Review Article

Applications of cone beam computed tomography for a prosthodontist

George Puthenpurayil John, Tatu Elenjickal Joy[1], Justin Mathew[2], Vinod R. B. Kumar[3]

Department of Prosthodontics, Mar Baselios Dental College, Kothamangalam, Departments of [2]Oral and Maxillofacial Surgery and [3]Oral and Maxillofacial Pathology, Malabar Dental College and Research Centre, Edappal, Kerala, [1]Department of Oral Medicine and Radiology, Sree Mookambika Institute of Dental Sciences, Kulasekharam, Kanyakumari, Tamil Nadu, India

Abstract

Cone beam computed tomography (CBCT) is a medical imaging technique of X-ray computed tomography where the X-rays are divergent, forming a cone. CBCT systems have been designed for imaging hard tissues of the maxillofacial region. The increasing availability of this technology provides the dental clinician with an imaging modality capable of providing a three-dimensional representation of the maxillofacial skeleton with minimal distortion. This article is intended to elaborate and enunciate on the various applications and benefits of CBCT, in the realm of maxillofacial prosthodontics, over and beyond its obvious benefits in the rehabilitation of patients with implants. With the onus of meticulous reconstruction of near ideal occlusion resting on the prosthodontist, CBCT provides a unique imaging option, which can be a boon in various aspects of prosthodontic practice – from imaging of the temporomandibular joint for accurate movement simulation, to template assisted maxillofacial reconstruction or even over denture therapy. CBCT could play a crucial role in lessening the burden of a hectic prosthodontic routine for the clinician and critically contribute to accurate and effective treatment for the patient. Apart from the authors' clinical experiences shared here, a web-based search for relevant articles in this specific area of interest was also conducted. The selected articles were critically reviewed and the data acquired were systematically compiled.

Key Words: Applications, cone beam computed tomography, implant, prosthodontics, temporomandibular joint

Address for correspondence:
Prof. George Puthenpurayil John, #8A, B. Paul Abrao Residency, Chittoor Road, Kacheripady, Kochi - 682 018, Kerala, India. E-mail: j.george@lycos.com
Received: 16th March, 2015, **Accepted:** 06th June, 2015

INTRODUCTION

The incorporation of the third dimension into dental and craniofacial imaging is now a practical reality. The future of maxillofacial/dental imaging appears exciting as the paradigm shifts from landmarks, lines, and distances to surfaces, area, and volumes. Cone Beam Computed Tomography (CBCT) is a medical imaging technique of X-ray computed tomography where the X-rays are divergent, forming a cone.[1] An attempt has been made to evaluate probable areas where cone beam computed tomography (CBCT) imaging finds application in prosthodontics, as literature search regarding its direct indications in prosthodontics was inconclusive, apart from those found pertaining to its relevance in implant dentistry. Broadly discussed in this article are areas where CBCT imaging can be applied in the diverse discipline of prosthodontics.

Access this article online	
Quick Response Code:	Website: www.j-ips.org
	DOI: 10.4103/0972-4052.161574

Indications in prosthodontics

- Implant prosthodontics
- Temporomandibular joint (TMJ) imaging
- Maxillofacial prosthodontics
- Craniofacial and airway analysis

- Comprehensive treatment planning in over denture patients.

Implant prosthodontics

The growing inclination for the selection of dental implants as a viable alternative to replace missing teeth has necessitated a reliable technique capable of obtaining highly accurate measurements to avoid likely damage to vital structures during implant surgery. Anatomic structures such as the inferior alveolar nerve, maxillary sinus, mental foramen, and adjacent roots are easily viewed using CBCT. Further, these specific CBCT images permit precise measurement of distance, area, and volume.[2]

In traditional panoramic radiography, the average machine produces approximately a 1:1.2 ratio magnification, depending on the center of rotation it takes for the particular structure. This must be accounted for when planning implants. Preliminary studies on CBCT have concluded that the CBCT image underestimates the actual distance. However, these differences were significant only for the skull base. Imaging of the dental and maxillofacial regions were found to be quite accurate as the voxels exhibit a sense of "isotropism" that is, uniformity in all dimensions, demonstrating no significant differences.

