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Role of Cone Beam Computed Tomography As A Multi Bagger - A Review Article

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Abstract

In the field of radiology, on contrast to conventional CT with the advantage of being 3-dimensional imaging technique, with lower radiation dose and cost effectiveness, CBCT has led to rapid ingress into the field of dentistry with the requirement of exploring its applications in the dental and other non-dental fields. Dental applications of CBCT includes assessing impacted teeth, TMJ disorders, salivary ductal involvement and calcifications, paranasal sinus, nerve mapping, canal assessment, evaluation and surgical planning for dental implants, tumours, cysts in maxillofacial region, cephalometric analysis and reconstruction surgery. CBCT also plays a role of multi-bagger in non-dental field such as in otolaryngology which includes assessing nasal septum deviations, adenoids and in somnology which includes evaluating quality of sleep disturbance based on airway obstruction. This review article thus highlights the multi-purpose role of CBCT.

Keywords: CBCT, MDCT, 3-Dimensional, Imaging, Implant, Impacted teeth, Treatment planning, Maxillofacial

Introduction

In 1895, after the discovery of X-rays, radiology in the dental field began to play an important role as an diagnostic adjunct for the clinical evaluation of the patient, diagnosis of the condition, treatment planning and assess the prognosis of the pertaining dental condition. There have been various 2-dimensional radiographic imaging techniques such as Intraoral periapical radiographs (IOPA) Panoramic radiographs (OPG), and other conventional radiographs being commonly used in dentistry, that are reported to cause superimposition of dental structures, distortion etc and sometimes the complexity of oro-facial pathologies such as cysts/tumours of oral cavity, TMJ disorders, any maxillofacial fracture etc makes it difficult to diagnose the condition. Advanced imaging techniques like Computed Tomography has limitations such as high cost, less accessibility for dental patients, high radiation dose etc. For this reason, advanced multi-planar imaging modalities were required that led to introduction of Cone Beam Computed Tomography (CBCT), which is also called as digital volumetric tomography (DVT).

Cone Beam Computed Tomography (CBCT) is a 3-dimensional imaging technique, first introduced for

the dental use in 1999 followed by which it was utilised in oral and maxillofacial imaging in various countries but in India, its use was limited due to the cost of purchasing the machine. However after knowing its benefits of producing good quality images, short scan times, volumetric analysis and relatively less radiation dose compared to the conventional medical CT, the availability of this technology is increasing in many dental institutions and diagnostic centres across our country. CBCT is pervasively expanding as a multidisciplinary imaging modality providing a 3D representation of the maxillofacial structures for diagnostics and treatment planning.

CBCT secured its utility in dental fields like implant planning, assessing the position of impacted teeth, evaluation of cysts or tumour of maxillofacial region, temporomandibular joint disorders (TMJ), disorders of salivary glands and salivary duct calcifications, paranasal sinus involvement, nerve mapping, 3D reconstruction surgery, assessing bone loss and tooth orientation, root canals assessments, cephalometric analysis. Furthermore, it gained its role in the various other field such as somnology like evaluation of sleep disturbances based on airway analysis and airway volume, otolaryngology like assessment of any deviation in nasal septum, enlargement of tonsils, adenoids etc. Thus it is important to have a maximal understanding about the utility of CBCT imaging modality in order to obtain its utmost benefits while minimising the radiation-exposure to the patients based on the principle of "As Low As Reasonably Achievable (ALARA)". Several literature review reported about the use of CBCT for dental aspects but only a handful of review articles reported about the other uncommon uses of CBCT. This review hence emphasises the various uncommon applications of CBCT and its multi-disciplinary role in other fields.

