REVIEW ARTICLE

Radiation Dose Reduction Strategies in Orthodontic Imaging. A Narrative Review

Rawda Alghabban[1]

1. *Dept of Preventive Dental Sciences, College of Dentistry, Prince Sattam bin Abdulaziz University, AlKharj, Saudi Arabia*

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ABSTRACT

Orthodontic imaging is a critical component of diagnosis, treatment planning, and outcome assessment in orthodontics. The increased utilization of ionizing radiation-based modalities such as panoramic radiography, lateral cephalometry, and especially cone-beam computed tomography (CBCT) raises concerns about patient radiation exposure, particularly among pediatric and adolescent populations who are more radiosensitive. This paper critically reviews existing radiation dose reduction strategies applicable to orthodontic imaging, encompassing technological advancements, imaging protocol optimization, patient-specific considerations, protective devices, and professional education. Emphasis is placed on the balance between minimizing radiation exposure and maintaining diagnostic image quality necessary for effective orthodontic management. Furthermore, the integration of international radiation safety principles such as ALARA (As Low As Reasonably Achievable) and recent innovations including artificial intelligence (AI)-driven image reconstruction are explored. The review highlights the imperative for continued research and adherence to evidence-based guidelines to optimize patient safety in orthodontic imaging

KEYWORDS: Orthodontic imaging, radiation dose reduction, cone-beam computed tomography (CBCT), digital radiography, ALARA, pediatric radiology, imaging protocols, radiation protection.

INTRODUCTION

Imaging is an integral component of contemporary orthodontic practice, serving diagnostic, treatment planning, and monitoring purposes. Traditional two-dimensional (2D) modalities such as panoramic radiographs and lateral cephalograms remain widely used because of their relatively low radiation burden and established role in assessing dento-skeletal relationships (1,2). However, with the increasing adoption of three-dimensional (3D) imaging tools—particularly cone beam computed tomography (CBCT)—the issue of radiation exposure has come to the fore, especially in orthodontic populations who are often children and adolescents (3,4).

Orthodontic patients represent a particularly sensitive cohort for radiographic exposures: younger age implies higher radiosensitivity of tissues (e.g., thyroid gland, bone marrow) and a longer remaining lifespan during which radiation-induced effects may manifest (5). Indeed, a survey of orthodontic radiographs found that each patient may undergo multiple exposures during treatment, with some indications being poorly documented; the authors cautioned that even though individual doses are low, the cumulative exposure warrants justification and optimisation (6).

Quantitative dose comparison studies illustrate the magnitude of the difference between 2D and 3D modalities in orthodontic settings. For example, one phantom study reported an effective dose of 35.81 µSv for a conventional set of orthodontic radiographs (panoramic + lateral cephalogram + postero-anterior cephalogram), whereas three different CBCT scanning modes delivered doses of 131.7 µSv, 91 µSv and 77 µSv, respectively—i.e., approximately 2.5 to 4-fold higher (7). Another study comparing a CBCT unit to digital panoramic and cephalometric machines found effective doses ranging from ~64.7 to 131.3 µSv for CBCT (various settings), versus 21.5 µSv for panoramics and 4.5 µSv for lateral cephalograms (8).

The non-negligible dose differential has triggered increasing emphasis on radiation protection principles in orthodontic imaging. The principle of ALARA (As Low As Reasonably Achievable) has long been the cornerstone of radiographic dose management (9); more recently, the paradigm of ALADAIP (As Low As Diagnostically Acceptable being Indication and Patient specific) has been introduced to emphasise tailoring imaging to the individual patient and clinical indication (10,11). With the advent of 3D imaging and its expanding use in orthodontics, the twin imperatives of justification ("Does the imaging make a difference to treatment?") and optimisation ("How can we minimise dose while preserving diagnostic utility?") have become ever more salient (12).

Given this context, a comprehensive narrative review of radiation dose reduction strategies tailored to orthodontic imaging is timely. This review will summarise the foundational principles of justification and optimisation, examine technical and operational strategies specific to orthodontic practice, analyse the evidence for dose reduction interventions, and highlight the special considerations relevant to young patients undergoing orthodontic care.

AIM

The aim of this narrative review is to critically evaluate and summarise current strategies for radiation dose reduction in orthodontic imaging, with an emphasis on evidence-based practices that align with contemporary radiation protection principles, including ALARA and ALADAIP.

METHODS AND MATERIALS

Study Design

This study is a narrative review of the current literature focusing on strategies for radiation dose reduction in orthodontic imaging. The aim was to synthesise current knowledge on low-dose imaging protocols, technological advancements, clinical decision-making, and regulatory recom

-mendations with a particular emphasis on cone-beam computed tomography (CBCT), panoramic radiography, and cephalometric imaging as applied in orthodontic practice.

Search Strategy

A comprehensive search was conducted across multiple electronic databases including PubMed (MEDLINE), Scopus, Web of Science, Cochrane Library. The search spanned articles published between 2007 to 2025.