The fact that measurements from the CBCT are routinely accurate throughout the maxilla and mandible makes this an excellent imaging modality for planning implant placement.[3] Using these features, an implantologist can gain confidence in treatment planning for complex surgical procedures such as sinus lift and ridge augmentation, apart from gaining a secure sense during intricate extraction procedures and implant placement – with or without a surgical guide.

The surgical guide can be fabricated with a CBCT image, in the complete absence of the patient (thereby reducing the number of patient appointments), thus, allowing precise placement of implants, prefabrication of the abutments and prosthesis, and "same day" delivery of the prosthesis. Computed tomography (CT) images also have similar capabilities, but the benefit of CBCT is less radiation exposure to the patient and greater image accuracy.

Cone beam computed tomography imaging also finds application in presurgical imaging, as well as surgical – intra-operative and postsurgical evaluation (for assessment of osseointegration). Furthermore, the availability of newer software to construct surgical guides has further reduced the possibility of structural damage.[1,4] CBCT data combined with data from intraoral scanners like the Cerec Omnicam® or Cerec Bluecam® (Sirona, Germany) is used to interface with other interactive machinery like CAD/CAM[5] or three-dimensional printers for precision milling/additive manufacturing resulting in immediate delivery of chair side fixed prostheses and surgical guides.[6]

In the "prosthetically driven implant" technique, a radiopaque marker (barium coated teeth) can be utilized to demarcate the final tooth position. This data, when aligned on CBCT, can be utilized to create a surgical guide for precise implant placement, which ensures final prosthesis to implant alignment.[1,7]

Cone beam computed tomography can be extremely helpful in identifying areas of inadequate bone to support dental implants. This information would allow in determining the volume of graft needed prior to surgery and the type of graft material to select. Heiland *et al.* described the intra-operative use of CBCT in two cases to guide the insertion of the implant after microsurgical bone transfer.[8,9] Postgraft imaging would reveal the amount of bone formed and will also provide information on bone density.

Cone beam computed tomography provides valuable information about the thickening and perforations involving the sinus membrane, patency of the osteomeatal complex and also aids in more informed planning with respect to surgical access into the sinus.

This confirms that the range of anatomical detail gained through a CBCT provides the implantologist ample amount of information to improve the success rate of grafting of the maxillary sinus and sinus implants.[1] Figure 1a-c demonstrate the improved visualization and comprehension of the sinus anatomy in the area in which the implants were placed.

TEMPOROMANDIBULAR JOINT IMAGING

One of the major advantages of CBCT is its ability to define the true position of the condyle in the fossa, which often reveals the possibility of dislocation of the disk in the joint and the extent of translation of the condyle in the fossa.[10] Due to its accuracy, CBCT facilitates easy measurement of the roof of the glenoid fossa and provides the ability to visualize the three-dimensional relation that the condylar head has with the glenoid fossa. Soft tissue calcifications around the TMJ are easily visible which reduces the requirement for the use of MRI in such cases.[11]

Due to these advantages, CBCT has become the imaging device of choice in cases of trauma [Figure 2a and b], pain and dysfunction, and fibro-osseous ankylosis, as well as in the detection of condylar cortical/sub-cortical erosion, and cysts.[12] The use of three-dimensional features facilitates the