Basic Principles Of Cbct :

The basic setup of CBCT includes a fixed X-ray source, a detector with a rotating gantry. The x- ray source will emit a cone-shaped beam of ionizing radiation to the x-ray detector on the opposite side. The beam passes through the centre of the region of interest (ROI) in the patient's head. Both the x-ray source and the detector is contained within the gantry. The gantry rotates around the patient's head in either 180 degree (single partial) or 360 degree (complete), where there will be emission of radiation in a continuous or pulsed mode resulting in projection radiographs or basis images which would be similar to lateral cephalometric images (1). During the exposure sequence, hundreds of sequential 2D projection images are acquired for the field of view (FOV). These series of projection images are called as projection images or raw images. These data are then incorporated into a software and after application of filtered projections, it generates a 3D volumetric data in 3 orthogonal planes such as axial, coronal and sagittal. Since for every rotation CBCT incorporates the entire field of view (FOV) , one single rotation of the gantry is required to obtain the sufficient data for reconstruction of the image.

CBCT when in comparison with multi-detector CT (MDCT), the beam orientation in CBCT differs from that of MDCT, which uses a fan-shaped X-ray beam with a simultaneous translation of the patient table (gantry) and rotation of the X-ray source and detector, resulting in a helical trajectory. Although producing similar images, both CT and CBCT has various differences in the image acquisition process such as x-ray generation, x-ray detection, image reconstruction etc. CBCT provides images of better resolution with detailed sections in 3 dimensions.

Applications In Dentistry Temporomandibular Joint Disorders :

Temporomandibular joint disorders (TMDs) is considered to be a common category of oro-facial pain. Currently CBCT has been reported to be useful in the evaluation of bony changes of the temporomandibular joint (TMJ), which includes ankylosis, dislocation, any abnormal growth, fracture involving TMJ, degenerative joint disorders like flattening of condyle, erosions, subchondral sclerosis, arthritis, arthralgia (Fig 1A and 1B). CBCT provides 3D images of the TMJ and the surrounding structures in the axial, sagittal, and coronal planes that facilitates the evaluation of bone morphological features, articular space, position of the condyle within the fossa, joint space and its functions without superimposition of structures (2). It also helps to quantify the roof of the glenoid fossa and assist soft tissue around TMJ, thus avoiding the necessity of Magnetic Resonance Imaging (MRI). These benefits of CBCT has made it a better imaging modality for TMJ disorders.

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Implantology :

Replacement of missing tooth with implants requires an accurate assessment of the site and size of the implant to avoid any injury to the surrounding vital structures. 2D radiographs and specifically CT were used previously for assessing the implant site. However with the commencement of CBCT, it was considered as the ideal choice for evaluating the width, height and the density of the bone and also the size and orientation of the implant. CBCT provides better visualisation of the bucco-lingual alveolar ridge patterns, such as any irregularities, undulating concavities, narrow crestal, or knife-edge ridge and alveolar bone quality and quantity (3). Initially a surgical guide is prepared and placed at the site of proposed implant and is followed by CBCT examination. This provides a cross-sectional images in several planes that helps as an accurate guidance for placement of implant (Fig 1C). This paved a better way for proper diagnosis and treatment planning for implant placement which brought down the failure rate of implants with the advantage of low radiation exposure (4).

Endodontics :

CBCT has secured its position superior to the 2D imaging modalities in elucidating the periapical lesions better and also by establishing its position to areas such as maxillary sinus and mandibular canals. Additionally it helps to determine the extent and the content of the lesion. Recently CBCT is also used in the assessment of root canals, such as number of root canals, the morphology of roots and its associated roots specially in case of any second mesiobuccal canals (MB2). It helps to determine the working length, the type and angulation of root and further it helps to assess the obturation of the root canal treated tooth (5) (Fig 1D). Additionally CBCT is recommended for determining the source of the lesion or cysts, whether it is endodontic origin or non-endodontic origin, which helps for better treatment planning. Other important endodontic application of CBCT are detecting vertical root fractures, horizontal root fractures, better detection of internal or external root resorption in initial stage, locating any broken instruments inside or beyond the root canals etc (6).

