structures similar to multi-slice conventional computed tomography (CT); however, it does so with reduced acquisition times, lower effective radiation doses, and a decreased financial burden compared with CT [2,3]. Introduction of CBCT technology presents the opportunity for 3D assessment of dental and craniofacial anatomy without the inherent limitations of conventional 2D imaging [4]. That is, an assessment can be conducted in all three planes of space without image distortion, superimposition of structures, and differential magnification of the image based on geometry.

INTRODUCTION

Dental implant surgery in general is considered a safe and minimally invasive procedure. However, just like any other surgical procedure, there are some inherent risks associated with implant surgery. The significance of accurate planning and surgical guidance as it pertains to critical anatomical landmarks, such as the mandibular canal, maxillary sinus and adjacent teeth, cannot be overemphasized. Accurate assessment of the location of these landmarks as well as the height, width, and angulation of bone is essential for an accurate treatment plan prior to placement of dental implants. Some of the common problems encountered during dental implant surgery include, insufficient bone volume, neurosensory disturbances and hemorrhage due to injury to neurovascular bundles during dental implant placement in severely resorbed arches [5-7].

Tolstunov identified and described four alveolar jaw regions—functional implant zones—with unique characteristics of anatomy, blood supply, pattern of bone resorption, bone quality and quantity, need for bone grafting and other supplemental surgical procedures, and a location related implant success rate [8].

The goal of this article is to review the literature that describes various anatomic diagnostic challenges that clinicians face during dental implant placement in the specified zones identified by Tolstunov [8] (Figure 1) and evaluate the selective application of Cone Beam Computed Tomography (CBCT) to help implant treatment plan and potentially avoid adverse events.

Functional Implant Zone 1

This zone is also known as the traumatic zone. It consists of alveolar ridge of pre-maxilla and eight anterior teeth: 4 incisors, 2 canines, and 2 first premolars. The greatest loss of bone following a tooth extraction in this zone occurs in the bucco-palatal or horizontal direction and occurs mainly on the buccal side of the alveolar ridge [9]. Any bone loss in the anterior maxillary area is vital due to the esthetic implications on dental implant supported restorations. Loss of teeth in this area is mostly due to trauma and if the teeth are not replaced immediately following trauma, the bone loss continues, leading to difficulty in dental implant placement in a prosthetically favorable position. An anatomic challenge in the anterior maxilla is the nasopalatine canal, located in the middle of the palate, posterior to the maxillary central incisors. The location and the size of the nasopalatine canal dictates the placement of a dental implant in area of the maxillary central incisors. In a CBCT analysis of 100 individuals, Bornstein et al found that the morphology of the nasopalatine canal exhibits many variations. The factors related to the variation in the location and the size of the nasopalatine canal include patient gender, age (canal length), status of the central incisors and the time span since tooth loss [10]. The location of the nasopalatine canal which contains the nasopalatine nerve, the descending branch of the nasopalatine artery and fibrous connective tissue is crucial, as studies have reported that contact of dental implant with neural tissue could result in failure of osseointegration [11]. Limited CBCT imaging as an additional radiographic method has been proposed to be of benefit to determine the dimensions and morphology of the nasopalatine canal before dental implant surgery, especially when one or both central incisors have been lost over a longer period of time [12,13] (Figures 2 and 3).

Functional Implant Zone 2

The second zone described by Tolstunov is the sinus zone. This bilateral maxillary posterior zone extends from the maxillary second premolar to the pterygoid plates and is located at the base of the maxillary sinuses [8]. The bone height between the floor of the maxillary sinus and alveolar bone needs careful evaluation

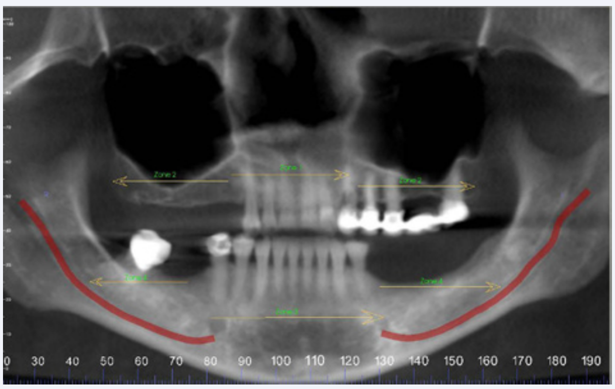

Figure 1 Functional zones identified on reformatted panoramic image.