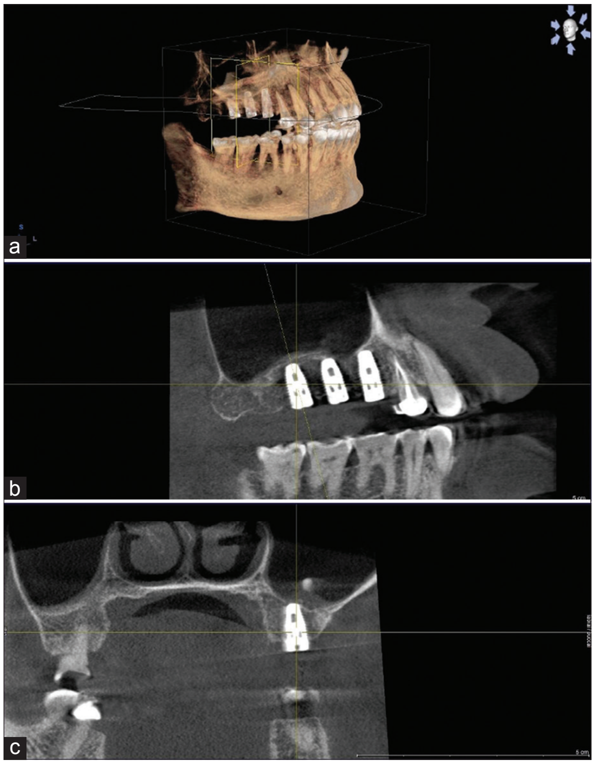

Figure 1: (a) Three-dimensional view of three implants in the right maxillary posterior region; GALAXIS GALILEOS viewer 1.9 software in SIRONA ORTHOPHOS XG 3D, permits the image to be viewed in all directions/probable angles, demonstrating the proximity to important vital structures. (b) The same three implants in a tangential view. (c) Cross-sectional view showing relationship of implant to the floor of the maxillary sinus

safe application of the image-guided puncture technique, which is a treatment modality for TMJ disc adhesion. The most recent advance is now in real time imaging, which is used for TMJ movement studies.[13,14]

MAXILLOFACIAL PROSTHODONTICS

Cone beam computed tomography has now replaced the standard CT in imaging and planning craniofacial defect reconstruction. Three-dimensional augmented virtual models of the patient's face, bony structures, and dentition can be created out of CBCT DICOM data by software volume rendering for treatment planning. DICOM or digital compatibility is the universally accepted data transfer protocol developed for rapid, mass data transfer with minimal or nil distortion and nonalterable primary image that helps prevent malpractice. DICOM enables the viewer to work on any workstation.

The shape of the graft can be virtually planned and can also be positioned in the defect creating a virtual reconstruction of the defect prior to the actual surgery. In addition, implant placement (if required) onto the graft can also be planned.[15] Obturators for cleft closures can be precisely milled in larger CAD/CAM units, thereby eliminating the entire cumbersome clinical process of obturator construction.

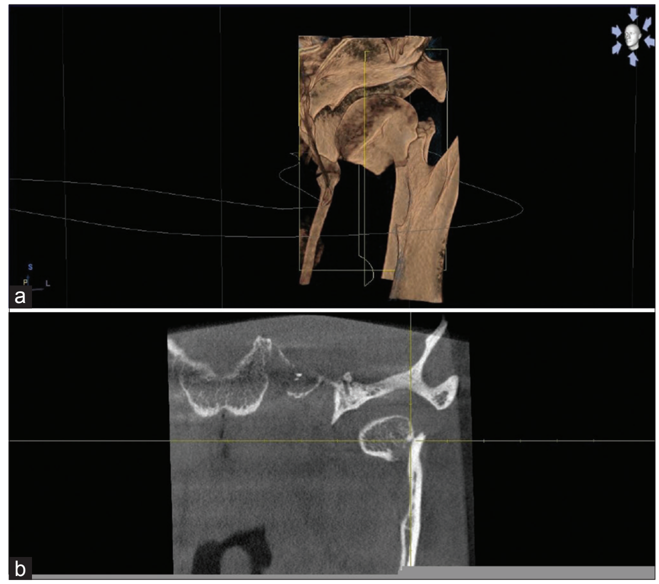

Figure 2: (a) Three-dimensional view of the fractured head of a condyle. The image also demonstrates the glenoid fossa, styloid process, and medial aspect of the mandibular ramus. (b) Cross-sectional view of the fractured condylar head