Periodontics :

CBCT can be a reliable choice for assessing the furcation involvement, any buccal or lingual periodontal bone defects, fenestration, dehiscence, periodontal cysts and its extent compared to other 2D radiographs (7). CBCT also helps to assess the outcome of the regenerative periodontal therapy and bone defects precisely (Fig 1D). The advantage of CBCT in periodontics is that, it provides a precise measurements of the bony defects without superimposition of the periodontal structures and post-periodontal therapy assessment (8).

Figure 1 : (A) CBCT depicting condylar erosions in patient with TMJ arthralgia (9) (B) CBCT 3D assessment of alveolar bone width and height for implant placement (C) CBCT showing periodontal status with furcation involvement (10) (D) CBCT showing the cross sections of incomplete root canal treated mandibular second molar.

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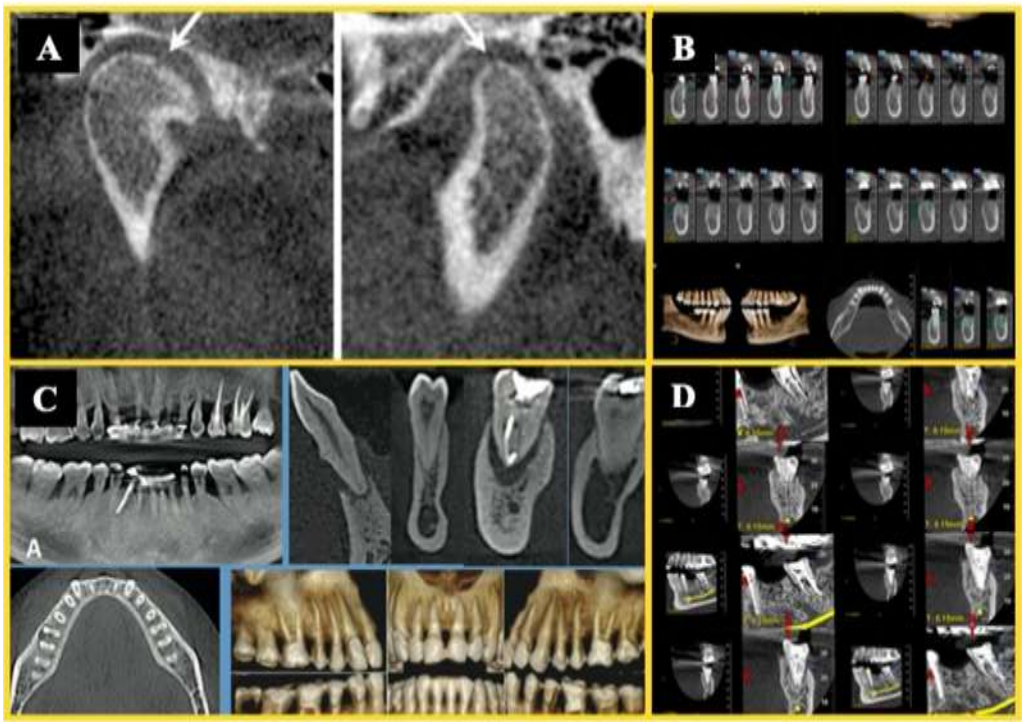
Figure - 1



Oral And Maxillofacial Surgery :