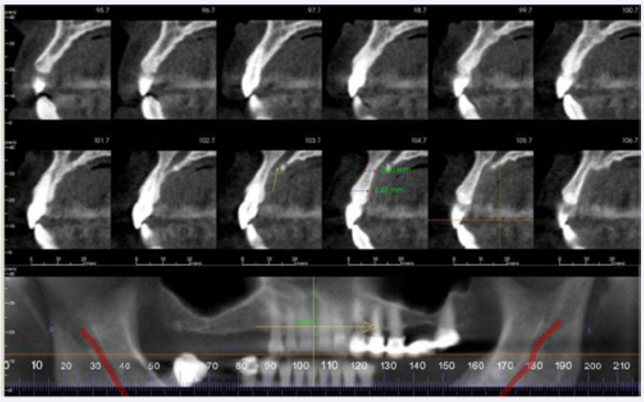

Figure 2 Cross-sectional images showing relation of naso-palatine canal to central incisors and presence of a facial concavity.

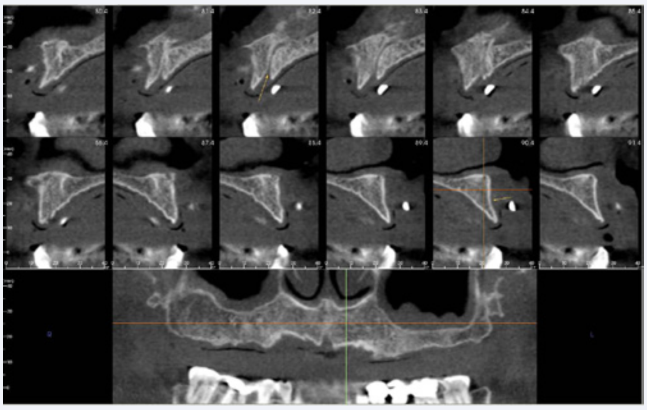

Figure 3 Cross-sectional views showing location of naso-palatine canal.

prior to placement of dental implants in the maxillary posterior region. Sinus volume increases following tooth extraction and often results in the need for vertical augmentation via a sinus lift procedure. Nunes et al confirmed a high percentage of edentulous sites in the posterior maxilla require sinus floor elevation to allow placement of dental implants [14]. Successful sinus elevation procedures require a clear view of the sinus anatomy which is not visible in panoramic radiographs. Maxillary sinus septa are barriers of cortical bone that divide sinus floor into multiple compartments. Recognition of sinus septa have become clinically significant following introduction of sinus floor augmentation surgery as their presence may complicate both creation and inversion of the access window in the lateral sinus wall, as well as elevation of the sinus membrane from the bony sinus floor. Sinus septa showing a sagittal orientation may not be diagnosable using panoramic radiographs and may thus lead to the false assumption of narrow internal sinus anatomy and subsequent non-augmentation of the medial portion of the sinus cavity (Figures 4, 5 and 6). In a meta-analysis, Pommer et al found septa in the maxillary sinus 28.4% of the time. However septa diagnosis using panoramic radiographs yielded an incorrect result in 29% of cases. In view of the high overall prevalence and significant morphologic variability in sinus septa seen in this investigation, 3D radiography prior to sinus floor augmentation surgery may help to reduce complication rates in the presence of maxillary sinus septa [15].