CRANIOFACIAL AND AIRWAY ANALYSIS

Identifying the area of airway obstruction has often proved to be challenging. During the past few decades, various methods have been used to evaluate the airway, including nasopharyngoscopy, cephalometry, nasal airway resistance, as well as polysomnography. Lateral and frontal radiographs have been used to assess the pharyngeal airway. CBCT offers a three-dimensional presentation of the airway and its surrounding structures [Figure 3] which makes volumetric analysis and accurate visualization of the airway possible.

By using CBCT scans to analyze the complex airway anatomy, previous studies have confirmed that volumetric measurement of airways utilizing CBCT are accurate and with minimal error, thus offering an increased view of both untreated obstruction tendencies and potential changes in the airway through treatment modality. Three-dimensional imaging is a very efficient method to inspect and identify diffuse narrowing or focal narrowing (encroachments) of the airway.[16]

COMPREHENSIVE TREATMENT PLANNING IN OVERDENTURE PATIENTS

The idea of retaining some teeth/roots for over denture rehabilitation is not new. It was first described over 150 years ago.[1,2] In the 1950s, clinicians noted that when teeth were extracted, the residual alveolar bone was in a continual state of

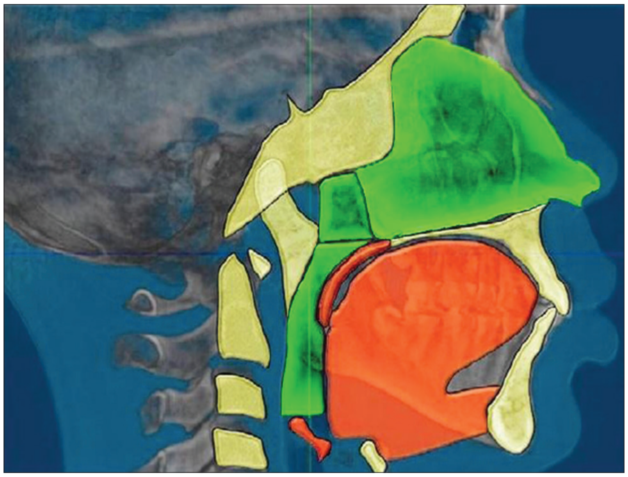

Figure 3: Airway zones (green) divided into nasal, nasopharyngeal, and oral airways; supported posteriorly by the spine, superiorly by the cranial base, and anteriorly by the maxilla, mandible and hyoid (cream). Mobile elements associated with airway – tongue, soft palate, and epiglottis (orange)

resorption, which left very little support for complete dentures, thus making them difficult to wear.

Analysis of several longitudinal studies[17,18] of edentulous patients wearing complete dentures found that the resorption was progressive, irreversible, and cumulative.[18] The rate of resorption was greatest in the first 6 months after the extraction of the teeth, but the rate varied and was affected by a variety of biological and mechanical factors.[18] However, the rate of resorption in the mandible was 4 times than that of the maxilla, as described by Tallagren,[18] who found that after 25 years of denture wear, the average bone loss in the mandible was 9–10 mm of vertical height compared to 2.5–3 mm on the maxilla. This process of initial assessment to a follow-up during a 4 years review would be precise with the use of a CBCT, thereby improving the prognosis of such dentures.