The main use of CBCT in maxillofacial surgery will be localisation of objects, such as assessment of position, angulation of impacted tooth and supernumerary tooth and its relation to the surrounding structures (Fig 2A and 2B). CBCT is considered to have a prime role in analysing the benign and malignant lesions of the oral and maxillofacial region, by evaluating the size, location, extent, any expansion and involvement of the surrounding structures due to the lesion (Fig 2C). It also helps to assess any fracture involving the maxillofacial region and its treatment planning (Fig 2D). Benign lesions of jaw may have diverse radiographic appearance that would assist the practitioners to arrive to a precise diagnosis and plan the management accordingly. One of the study comparing CBCT with conventional radiograph reported that the CBCT has a sensitivity of 89%–93% and specificity 60%–96.5% in detecting the destruction of bone in oral cancer (11). It reported that CBCT was in comparable with the MRI, CT and bone scintigraphy and its accuracy was more when compared to panoramic radiograph. In case of trauma, CBCT helps to identify any foreign object in the maxillofacial region that can be difficult to locate, sometimes even as an incidental finding. In salivary gland pathologies, CBCT can be used as a superimposition free imaging modality which has been reported to improve the sensitivity and specificity for diagnosis of salivary gland calculus, stenosis and dilatation of ductal system (12). Thus CBCT plays a major part for diagnosis and treatment planning and also for post-surgical review and management in the field of oral and maxillofacial surgery.

Figure 2 : (A) 3D assessment of impacted supernumerary tooth in relation to 11 and 21 (B) CBCT showing horizontally impacted lower third molars in relation to 38 and 48 and the associated structures (C) CBCT depicting Dentigerous cyst in relation to 36, 37, 38 (D) 3D visualisation of right parasymphysis fracture of mandible on CBCT scan-Panoramic view using CBCT.

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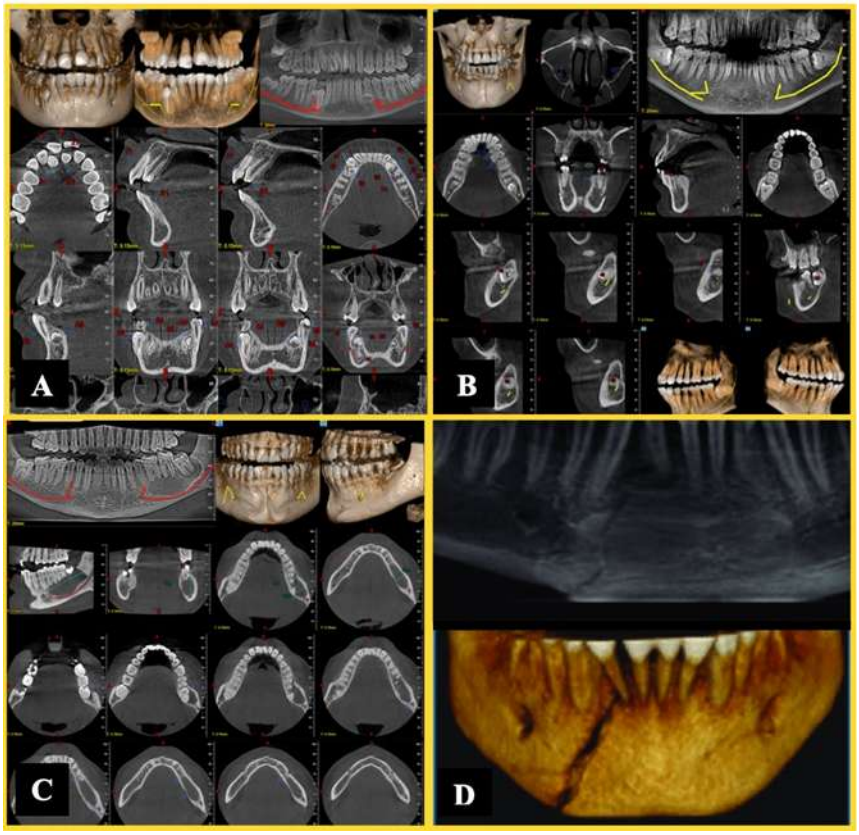
Figure - 2



Orthodontics :