Functional Implant Zone 3

Inter-foraminal zone: This zone is comprised of the area of the mandibular alveolar ridge between mental foramen and first premolar on each side [8]. This zone is also associated with a thin alveolar ridge. There is abundant evidence in the literature reporting severe bleeding with the formation of expanding sublingual hematomas due to the perforation of the lingual cortex [5,16,17].

In a study where entrances of the lingual vascular canals were analyzed on one hundred CT scans of the mandible of Caucasian patients, 80% of the dry skull mandibles showed at least one lingual canal, and the CT scan detected the presence of at least one lingual vascular canal in up to 60% of patients. The authors concluded that a CT examination should routinely be performed before any surgical approach to the inter-foraminal region [18,19] (Figure 7). The anterior mandible presents with another challenge regarding the osseous architecture. Following a tooth extraction, the basal osseous structure stays stable. However the alveolar bone goes through resorptive changes in most individuals following tooth extraction [20,21]. Although anatomic, systemic and inflammatory factors could play a major role in the ridge resorption, the alveolar processes are resorbed in a fairly predictable fashion. Bone loss in the anterior mandible

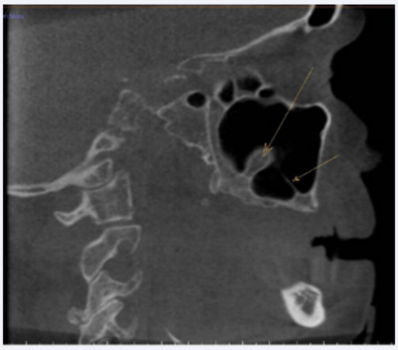

Figure 4 Sagittal view showing septa in left maxillary sinus.

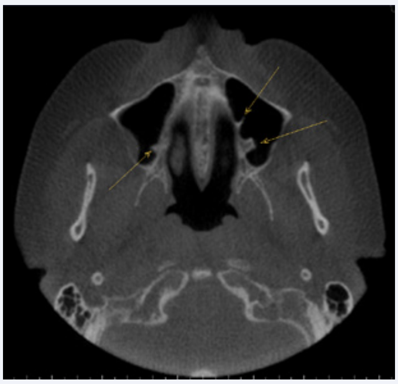

Figure 5 Axial view showing incomplete septa in right and left maxillary sinuses. Mild mucosal.

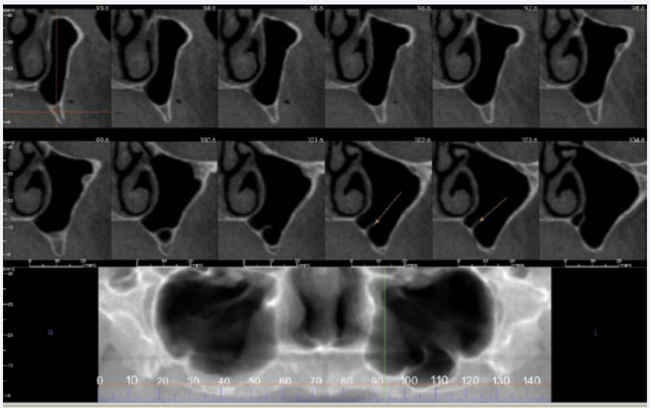

Figure 6 Cross-sectional views of zone 2 showing maxillary left posterior ridge and septa in left maxillary sinus.

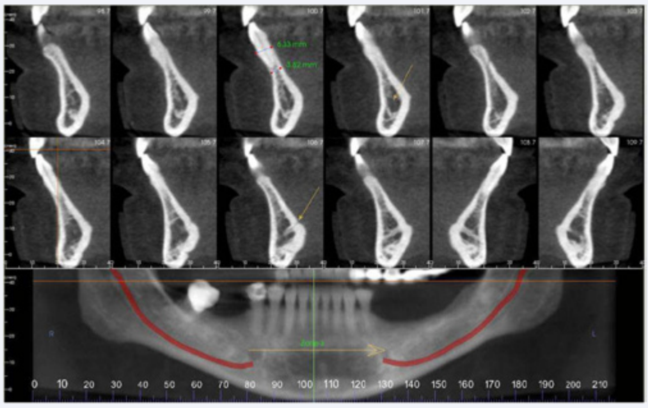

Figure 7 Cross-sectional views of zone 3 showing topography of mandibular anterior region.

