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REVIEW ARTICLE

Radiation Dose Considerations in CBCT: Balancing Safety and Diagnostic Value

Jasmine Malhotra

ABSTRACT

CBCT has now developed to be a key imaging modality in the field of dentistry and maxillofacial view, providing 3 dimensional visualization with a lot of diagnostic utility. Nevertheless, the radiation dose is of concern and this poses serious safety issues especially to the pediatric populations and vulnerable populations. The paper will evaluate existing evidence on CBCT radiation dose level, compare with the existing radiographic and medical CT protocols, and identify factors that affect exposure to patients. Dose optimization strategies, including customized field of view (FOV), customized exposure parameters and application of advanced image reconstruction methods, are discussed in the context of ALARA (As Low As Reasonably Achievable) and ALADAIP (As Low As Diagnostically Acceptable is Indication-oriented and Patient-specific) principles. The main clinical guidelines used by the major international entities are addressed to facilitate the practice-based risk-benefit decision-making. Prospective opportunities, such as the use of AI to optimise imaging and protocols tailored to patients are also discussed. CBCT imaging should be balanced to guarantee the efficacy of the diagnosis and keep the patients safe.

Keywords: Cone Beam Computed Tomography, Radiation Dose, Patient Safety, ALARA, ALADAIP, Diagnostic Value, Dose OptimizationIndian J. Pharm. Biol. Res. (2022): https://doi.org/10.30750/ijpbr.10.4.03

INTRODUCTION

Cone Beam Computed Tomography (CBCT) has revolutionized dental and maxillofacial imaging by offering high-resolution, three-dimensional images with comparably less radiation dose of a conventional medical CT scan (Singh, 2018; Lurie, 2019). The ease with which it is used in implantology, endodontics, orthodontics, and oral surgery demonstrates its diagnostic strength, especially in instances where standard two-dimensional radiographs fail to provide the required information (Hartshorne, 2018; Singh, 2019). Although these advantages are presented in the case, the issue of radiation exposure is in the center of attention, and one must strike a balance between the diagnostic value and patient safety.

The effective radiation dose from CBCT varies widely depending on factors such as field of view (FOV), exposure parameters, voxel size, and patient positioning (Ludlow, 2009; Sykes et al., 2013). While smaller FOVs and optimized protocols significantly reduce exposure, inappropriate or unjustified use of CBCT can subject patients to unnecessary risks (Pauwels & Scarfe, 2017; McGuigan, Duncan, & Horner, 2018). These risks are particularly critical in pediatric patients, who demonstrate greater tissue radiosensitivity and longer lifetime risk of radiation-induced effects (Hess et al., 2016).

To guide responsible use, international principles such as ALARA (“As Low As Reasonably Achievable”) and ALADAIP (“As Low As Diagnostically Acceptable, being Indication-oriented and Patient-specific”) have been emphasized to ensure imaging is justified, optimized, and tailored to the clinical scenario (Nagi, 2021; Ordóñez-Sanz et al., 2021). These frameworks highlight the ethical responsibility of practitioners to weigh diagnostic benefits against potential long-term harm (Van Dyk, Battista, & Bauman, 2013).

Recent technological advancements including AI-assisted imaging optimization, improved detectors, and iterative reconstruction algorithms show promise in further reducing dose while preserving or enhancing diagnostic

B.D.S, M.D.S, Periodontics

Corresponding Author: Jasmine Malhotra, B.D.S, M.D.S, Periodontics. E-Mail: jmjasminemalhotra@gmail.com

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Table 1: Comparison of Risks and Benefits of CBCT in Dental and Maxillofacial Imaging

Domain	Benefits (Diagnostic Value)	Risks (Radiation & Safety)	Key References
Implant Dentistry	Accurate 3D assessment of bone dimensions, nerve mapping, improved treatment planning	Higher radiation compared to panoramic radiography	Hartshorne (2018), Lurie (2019)
Endodontics	Detection of root canal morphology, periapical pathology, and treatment planning accuracy	Dose higher than intraoral radiographs; must be justified	Singh (2018), Singh (2022)
Orthodontics	Comprehensive craniofacial assessment, airway evaluation, growth monitoring	Increased exposure in children and adolescents	Ludlow (2009), Hess et al. (2016)
Maxillofacial Pathology	Identification of cysts, tumors, fractures with higher sensitivity	Requires careful justification due to dose accumulation	Pauwels & Scarfe (2017), McGuigan et al. (2018)
General Use	Reduced diagnostic uncertainty, improved medico-legal defensibility	Overuse concerns; risks amplified in pediatric patients	Nagi (2021), Sykes et al. (2013)

quality (Singh, 2022; Chandra et al., 2021). However, appropriate training, adherence to guidelines, and patient-centered risk communication remain essential for safe implementation (Hartshorne, 2018; Lurie, 2019).