Orthodontists usually use panoramic radiograph and lateral cephalometric imaging for the diagnosis and treatment planning for malocclusion. CBCT is primarily recommended in cases where the diagnostic information is not adequate with the 2D radiographs. CBCT in orthodontics is mainly used for complex dentofacial orthopaedic conditions that require evaluation in all 3 planes to measure the vertical, anterior-posterior and transverse dimensions. However other uses can be assessing palatal bone thickness, skeletal growth patterns, tooth movement in bucco- lingual direction, analysing the position of impacted teeth (Fig 3A). Inspite of these benefits, CBCT is still recommended in orthodontic patients only when there is selective indication based on the history of the patient and clinical examination since large Field of view (FOV) delivers more radiation than small Field of view (FOV). Compared to 2D imaging modalities, CBCT has an advantage of visualisation in 3 dimensions to assess tooth inclination, calculate torque and detailed information about the vital structures and soft tissue in the dentofacial region. Currently 3D illustration with CBCT images superimposed on model casts helps to analyse the illustrations of placement of temporary anchorage devices, its pre-treatment and post-treatment outcomes (Fig 3B). Consequently 3D printing with CAD-CAM can be used to fabricate orthodontic appliances and bring about greater precision in their outcome.

Forensic Odontology :

Estimating the age of living or deceased individual is the prime aspect of forensic odontology. Several methods of age estimation using tooth are reported in literatures among which examination of pulp space is a new emerging technique. CBCT provides a 3D view of the pulp, facilitating the estimation of size of the pulp chamber, height of pulp that helps to determine the age of an individual more accurately than any other radiograph. It also helps to analyse the secondary dentin changes with advancing age and measures the bucco-lingual and mesio-distal dimensions of tooth (13). Measuring the mesio-distal and bucco-lingual dimensions of tooth using CBCT helps in age estimation. Visualisation of individual cervical vertebrae for estimating skeletal age using CBCT has been reported in various literature. For sexual dimorphism, Osteometric assessment of

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mandible using CBCT, measures nine parameters such as ramps height, right and left coronoid height, lower jaw length, gonial angle, intergonial width, intercondylar width, mental and mandibular foramen. It shows that the score of these parameters are higher in males and low in females. In previous studies, based on mandibular morphology, the angle formed by intersection of lines from left and right gonion to menton was evaluated using CBCT for sexual determination which ranged from 129.9 ± 11.9 in males and 126.7 ± 12.6 in females (Fig 3C).

CBCT helps to measure the dimensions of paranasal sinus for sex determination where the dimensions are larger in males than females. In case of mastoid process, the length, width and height of mastoid process, inter-mastoid distance, distance between portion and mastoid where all found to be greater in males than females except the mastoid width. The inter-mastoid distance has more influence on sex determination among these variables. CBCT also provides accurate and reliable measurements of soft tissue thickness for specific landmarks of the face and scalp by producing 3-dimensional facial reconstruction images and photographic facial superimposition in less time, at low radiation exposure and it provides higher-quality images than spiral CT and other methods (14). Thus CBCT is currently used in forensic investigations for postmortem imaging and for imaging high-density metal projectiles mainly due to its small apparatus size, portability, low cost, and the reduction of metal artefacts on the images that it provides.

Figure 3 : (A) CBCT for orthodontic assessment of impacted canines (10) (B) 3D Superimposition of CBCT over Digital Models for evaluation of temporary anchorage device placement (C) 3- Dimensional facial reconstruction and photographic facial superimposition and assessment of angle and distance between gonion and menton using CBCT (15)