Cone beam computed tomography versus computed tomography

- Cost of equipment is approximately 3–5 times less than traditional Medical CT
- The equipment is substantially lighter and smaller
- CBCTs have better spatial resolution (i.e., smaller pixels)
- No special electrical requirements are needed
- No floor strengthening required as most CBCTs are wall mounted
- Very easy to operate and to maintain; little technician training is required
- Some cone beam manufacturers and vendors are dedicated to the dental market. This makes for a greater appreciation of the dentist's needs
- In the majority of CBCTs, the patient is seated, as compared with lying down in a medical CT unit. This, together with the open design of the CBCTs virtually eliminates claustrophobia and greatly enhances patient comfort and acceptance. The upright position is also thought by many to provide a more realistic picture of condylar positions during a TMJ examination, thereby opening possibilities of real-time imaging
- The lower cost of the machine may be passed on to the patient in the form of lower fees
- Both jaws can be imaged at the same time
- Radiation dose is considerably less than with a medical CT
- Protocol selection (e.g., slice thickness) selection is at times difficult with CT in comparison to CBCT
- Metal artifacts or metal spraying is much lesser in the CBCT when compared to the CT. Therefore, use of localization markers for precision marking is possible
- The primary use of CBCT in the facial region is for implant planning, and CBCT scores much higher in all aspects when compared to the CT
- Probably the only disadvantage that CBCT holds over CT is the "Hounsfield units" density measurements. CT gives precise Hounsfield units in comparison to the CBCT which due to the nature of volumetric imaging renders it inaccurate and the reading got is an average of the entire volume in the section
- Finally, in our opinion, the CBCT beats the CT in the facial skeleton (due to the complex nature of the anatomy and the machine design) while in all other regions CT may have the edge.

Future and on-going research

- Pretreatment and posttreatment comparative analysis of the facial skeleton and soft tissue provides a novel opportunity for immense possibilities in facial asymmetry correction and predictive reconstructive surgeries, which has developed in leaps and bounds with this new tool – one that could be the gold standard soon
- Finite element analysis (FEA) in the stress force analysis of the jaws is another aspect being researched upon. FEA is a fairly recent discipline crossing the boundaries of mathematics, physics, engineering principles, and computer science. The method has wide application and enjoys extensive utilization in the structural, thermal, and fluid analysis areas. The FEA method is comprised of three major phases:
    - Preprocessing, in which the analyst develops a finite element mesh to divide the subject geometry into subdomains for mathematical analysis and applies material properties and boundary conditions,
    - Solution, during which the program derives the governing matrix equations from the model and solves for the primary quantities and
    - Postprocessing, in which the analyst checks the validity

of the solution, examines the values of primary quantities (such as displacements and stresses), and derives and examines additional quantities (such as specialized stresses and error indicators)

- The addition of muscle volume analysis should provide a boost to the science of TMJ management
- Growth and development analysis with predictive protocols are being researched upon and should soon see a paradigm shift to predictive surgery
- Developing Hounsfield like units for density measurements in CBCT and further dose reduction are important parameters in the offing that could further substantiate the use of this technology.[12]

CONCLUSION

In summary, with the continued decreasing cost of CBCT technology, it is only a matter of time until CBCT finds its way into all clinical practices. The increased diagnostic capability combined with the lower radiation dose will also help bring this technology into the limelight. The applications described herein are merely the humble beginnings of a much more elaborate and versatile imaging modality, which will provide an valuable user interface with associated machinery and thus transform the pressing work schedule of a prosthodontist into a relaxed, easier, and reliably more precise one.