This paper examines radiation dose considerations in CBCT with emphasis on balancing safety and diagnostic value. It discusses dose levels, optimization strategies, clinical guidelines, and future directions, aiming to provide a framework for evidence-based and ethically responsible imaging practice.

Radiation Dose in CBCT

Cone Beam Computed Tomography (CBCT) delivers three-dimensional imaging with significantly lower radiation exposure compared to conventional medical CT, yet higher than most conventional dental radiographic modalities (Ludlow, 2009; Lurie, 2019). The effective radiation dose from CBCT varies considerably depending on technical and patient-related factors, including field of view (FOV), voxel size, tube current (mA), tube voltage (kVp), exposure time, and patient positioning (Hartshorne, 2018; McGuigan, Duncan, & Horner, 2018). Small FOV protocols and optimized exposure parameters can reduce patient dose by more than 50% without compromising diagnostic efficacy (Pauwels & Scarfe, 2017; Nagi, 2021).

Compared with conventional periapical or panoramic imaging, CBCT typically results in higher patient exposure, though the actual dose depends heavily on equipment and protocol. For example, effective doses for dental CBCT range from approximately 19 µSv to over 600 µSv, whereas panoramic radiographs average 14–24 µSv (Ludlow, 2009; Sykes et al., 2013). While these values are substantially lower than medical CT scans of the maxillofacial region (which may exceed 2,000 µSv), they remain a concern, particularly in pediatric populations where tissue radiosensitivity and cumulative lifetime risk are higher (Hess et al., 2016; Hartshorne, 2018).

Radiation risk must therefore be contextualized within the diagnostic value gained. CBCT offers superior detection of root fractures, complex anatomy, bone morphology, and treatment planning for implantology, orthodontics, and endodontics (Singh, 2018; Chandra et al., 2021). However, unjustified or repeated CBCT scans can result in unnecessary dose accumulation (Van Dyk, Battista, & Bauman, 2013). Consequently, adherence to the ALARA (As Low As Reasonably Achievable) and ALADAIP (As Low As Diagnostically Acceptable being Indication-oriented and Patient-specific) principles is strongly recommended (Nagi, 2021; Ordóñez-Sanz et al., 2021).

Recent advances such as dose-reduction algorithms, iterative image reconstruction, and artificial intelligence (AI)-based optimization are being increasingly integrated into CBCT systems to minimize exposure while preserving image quality (Singh, 2022; Ordóñez-Sanz et al., 2021). These developments reinforce the clinical imperative to balance radiation safety with diagnostic accuracy, ensuring CBCT is used judiciously and only when it provides a clear

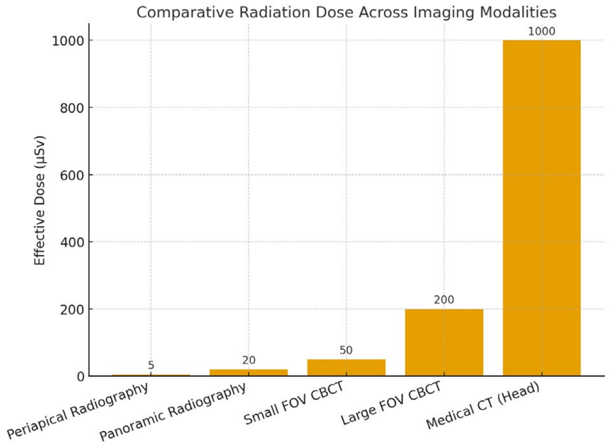

Fig 1: The comparative radiation dose graph shows effective dose levels (µSv) across different imaging modalities, highlighting the impact of optimized CBCT protocols versus larger FOV CBCT and medical CT.

benefit over lower-dose alternatives.

Risk–Benefit Assessment

The adoption of Cone Beam Computed Tomography (CBCT) in dental and maxillofacial practice has transformed diagnostic capabilities, offering detailed three-dimensional visualization and improved treatment planning. However, the use of CBCT also introduces concerns regarding radiation dose, patient safety, and justification of exposure, particularly in vulnerable populations such as children and young adults (Hess et al., 2016; Ludlow, 2009).