Figure - 3

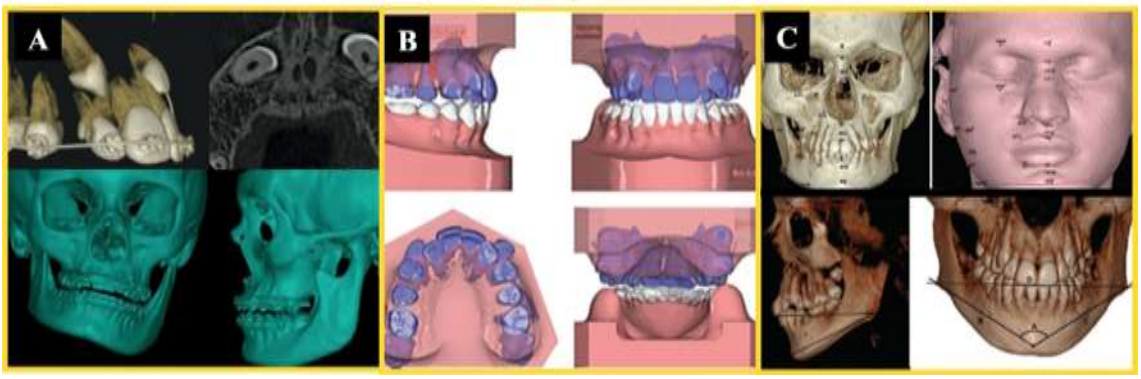

Table I. — Most frequent dental indications (based on 899 CBCT studies performed during 2 consecutive months in 2012) (16)

Presurgical implant planning	64%
Endodontics – periodontology	19.5%
Pre-operative screening (cardiac surgery etc.)	10%
Pre-operative wisdom teeth removal	4.5%

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Trauma	2%

Applications Beyond Oral Cavity :

Paranasal Sinus :

The first CBCT application beyond the oral cavity was the sinus imaging. Initially MDCT was replaced by conventional CT since the image in MDCT was very noisy at that low dose required for imaging and images was degraded by the metals artefacts (16). Later the conventional CT was replaced by CBCT again. Many studies reported that CBCT and MDCT helps to achieve an image at similar low dose and it was important since in cases such as inflammatory sinus conditions, any variation of paranasal sinus repeated imaging would be required. Hence although both have similar radiation dose, CBCT is recommended since it can produce a noise less image with same resolution in all 3 planes. Additionally knowledge on small FOV of CBCT would make it easier way to reduce the radiation dose. Other important indications can be evaluation of maxillary sinusitis and benign lesions of sinus. Various events that can lead to long standing chronic sinusitis are anatomic abnormalities, infections, immunity defects, allergies, and mucociliary transport disorders. Such events may cause changes in the morphology of the maxillary sinus which are sometimes noted as incidental findings.

There have been various incidental findings of paranasal sinus reported in many CBCT studies and also, any lesions in maxillary tooth extending to the sinus have also been reported in various literatures. CBCT in such cases, not only provides diagnostic information about the extension of periapical lesions into the maxillary sinuses (17), but also provides reliable details about the septa of the sinus, presence of exostoses, antral polyps, sino-nasal polyposis, required pre-surgical information when planning sinus floor augmentation, identify mucous retention phenomena and malignant tumours of the sinuses (Fig 4A). The only disadvantage is that assessment of soft tissue is substandard in CBCT. Hence patients with any malignant lesion are advised to take MRI for soft tissue evaluation.

Obstructive Sleep Apnea And Airway Analysis :

Obstructive sleep apnea (OSA) is a sleep-related breathing disorder that occurs as a function of increased collapsibility of the upper airway during sleep (18). Individuals suffering from OSA experience repetitive episodes of cessation of breathing (apnea) or partial upper airway obstruction (hypopnea). Lateral cephalometric radiography is the traditional method performed for imaging of the upper airway and associated dentofacial structures. However the upper airway can be visualized better with advanced imaging modalities such as magnetic resonance imaging (MRI), multidetector computed tomography (MDCT), and cone-beam CT (CBCT) scans. Some studies proposed that, better screening methods for OSA involve CBCT analysis of the airway since it is readily available to dentists and provides 10 times less ionizing radiation than does MDCT by means of its large, cone-shaped X-ray beam (19).