REFERENCES

1. Tischler M. In-office cone beam computerized tomography: Technology review and clinical examples. Dent Today 2008;27:102, 104, 106.
2. Palomo JM, Kau CH, Palomo LB, Hans MG. Three-dimensional cone beam computerized tomography in dentistry. Dent Today 2006;25:130, 132-5.
3. Worthington P, Rubenstein J, Hatcher DC. The role of cone-beam computed tomography in the planning and placement of implants. J Am Dent Assoc 2010;141 Suppl 3:19S-24.
4. Gulsahi A. Bone Quality Assessment for Dental Implants, Implant Dentistry - The most promising discipline of dentistry. In: Prof. Ilser Turkyilmaz editor, ISBN: 978-953-307-481-8, InTech, 2011. doi: 10.5772/16588. Available from: http://www.intechopen.com/books/implant-dentistry-the-most-promising-discipline-of-dentistry/bone-quality-assessment-for-dental-implants. [Last cited on 2015 Mar 16].
5. Kunkela J. One-visit guided treatment thanks to CAD/CAM and CBCT. Dent Trib 2013. Available from: http://www.dental-tribune.com/articles/specialities/implantology/13966_one-visit_guided_treatment_thanks_to_cadcam_and_cbct_.html. [Last cited on 2015 Mar 16].
6. Parmar NR. Guided implant surgical placement with Cad/CAM CEREC crown. Implant Trib 2013. Available from: http://www.drnileshparmar.com/publications_pdf/1359378785_FINAL.pdf. [Last cited on 2015 Mar 16].
7. Claudia C, Adrian A, Francesco NP, Dario B. Cone-beam volumetric imaging in craniofacial medicine, CT Scanning - techniques and applications. In: Dr. Karupppasamy Subburaj editor, ISBN: 978-953-307-943-1, InTech, 2011. DOI: 10.5772/24442. Available from: http://www.intechopen.com/books/ct-scanning-techniques-and-applications/cone-beam-volumetric-imaging-in-craniofacial-medicine. [Last cited on 2015 Mar 16].
8. Alshehri MA, Alamri H, Alshalhoob M. CBCT applications in dental practice: A literature review. CAD/CAM; 2010. Available from: http://www.endoexperience.com/documents/CAD0210_26-31_AlshehriAlamriAlshalhoob.pdf. [Last cited on 2015 Mar 16].
9. Heiland M, Pohlenz P, Blessmann M, Werle H, Fraederich M, Schmelzle R, *et al*. Navigated implantation after microsurgical bone transfer using intraoperatively acquired cone-beam computed tomography data sets. Int J Oral Maxillofac Surg 2008;37:70-5.
10. Miles DA. Temporomandibular Joint Imaging Using CBCT: Technology Now Captures Reality. Learn Digital; 2012. Available from: http://www.learndigital.net/articles/2012/Temporomandibular-Joint-Imaging-Using-CBCT.pdf. [Last cited on 2015 Mar 16].
11. Tsiklakis K, Syriopoulos K, Stamatakis HC. Radiographic examination of the temporomandibular joint using cone beam computed tomography. Dentomaxillofac Radiol 2004;33:196-201.
12. Makhija PG, Makhija P. Integrating cone beam computed tomography (CBCT) in dentistry-review. Bhavnagar Univ J Dent 2013;3:49-55.
13. YOUTUBE.COM. SICAT Function – Track Real Motion in Motion. Available from: https://www.youtube.com/watch?v=rDbab8MDWN4#t=76. [Last updated on 2014 Mar 07; Last cited on 2015 Mar 16].
14. YOUTUBE.COM. The VIP Project – FaceScan, CEREC Omnicam Integration, Articulation, Digital Appliance Tx. Available from: https://www.youtube.com/watch?v=jQKlqPTs2D4. [Last updated on 2012 Nov 01; Last cited on 2015 Mar 16].
15. Sarment D. Three dimensional planning in maxillofacial reconstruction of large defects using cone beam tomography. In: Cone Beam Computed Tomography: Oral and Maxillofacial Diagnosis and Applications. 1st ed. USA: Wiley-Blackwell; 2014. p. 109-26.
16. Hatcher DC. Cone beam computed tomography: Craniofacial and airway analysis. Sleep Med Clin 2010;5:59-70.
17. Macleod I, Heath N. Cone-beam computed tomography (CBCT) in dental practice. Dent Update 2008;35:590-2, 594.
18. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc 2006;72:75-80.

How to cite this article: John GP, Joy TE, Mathew J, Kumar VR. Applications of cone beam computed tomography for a prosthodontist. J Indian Prosthodont Soc 2016;16:3-7.

Source of Support: Nil, **Conflict of Interest:** None declared.