APPLICATION OF CBCT IN DENTAL IMAGING IN THE FIELD OF PROSTHODONTICS: A REVIEW

ABSTRACT

Cone Beam Computed Tomography (CBCT) is a sophisticated digital imaging method that enables the creation of multiplanar slices of a targeted area and the reconstruction of three-dimensional images of the structures using a cone-shaped rotating X-ray beam combined with mathematical algorithms[1,2]. The introduction of CBCT has greatly enhanced the ability to visualize the teeth, maxillofacial skeleton, and the spatial relationships between anatomical structures in three dimensions[3].

Introduction

The use of CBCT in dentistry is rapidly growing, driven by the rise in equipment manufacturers and wider adoption of this imaging technology. The field of view (FOV) defines the scan volume of a CBCT machine and depends on factors such as the detector's size and shape, beam projection geometry, and the machine's ability to collimate the beam—features that vary between manufacturers[4,5].

Beam collimation helps limit the patient's exposure to ionizing radiation by focusing only on the region of interest, allowing clinicians to select an appropriate FOV based on the case at hand. CBCT units are typically categorized as small, medium, or large volume depending on their FOV size. A major drawback of large FOV units is the extensive area exposed to radiation.

Additionally, unless the smallest voxel size is chosen on larger FOV machines, the image resolution is lower compared to intraoral radiographs or small FOV CBCT units, which naturally offer finer voxel sizes. Therefore, limiting the scan volume should be determined by the clinician's judgment according to each case[6].

For most dental implant procedures, a small or medium FOV is adequate to capture the area of interest[7]. Small volume CBCT machines are becoming increasingly popular as they offer several advantages over larger units:

1. Higher spatial resolution.
2. Reduced radiation exposure to the patient.
3. A smaller dataset to interpret.
4. Lower equipment cost.

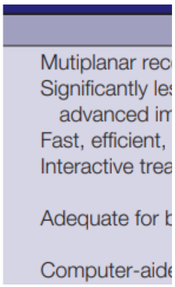

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TABLE 1: **ADVANTAGES AND LIMITATIONS OF CBCT**

COMPONENTS OF CBCT

- CBCT involves a rotational scan that moves through an angle greater than 180 degrees. It includes an X-ray source and a reciprocating detector that move in sync around the patient's head.
- During the rotation, multiple exposures are taken at fixed intervals, producing individual projection images known as **basis images**. The entire collection of these basis images is referred to as **projection data**[8,9].
- Flat-panel imaging uses an "indirect" detector to capture X-rays. This detector consists of a large-area solid-state sensor panel paired with an X-ray scintillator layer. The most common setup uses a cesium iodide scintillator mounted on a thin-film transistor made of amorphous silicon[10].

PRINCIPLES OF CBCT

- All CT scanners consist of an X-ray source and a detector mounted on a rotating gantry. The X-ray source passes through the object being examined, and as it travels through, its intensity is reduced by the tissues it encounters. As the gantry rotates, the remaining (attenuated) X-ray energy is captured by a sensor or film. In cone beam CT, the X-ray beam is uniquely shaped like a cone.

- The outcome of a CBCT scan is a series of images with defined slice thicknesses, creating a three-dimensional dataset[11]. A single scan can produce up to 1024 axial images. By compiling these images, we obtain a complete volume that can be reconstructed in any plane or axis as needed to study the anatomy. The final result is a true 3D image with multiplanar reconstruction, allowing examination from any chosen plane within the volume.

USES OF CBCT

- CBCT is highly useful for evaluating mid-facial and orbital fractures, including dentoalveolar fractures, as well as for post-fracture assessments. It allows for precise identification of the location and extent of pathologies such as odontogenic and non-odontogenic tumors, cysts of the jaws, and osteomyelitis[12].
- It plays a crucial role in assessing unerupted, impacted, or supernumerary teeth and their proximity to critical anatomical structures.
- CBCT provides multiplanar and potentially three-dimensional images of the condyle and surrounding tissues, facilitating analysis of the temporomandibular joint (TMJ), its function, and conditions such as asymmetry or planning for surgery[13].
- It enables detailed examination of the joint space and accurate positioning of the condyle, while also assisting in identifying soft tissues around the TMJ.
- Compared to 2D radiographs, CBCT offers superior visualization of buccal and lingual defects due to the absence of structural superimposition.
- It allows precise measurement of intra-bony defects and helps clinicians evaluate conditions like furcation involvement, dehiscence, fenestration, and cysts.