is primarily horizontal from the labial side. This resorptive pattern leads to a knife edge alveolar ridge. Implant placement with a favorable prosthetic angulation is then complicated due to a high chance of lingual perforation and a possibility of severe hemorrhage. The sublingual fossa located on the lingual aspect of the anterior mandible also complicates instrumentation for implant placement by presenting as an extreme concavity. The concavity could result in lingual perforation during implant placement [5]. Although undercuts can be palpated during an intraoral examination, the thickness of the soft tissue can mask the severity of the undercut. A CBCT scan can provide an accurate view of the lingual osseous architecture and help avoid dangerous hemorrhage in the presence of extreme sublingual undercuts [17].

Dental implants in the mandibular pre-molar region are dictated by the size and the location of the mental foramen. Its location can vary from the mandibular canine to the first molar. The foramen may not appear on conventional radiographs, and any measurements made must be adjusted to account for radiographic distortion. In comparison, Computerized tomography (CT) scans are more accurate for detecting the mental foramen. To avoid nerve injury during surgery in the foraminal area, guidelines recommend leaving a 2 mm zone of safety between an implant and the coronal aspect of the nerve; therefore, observation of the inferior alveolar nerve and mental foramen on panoramic and periapical films prior to implant placement; and use of CT scans when traditional radiographs do not provide precision with respect to the position of the nerve. Once a safety zone is identified, implants can be placed anterior to, posterior to, or above the mental foramen. In general, altered lip sensations can be prevented if the mental foramen is located and this area is dealt with carefully during surgery [22-24].

Radiographic assessment of the mental foramen must be interpreted with caution. Jacobs et al. reported the foramen was detected on 94% (N = 545) of panoramic radiographs, but clear visibility was only attained 49% of the time [25,26]. Similarly, Yosue and Brooks noticed the foramen on 87.5% (N = 297) of panoramic radiographs, and it was distinct 64% of the time [24].

The traditional radiographs such as periapical films displayed the mental foramen only 75% (N = 75) of the time in one investigation [27] and on 46.8% (N = 1,000) in another study [23]. It is hypothesized that the inability to see mental foramen may be due to the difficulty in differentiating the foramen from the trabecular pattern, a lack of radiographic contrast due to thin mandibular bone or overly dark radiographs. A variation in angulation of periapical films may also account for failure to detect the foramen [24]. Errors in making measurements during assessments could also occur. Sonick et al determined the following average linear errors was seen during routine bone assessments (N = 12): panoramic films = 24% (mean: 3 mm; range: 0.5 to 7.5 mm); periapical films = 14% (mean: 1.9 mm; range: 0.0 to 5.0 mm); and computerized tomography (CT) scans = 1.8% (mean: 0.2 mm; range: 0.0 to 0.5 mm) [28]. It can be concluded that neither periapical nor panoramic films precisely illustrate the amount of bone coronal to the mental foramen. CT scans are more accurate than conventional radiographs (Figure 8). Conventional radiographs can usually be used if all possible radiographic distortions are taken into account. However, if it is difficult to locate the inferior alveolar canal or the mental foramen, consideration should be given to obtaining a CT scan.

The anterior loop refers to the anterior extension of the inferior alveolar nerve anterior to the mental foramen. Jacobs et al [25]. found an anterior loop on 11% of patient panoramic radiographs (N = 545); however they did not record the size of the anterior loops. Misch and Crawford noted an anterior loop whose average length was 5mm in 12% of patient panoramic radiographs (N = 324) however, did not provide incidence data regarding sizes [29,30]. Jacobs et al. found an anterior loop of the mental nerve in 7% of CT scans of patients (N = 230) [26]. Violation of the mandibular canal or the mental foramen during osteotomy can result in an injury to the inferior alveolar nerve or mental nerve resulting in an altered sensation in the lower lip, surrounding skin and mucosa. Care must be taken to avoid this injury by careful diagnosis. If the anterior loop is still not easily discernible, then it is best to surgically visualize the area prior to placing a dental implant.