Diagnostic Benefits

CBCT provides superior spatial resolution compared to conventional two-dimensional radiography, allowing accurate assessment of bone quality, root canal morphology, implant placement, and pathology localization (Singh, 2018; Hartshorne, 2018). It also reduces diagnostic uncertainty, which in turn can lower the risk of treatment failures and medico-legal implications (Lurie, 2019). In endodontics and implantology, CBCT is frequently justified due to its capacity to detect periapical lesions and measure anatomical structures precisely (Singh, 2022).

Radiation Risks

Despite lower radiation doses than conventional medical CT, CBCT still imparts higher effective doses than intraoral or panoramic radiographs (McGuigan, Duncan & Horner, 2018; Pauwels & Scarfe, 2017). Factors such as field of view (FOV), voxel size, exposure settings, and patient positioning significantly influence dose outcomes (Sykes et al., 2013). Children are particularly at risk due to their increased radiosensitivity and longer life expectancy for radiation effects to manifest (Hess et al., 2016).

Balancing Safety and Diagnostic Value

Professional guidelines emphasize the ALARA (As Low As Reasonably Achievable) and ALADAIP (As Low As Diagnostically Acceptable being Indication-oriented and Patient-specific) principles, requiring CBCT to be used only when the expected diagnostic or therapeutic gain outweighs the radiation risk (Nagi, 2021; Hartshorne, 2018). Advances such as iterative reconstruction algorithms, patient-specific exposure protocols, and AI-driven optimization are expected to further refine this balance (Ordóñez-Sanz et al., 2021; Singh, 2022).

CBCT offers significant diagnostic advantages but must be carefully justified against its radiation risks. Clinicians are urged to adopt evidence-based protocols, select the smallest effective FOV, and tailor scan parameters to individual patients. By integrating technological advances with strict adherence to ALARA and ALADAIP principles, practitioners can achieve an optimal balance between safety and diagnostic efficacy.

Dose Optimization Strategies

Radiation dose optimization in Cone Beam Computed Tomography (CBCT) is essential to ensure diagnostic efficacy while minimizing unnecessary patient exposure. A balanced approach, guided by the principles of ALARA (As Low As Reasonably Achievable) and ALADAIP (As Low As Diagnostically Acceptable being Indication-oriented and Patient-specific), requires careful adjustment of technical, clinical, and patient-related factors (Nagi, 2021; Pauwels & Scarfe, 2017).

One of the most effective strategies is limiting the field of view (FOV) to the smallest region necessary for diagnosis. Smaller FOVs not only reduce dose but also improve image sharpness by minimizing scatter (Ludlow, 2009; Hartshorne, 2018). Adjusting exposure parameters, such as tube voltage (kVp), current (mA), and exposure time, is equally critical. Evidence shows that lowering kVp and mA can significantly reduce radiation burden while still providing diagnostically acceptable images when tailored to the clinical task (McGuigan, Duncan, & Horner, 2018; Sykes et al., 2013).

Voxel size selection also influences optimization. Larger voxels, though offering slightly less resolution, may be adequate for many diagnostic purposes and deliver substantially lower doses compared to small voxel scans used unnecessarily (Lurie, 2019). Furthermore, patient positioning accuracy prevents repeat exposures, underscoring the importance of operator training and adherence to standardized protocols (Singh, 2018; Van Dyk, Battista, & Bauman, 2013).

Emerging dose reduction strategies include iterative reconstruction algorithms and AI-based noise reduction techniques, which allow for lower-dose acquisitions without compromising diagnostic integrity (Ordóñez-Sanz et al., 2021; Singh, 2022). Such technologies are particularly valuable in pediatric imaging, where patients are more radiosensitive and long-term risks are heightened (Hess et al., 2016).

Collectively, dose optimization requires a multifactorial approach balancing technological capabilities, operator expertise, and patient-specific considerations. Clinicians must continuously justify each scan, apply tailored protocols, and integrate evolving innovations to uphold both patient safety and diagnostic value (Chandra et al., 2021; Makkar et al., 2016).

CLINICAL GUIDELINES AND RECOMMENDATIONS

The safe and effective use of Cone Beam Computed Tomography (CBCT) requires balancing diagnostic benefits against radiation risks. Clinical decision-making must always follow the principles of justification, optimization, and dose limitation, consistent with ALARA (As Low As Reasonably Achievable) and ALADAIP (As Low As Diagnostically Acceptable being Indication-oriented and Patient-specific) frameworks (Nagi, 2021; Hartshorne, 2018).