Size and Cost

- The size of CBCT machines has been significantly reduced by limiting the irradiated area through collimation of the primary X-ray beam, which also minimizes radiation exposure.
- Most CBCT units can be tailored to scan small, specific regions based on diagnostic needs. They are also more cost-effective, typically costing only one-fourth to one-fifth of conventional CT scanners[14,15].

Fast Acquisition or Rapid Scan Time

- Conventional CT scanners require multiple fan-beam rotations to capture images, whereas CBCT acquires all basis images in a single rotation. Scan times are much quicker, generally between 10 and 70 seconds, often under 30 seconds.

Image Accuracy or Sub-Millimeter Resolution

- CBCT offers voxel resolutions ranging from 0.4 mm to as low as 0.125 mm, which is highly advantageous for accurate diagnosis and treatment planning in maxillofacial cases[16].

Dose Reduction

- According to the 2005 International Committee on Radiation Protection, conventional CT systems have effective doses ranging from 1,320–3,324 μSv for the mandible and 1,031–1,420 μSv for the maxilla. In contrast, CBCT devices range from 52 to 1,025 μSv.
- CBCT can reduce radiation exposure by between 51% and 96% compared with conventional head CT scans, which typically range from 1,400 to 2,100 μSv[17].

Reduced Image Artifact

- Using manufacturer-developed artifact suppression algorithms and increasing the number of projections, CBCT images can achieve lower levels of metal artifacts, particularly in secondary reconstructions focused on the teeth and jaws.

Image Noise

- Noise arises from additional X-ray attenuation caused by nonlinear interactions, which degrade image quality.
- During CBCT imaging, scattered radiation is produced when a significant portion of photons undergo scattering interactions.
- The amount of scattered radiation correlates with the total mass of tissue within the primary X-ray beam and increases with larger object thickness and field size.
- In clinical settings, the scatter-to-primary ratios range from about 0.01 in single-ray CT to between 0.4 and 2 in CBCT.

Poor Soft Tissue Contrast

- Contrast, defined as the variation in transmitted X-ray intensities, measures differences between regions in the image.
- Several inherent artifacts in flat-panel detectors affect image linearity and response, including saturation (nonlinear pixel effects above certain exposures), dark current (charge accumulation over time), and defective pixels (unresponsive pixels).

- Like all imaging technologies, CBCT has limitations. It struggles to accurately depict soft tissue structures such as muscles, salivary glands, and lesions. It also lacks reliable correlation with Hounsfield units for bone density measurement and is susceptible to artifacts from metal restorations that can obscure anatomical details.
- To enhance soft tissue visualization, techniques like using a cotton roll or air to separate the lip from the vestibule have been successfully employed.

Software Applications

- Numerous third-party software packages are available to import and analyze CBCT data in DICOM format (Digital Imaging and Communication in Medicine).
- These software solutions vary in navigation ease, cost, available diagnostic tools, and implant planning capabilities.
- Advanced applications can significantly reduce scatter effects and artifacts, improving diagnostic accuracy and helping to overcome some of the inherent limitations of CBCT imaging[18,19].

CONE-BEAM COMPUTED TOMOGRAPHY IMPLANT PLANNING PROTOCOL

- Restrict the field of view to the dental arch being examined and the crowns of the opposing arch.
- Position the occlusal plane so that it is parallel to the horizon.
- Separate the maxillary and mandibular teeth using a thin layer of wax, and choose a small voxel size (0.20 mm or 0.25 mm). A smaller voxel size enhances the visualization of anatomical structures, such as the mandibular canal, especially in patients with low attenuation values[20].
- Scan stone models, impressions, or teeth using an intraoral laser scanner.
- Develop an image portfolio—a targeted collection of specific image views and anatomical renderings—to better visualize and communicate diagnostic goals and findings[21].