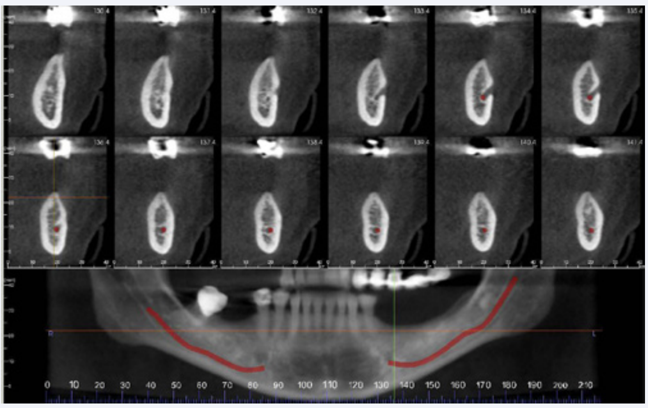

Figure 8 Cross-sectional views showing location of mental foramen.

Functional Implant Zone 4

This zone of the alveolar process of the mandible behind the mental foramen on each side and extends from the second premolar to retromolar pad [8]. The distance of the alveolar bone height from the inferior alveolar canal is evaluated when dental implants are considered in the posterior mandible. Careful assessment of the height must be made to avoid injury to the inferior alveolar canal. If there is a violation of the inferior alveolar nerve (IAN) , depending on the degree of nerve injury, alteration in sensation , from mild paresthesia to complete anesthesia, is reported [31]. The IAN leaves the mandibular canal through the mental foramen as the mental nerve. Within the canal, the nerve is about 3 mm in diameter, and its course varies [31]. It can run with a gentle curve toward the mental foramen, or it can have an ascending or descending pathway [32,33].

In a recent study, Kim et al. classified the bucco-lingual location of the IAN into 3 types.

Most cases (70%) were type 1, in which the IAN canal follows the lingual cortical plate of the mandibular ramus and body. In type 2 (15%), the IAN canal is located in the middle of the mandibular ramus posterior to the second molar. It then runs lingually to follow the lingual plate. In type 3 (15%), the IAN canal is located near the middle of the ramus and body [34].

Several methods are used to localize the IAN during treatment planning. These include traditional panoramic radiography, three dimensional computerized tomography (CT) and direct surgical exposure. Surgical exposure of the mental nerve by blunt dissection to allow direct vision of the nerve and to estimate the distance between the mandibular ridge crest and the IAN was suggested, but the irregular intra-osseous course of the nerve limits the value of this surgical technique [32]. The magnification and superimposition of structures is a major limitation of panoramic radiography [32]. Clinicians who depend mainly on the panoramic radiographs for localizing the IAN must take these factors into consideration. The IAN canal typically appears as a well-defined radiolucent bundle with superior and inferior radiopaque borders. The clinician must follow the canal from the mandibular foramen to the mental foramen and must keep in mind that magnification is a built-in feature of panoramic radiographs. Knowing the magnification factor, the clinician calculate the amount of available bone using the formula, Clinical bone height ~Radiographic bone height= Magnification factor [31]. Panoramic radiographs were found to provide sufficient information for implant length selection when a safety margin of at least 2 mm above the mandibular canal is respected [35-38].

Although clinical examination and traditional radiographs may be adequate for patients with wide residual ridges precise measurement of the bucco-lingual dimension of the bone or assessment of the location of unanticipated undercuts is not possible on plain radiographs [39]. Cross-sectional imaging is found to be beneficial when bone height measurements are less than 15 mm. in resorbed ridges [40].