Table 2. Comparative Overview of Major Guidelines and Recommendations on CBCT Radiation Dose

Aspect	Key Guideline/Recommendation	References
Justification	Use CBCT only when conventional imaging is insufficient; mandatory justification for pediatric cases.	Lurie (2019); Singh (2018); Hess et al. (2016)
Field of View (FOV)	Select the smallest FOV consistent with diagnostic need; avoid large scans for localized conditions.	Ludlow (2009); Pauwels & Scarfe (2017)
Dose Optimization	Adjust voxel size, exposure parameters (kVp, mA), and scan time to minimize exposure without compromising diagnostic quality.	McGuigan et al. (2018); Nagi (2021)
Pediatric Protocols	Apply the lowest dose possible; use child-specific preset protocols and dose-reduction technologies.	Hess et al. (2016); Ordóñez-Sanz et al. (2021)
Technological Advances	Use AI, iterative reconstruction, and software-based enhancements to maintain image quality at reduced doses.	Singh (2022); Van Dyk et al. (2013)
Training & Ethics	Ensure clinicians are trained in radiation protection; adhere to ethical and medico-legal obligations in CBCT prescribing.	Hartshorne (2018); Sykes et al. (2013)
Risk Communication	Patients must be counseled regarding risks, benefits, and alternatives to CBCT before exposure.	Hartshorne (2018); Van Dyk et al. (2013)

Key Recommendations

Justification of Use

- CBCT should only be prescribed when conventional radiography fails to provide sufficient diagnostic information (Lurie, 2019; Singh, 2018).
- Pediatric and adolescent patients require heightened justification due to increased radiosensitivity (Hess et al., 2016).

Dose Optimization

- Tailor field of view (FOV), voxel size, kVp, and mA to the diagnostic task (McGuigan et al., 2018).
- Use small FOV for localized assessments (endodontics, implant site evaluation) to reduce unnecessary exposure (Ludlow, 2009; Pauwels & Scarfe, 2017)

Patient-Specific Protocols

- Adjust scanning protocols based on patient size, age, and clinical indication (Sykes et al., 2013; Ordóñez-Sanz et al., 2021).
- Children should be imaged using lowest possible exposure settings, with image enhancement software compensating for quality loss (Hess et al., 2016).

Technology and AI Integration

Employ dose-reduction technologies such as iterative reconstruction and AI-based algorithms for improved diagnostic value at lower exposures (Singh, 2022).

Practitioner and Patient Education

- Training clinicians in radiation safety, medico-legal considerations, and patient communication is essential (Hartshorne, 2018).
- Patients should be informed about benefits, risks, and alternatives to CBCT imaging (Van Dyk et al., 2013).

In summary, the adoption of CBCT should follow a justified, patient-centered, and technology-assisted framework, ensuring diagnostic value while minimizing unnecessary exposure. The integration of AI, patient-specific protocols, and adherence to international safety standards represent the way forward in clinical practice.

CONCLUSION

Cone Beam Computed Tomography (CBCT) has become an indispensable imaging modality in dentistry and maxillofacial diagnostics, offering superior three-dimensional visualization and improved treatment planning across disciplines such as implantology, endodontics, and orthodontics (Singh, 2018; Hartshorne, 2018). However, its advantages must be weighed carefully against radiation dose considerations, especially when compared with conventional radiography and multislice CT (Ludlow, 2009; Lurie, 2019). While CBCT generally delivers lower doses than medical CT, inappropriate use, large fields of view, or repeated exposures can significantly increase patient risk (Sykes et al., 2013; Pauwels & Scarfe, 2017).

The principle of justification remains paramount: CBCT should only be prescribed when conventional imaging cannot provide sufficient diagnostic information (Nagi, 2021; McGuigan, Duncan, & Horner, 2018). Adherence to optimization frameworks such as ALARA and ALADAIP ensures that radiation exposure is minimized without compromising diagnostic quality (Hartshorne, 2018; Ordóñez-Sanz et al., 2021). Effective dose reduction can be achieved by tailoring field of view (FOV), voxel size, and exposure parameters to the clinical indication and patient's age, with pediatric patients requiring particular caution due to their heightened radiosensitivity (Hess et al., 2016).

Emerging technologies, including AI-driven reconstruction and patient-specific imaging protocols, present promising avenues for further dose reduction while enhancing image quality (Singh, 2022; Van Dyk, Battista, & Bauman, 2013). As highlighted in recent literature, the future of CBCT lies in balancing diagnostic value with patient safety through a combination of evidence-based guidelines, practitioner training, and patient-centered decision-making (Lurie, 2019; Nagi, 2021).

Ultimately, responsible utilization of CBCT requires a commitment to ethical imaging practices, careful dose optimization, and continual integration of technological advances. By doing so, clinicians can maximize the diagnostic potential of CBCT while upholding the highest standards of patient safety (Hartshorne, 2018; Pauwels & Scarfe, 2017).

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