Steps to Create an Image Portfolio

- Display a reconstructed panoramic image at a slab thickness of approximately 15.0 mm to adequately show the alveolar process and teeth.
- Display another reconstructed panoramic image with a slab thickness of 1.0 mm or less, highlighting nerves on mandibular scans.
- Show cross-sectional slices for each proposed implant site. These slices, automatically generated by the software, should use a slice thickness of 1.0 mm and spacing of 1.0 or 2.0 mm[22].

- Create a multi-object 3D model of the planned implant sites.
- Optimal implant planning involves integrating all key anatomical information. Unlike conventional 2D imaging, CBCT provides high anatomical accuracy[23].
- Virtual modeling enables clinicians to collaborate with a multidisciplinary team to develop a single, comprehensive treatment plan.
- Utilizing a virtual environment offers an efficient and cost-effective approach to treatment planning. Limiting the CBCT scan area to regions of interest helps reduce radiation exposure.
- Thorough planning helps avoid nerve injury, jaw boundary perforations, and improper implant positioning near adjacent teeth, while also supporting proper alignment with prosthetic components—thereby improving the chances of successful treatment outcomes.

Creating a Surgical Guide: Step-by-Step Procedure[24,25]

Step 1 – Acquire CBCT and Intraoral Scans
Begin by obtaining a CBCT scan in DICOM format and an intraoral scan in STL format of the patient's teeth and surrounding structures.

Step 2 – Import Files into Planning Software
Import both the DICOM and STL files into dedicated dental planning software, such as BlueSky Plan. This software enables the integration of both datasets to build a detailed 3D model of the patient's oral anatomy.

Step 3 – Align and Merge the Data
Carefully align the STL file with the DICOM scan to ensure that the digital impressions of the teeth and soft tissues are accurately positioned within the 3D model of the jaw[25,26].

Step 4 – Identify Landmarks and Plan Implant Placement
Mark essential anatomical landmarks like nerves and sinus cavities to avoid complications. Plan the implant's location by considering factors such as bone density, available bone volume, and ideal implant angulation.

Step 5 – Design the Surgical Guide
Use the planning software to create a surgical guide that securely fits onto the patient's teeth or soft tissue. Make sure the implant sleeves are correctly aligned with the predetermined implant sites.

Step 6 – Export the Design
Once the design is complete, export the surgical guide as an STL file to be used by a 3D printer or milling device for manufacturing.

Step 7 – Fabricate the Guide

Produce the physical surgical guide using a 3D printer or milling station based on the exported STL file, ensuring precision and accuracy for the surgical procedure.

Conventional vs. CBCT-Guided Stent

- **Beretta et al.** highlighted that flapless, computer-assisted implant surgery offers clear benefits. This minimally invasive approach reduces surgical trauma and patient discomfort during the immediate postoperative period. Additionally, the use of computer guidance lowers the risk of intraoperative complications and supports optimal, prosthetically driven implant placement[27].

- **David et al.** reported that the survival rates for implants placed using computer-guided techniques are comparable to those placed conventionally, with success rates ranging from 91% to 100% over a follow-up period of 12 to 60 months[28].

- **Nickeing et al.** concluded that, based on assessments of implant position and axis, virtual planning with CBCT data and surgical guides results in highly accurate implant placement, significantly outperforming freehand techniques[29].

- **Kochar et al.** noted that implant location, size, angulation, and depth are carefully planned before surgery begins. This enables less invasive procedures without flap elevation, resulting in faster healing, quicker rehabilitation, reduced treatment time, and improved patient comfort—making it a favorable treatment option[30].

CONCLUSION

Virtual implant planning using CBCT data enables clinicians to design and preview the final outcome prior to starting treatment. CBCT scans offer high accuracy and cost efficiency, while also enhancing communication and collaboration among multidisciplinary teams to ensure the best clinical results.With virtual planning, clinicians can explore various treatment options and refine them until the most effective approach is identified. Once finalized, the optimized plan can be transformed into a surgical guide through modeling for practical use during the procedure.

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