CT provides the most accurate and precise method for localization of the IAN (Figure 9). Also, the image can be reconstructed into a 3-dimensional model that can be used as an accurate surgical guide. This 3-dimensional image is very useful in determining the bucco-lingual width of the bone, as well as the bucco-lingual position of the nerve. This allows positioning of the implant lingual or buccal to the nerve to avoid its injury in cases of limited bone height [34,41-43].

A bifid IAN canal has been reported to occur very infrequently. Nortje´ et al. [44,45] found an occurrence of 0.9%. Despite the rare occurrence of the bifid IAN canal, the clinician must be on the lookout for these cases when planning for dental implants [31,46].

Though CBCT is considered as an invaluable diagnostic tool that can be used effectively in pre-surgical work-up for any implant patient, however, like any other diagnostic procedure involving ionizing radiation, its use should involve clinical judgment rather than routine practice. The doses from CBCT are significantly lower than conventional CT, yet are higher than doses from the traditional views used in dentistry [47-52]. Therefore, a risk/benefit analysis must be carried out before a CBCT scan is requested. Significant differences in dose for the same examination have been reported for different CBCT units and significant differences in dose have been reported for different fields of view (FOVs) or techniques with the same unit [53]. According to the position paper published by American Academy of Oral and maxillofacial Radiology (AAOMR), although FOV limited to the area of interest is well suited for periapical diagnosis and implant planning, the FOV may extend beyond the implant site to include the maxillary sinus or opposing dental arch [54]. This will help define the surgical site and reduce the patient morbidities.

It is imperative to pay attention to radiation hygiene by following the fundamental principle of choosing exposures " As Low As Reasonably Achievable" (ALARA) and reserving CBCT procedures for selected cases- and appropriately collimating the beam to the chosen region of interest.

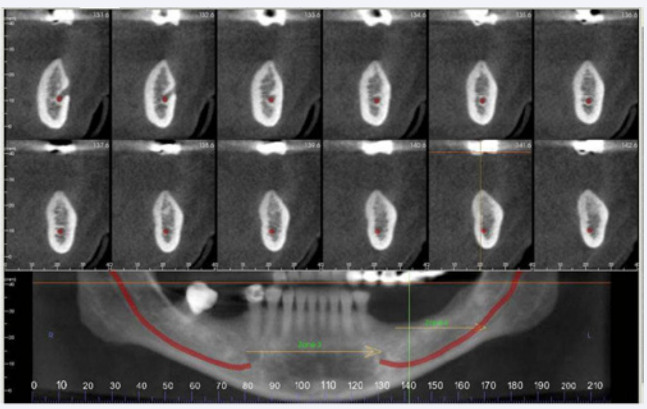

Figure 9 Cross-sectional views showing relation of mandibular canal to mandibular posterior ridge in zone 4.

CONCLUSION

Although clinical examination and traditional radiographs may be adequate for patients with wide residual ridges that exhibit sufficient bone crestal to the mandibular nerve and maxillary sinus, these methods do not allow for precise measurement of the bucco-lingual dimension of the bone or assessment of the location of unanticipated undercuts. For these concerns, it is necessary to view the recipient site in a plane perpendicular to a curved plane through the arch of the maxilla or mandible in the region of the proposed implants. Cross-sectional views of the maxilla and mandible are the ideal means of providing necessary pre-operative information. In simple cases, where a limited number of implants are to be placed, panoramic radiography may be used to obtain a view of the arch of the jaw in the area of interest. For complex cases, where multiple implants are required, the CBCT scan is recommended. A CBCT is also ideal when working with severely resorbed maxilla and the mandible. Depending upon the pattern of resorption the anatomical landmarks might pose a risk to placement of dental implants. Use of a CBCT, because of its ability to reconstruct a fully three dimensional model of the maxilla and mandible, will help identify critical anatomic structures accurately for precise placement of dental implants with minimal complications.

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