Software such as Anatomage Invivo 6 and Dolphin 3D allows 3D visualisation to determine the measurement of the total airway volume (cc) and measurement of the cross-sectional area (mm2) at any level of the airway and assess shape of the airway (Fig 4B) (20). The shape and size of the airway are mostly affected by the position of head, tongue, mandible, as well as breathing, and swallowing. There are various CBCT studies to support its role in the evaluation of airway and OSA diagnosis. Despite the benefits, CBCT imaging of the airway still has a skeptical overview because of the dynamic nature of human airway versus the static nature of CBCT scans (21).

American Association of Orthodontics task force on OSA and Orthodontics reported that, “CBCT provides no much information or spare information on the neuromuscular tone, susceptibility to collapse, or actual function of the airway” (18). Hence in future CBCT-airway studies on new innovative technology may be able to improve or track down the application of CBCT in airway analysis.

Nasal Septum Deviation :

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Nasal septal deviation (NSD) is improper alignment of the nasal septum from the midline. NSD is the most common deformity of the nose in humans (22). Various literatures reported that NSD occurs due to any trauma in life. It is also reported that NSD maybe related to sleep apnea, nasal bleeding, repeated sneezing, sinusitis for longer duration or breathing difficulties leading to forced breathing. Concha Bullosa (CB) also known as middle turbinate pneumatization or aerated turbinate, is a common anatomic variant in the nasal cavity and may occur unilaterally or bilaterally (23). The correlation between the presence of CB and contralateral NSD, though reported in different studies, and some believe that NSD or the presence of CB affect proper nasal airflow and cause sinonasal obstruction, and hence predispose to sinus disease (24) According to the severity of nasal septum deviation, partial or complete blockage of the respiratory passage may occur. CBCT became important radiographic modality in dentistry while in otolaryngology, the potential use of CBCT in their field is not yet fully explored. As incidental findings, various anatomical variations as well as pathologic conditions of nasal cavity are being reported with CBCT. Several CBCT studies have reported various types of NSD such as C-shaped septum deviation, S-shaped septum deviation etc out of which C-type can be most common type (Fig 4C). CBCT can thus be used for evaluation of nasal septum deviation and its treatment planning.

Dacryocystography :

The lacrimal duct extends from lacrimal punctum to the lower opening of the nasolacrimal duct along the lateral walls of the inferior nasal meatus. There are various cases of obstruction of this lacrimal ducts such as lacrimal canaliculus obstruction, nasolacrimal duct obstruction etc. (25) Dacryocystography (DCG), as a gold standard, is performed to demonstrate the obstructions and its level and to determine to their cause . However, DCG gives limited information only about the drainage lumen. Computed tomographic dacryocystography (CT-DCG) is reported to be a relatively safe and well-tolerated radiological technique which provides detailed imaging of the Lacrimal Drainage System (LDS) and its surrounding structures. (26) Recently CBCT is an established imaging modality, that produces images that are similar to conventional CT, which was initially developed for use during oral surgery. Later CBCT dacryocystography (CBCT- DCG) was introduced , which combines the technique of CBCT and dacryocystography, a new technique similar to CT-DCG (Fig 4D). It represents a reproducible, valid, and safe technique for the identification of sino-nasal anatomical structures and any obstruction thus being a valuable tool for demonstrating obstruction of the LDS. (25)

Figure 4 : (A) CBCT showing right maxillary sinusitis, left maxillary mucositis (B) 3D airway models using CBCT for airway analysis (29) (C) CBCT showing Normal nasal septum, C-shaped septum deviation, S-shaped septum deviation, Septal spur (28) (D) Dacryocystography using CBCT showing the lacrimal duct

(E)Various grades and Adenoid size in CBCT midsagittal slice and corresponding adenoid viewed with Nasoendoscopy.

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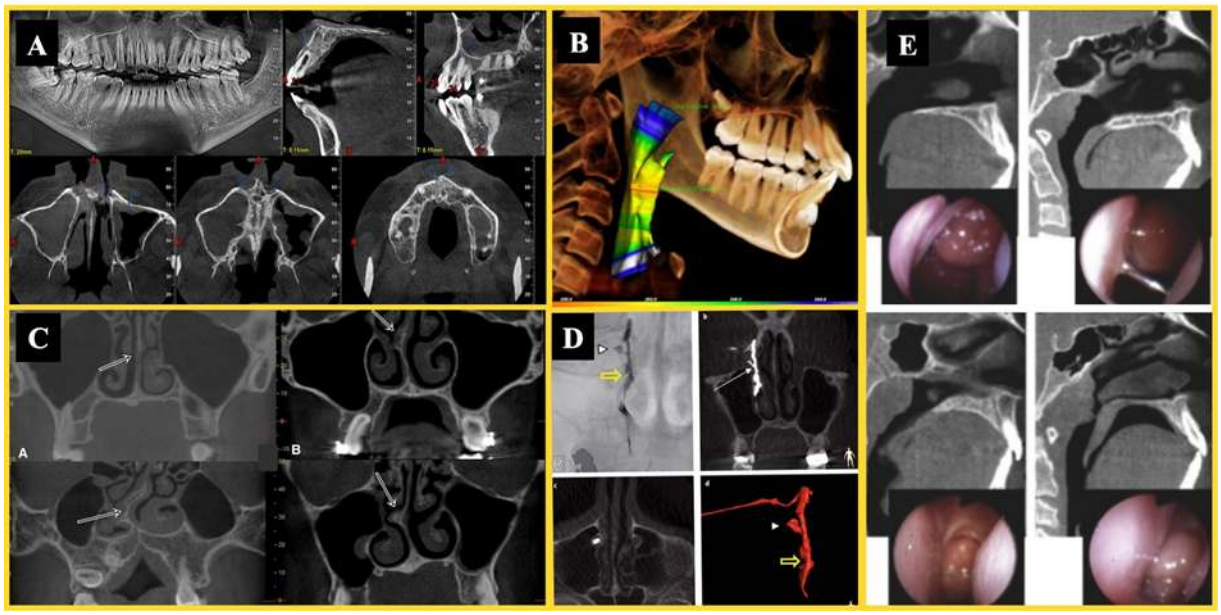
Figure - 4



Adenoids And Tonsils :

Pharyngeal tonsils constitutes a part of the nasopharyngeal airway which are a complex network of lymphatic tissues found in the posterior portion of oral cavity. Hypertrophy of such pharyngeal tonsil that are caused by chronic recurrent inflammatory reaction are also called as adenoids. In growing children, predisposing factors such as repeated infections or inflammation can lead to adenoid hypertrophy and constriction of the posterior airway (27). Adenoid hypertrophy is one of the common etiology of nasopharyngeal obstruction especially in children. This can be associated with mouth breathing habits and sleep disorders due to improper breathing patterns. Both of these habits are proposed to be a risk factor and on a long duration, these can lead to altered craniofacial growth like narrow maxillary arch, crossbite, long face height, anterior open bite, mandibular retrognathia etc. Sleep disordered breathing can also cause systemically illness affecting both physical and mental health. CBCT imaging is recommended for evaluating hypertrophic adenoids and tonsils (Fig 4E) by otolaryngologists along with nasoendoscopy for diagnosis and treatment of the condition collaboratively with orthodontist to treat if any malocclusion present.

Conclusion :

CBCT is currently used for a variety of purposes in both dental and non-dental field. In initial days, CBCT devices were dedicated mainly to implantology and dental imaging, but with advancing technologies CBCT applications now extended to the face and skull base as a whole. Depending on the field of view, the CBCT images may involve structures beyond oral cavity also. Moreover with software advancement, CBCT have rapidly ingressed in the fields beyond the oral cavity such as in otolaryngology and for somnology by assessing airway. Thus with technological evolution and new software development, CBCT proves to be a multi-bagger with its applications extending into various fields. Hopefully at some point CBCT may even entirely replace medical CT imaging in certain applications with promising future advancement of the device.

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