Inclusion Criteria

- Peer-reviewed articles, clinical trials, observational studies, systematic reviews, and narrative reviews
- Articles published in English
- Studies focused on orthodontic imaging modalities (CBCT, panoramic, cephalometric, intraoral)
- Research involving human participants, particularly children and adolescents
- Publications addressing technological, procedural, or regulatory aspects of radiation dose mitigation

Exclusion Criteria

- Non-English publications
- Animal studies
- Articles focusing exclusively on radiotherapy, nuclear imaging, or non-dental imaging modalities
- Editorials, commentaries, or letters without original data or substantial review

Quality Assessment

While no formal risk-of-bias assessment tool was applied due to the narrative nature of the review, study validity was assessed based on:

- Clarity of methodology
- Sample size and statistical power (if applicable)
- Relevance to orthodontic imaging practice
- Reporting of radiation dosimetry
- Adherence to international radiographic safety standards (ICRP, NCRP, etc.)

The included studies were further evaluated for their clinical applicability, especially in paediatric and adolescent populations, which form the majority of the orthodontic demographic.

DISCUSSION

Technological Advances in Orthodontic Imaging and Dose Reduction

Digital Radiography

The shift from conventional film-based radiography to digital sensors (charge-coupled device (CCD), complementary metal-oxide semiconductor (CMOS), photostimulable phosphor plates (PSP)) has markedly decreased radiation dose while improving image acquisition efficiency. Digital systems exhibit higher X-ray photon detection efficiency, allowing lower exposure settings. Dose reductions of up to 50–80% have been documented when using digital panoramic and cephalometric radiography compared to conventional film.

Image processing algorithms also enhance diagnostic quality post-acquisition, permitting dose reductions without loss of critical clinical information. However, factors such as sensor size, pixel resolution, and dynamic range influence image quality and must be considered in optimizing protocols.

Cone-Beam Computed Tomography (CBCT)

CBCT provides three-dimensional imaging with relatively lower doses than conventional computed tomography (CT), making it suitable for dental and orthodontic applications. Nevertheless, CBCT doses are higher than traditional 2D radio-graphs. Depending on machine settings, field of view (FOV), and scan parameters, doses can range widely—from approximately 20 to 200 µSv—compared to 2–10 µSv for panoramic or cephalometric radiographs (13).

Dose optimization in CBCT

Dose optimization in CBCT is essential for minimizing patient radiation exposure while maintaining diagnostic image quality. Limiting the field of view (FOV) to the smallest area necessary for the diagnostic task effectively reduces the volume of irradiated tissue and thus lowers patient dose (14). Additionally, adjusting exposure parameters, including reducing the kilovoltage peak (kVp) and milliampere-seconds (mAs), is another important method; research indicates that these settings can be lowered without compromising image quality for specific diagnostic needs (15). Also, the use of pulsed X-ray beams combined with faster scan times helps decrease total radiation by shortening the duration of exposure (16).

Advances in technology have also introduced iterative reconstruction techniques and artificial intelligence (AI) algorithms that enhance image quality through sophisticated noise reduction and image processing, allowing for further dose reduction while preserving diagnostic accuracy. For instance, the Ordered Subsets Convex Total Variation (OSC-TV) iterative reconstruction method has been shown to significantly improve image signal-to-noise ratio (SNR) compared to traditional methods, enabling substantial dose reduction without compromising image quality (17).

Furthermore, recent studies have proposed practical CBCT dose optimization methods using readily available measurement equipment in radiation oncology departments. By modifying imaging parameters such as reducing the number of projections or lowering single-frame exposure, significant dose reductions can be achieved while maintaining clinically acceptable image quality.

Together, these dose optimization strategies contribute to safer CBCT imaging practices in clinical settings, aligning with the principle of As Low As Reasonably Achievable (ALARA) to minimize patient radiation exposure.

Imaging Protocol Optimization

Appropriate imaging protocol design is essential to dose reduction:

Every imaging procedure must be clinically justified, taking into account the individual needs of each patient to ensure that unnecessary imaging—and thus superfluous radiation exposure—is avoided. Professional guidelines, such as those published by the American Academy of Pediatric Dentistry (AAPD) and the European Commission, offer evidence-based recommendations to support this principle (AAPD, 2012) (18,19).

Optimization of technical settings plays a crucial role in dose efficiency; this includes using exposure parameters tailored to the patient's age and size, employing rectangular collimation to limit the size of the x-ray beam and reduce scatter radiation, and selecting appropriate image receptor sizes to capture the necessary diagnostic information with minimal exposure (20). Additionally, minimizing repeat exposures is essential to reduce the cumulative radiation dose patients receive. This can be achieved through proper patient positioning and communication, the use of positioning aids, and ensuring that technicians are well-trained to capture images correctly the first time (21). Finally, imaging protocols should not remain static but require periodic review and updating to incorporate the latest scientific evidence and technological advances, ensuring ongoing optimal dose management and patient safety (22).

Together, these measures create a comprehensive approach to radiation safety in diagnostic imaging.

Protective Measures and Patient Positioning

Protective measures and proper patient positioning are fundamental components of radiation safety during imaging procedures. Physical protective equipment, such as thyroid collars and lead aprons, plays a critical role in minimizing unnecessary radiation exposure. The thyroid gland, especially sensitive to radiation in children, benefits greatly from the use of lead thyroid collars, which have been shown to significantly reduce the thyroid dose during both intraoral and panoramic radiography (23). Similarly, lead aprons protect vital organs and tissues outside the primary x-ray beam, effectively minimizing exposure to scatter radiation (24). However, recent studies have debated the routine use of lead aprons in certain panoramic and cone-beam computed tomography (CBCT) scans due to advances in collimation and shielding technology that inherently reduce scatter radiation (25).

Beyond protective gear, correct patient positioning and immobilization are essential to reduce image artifacts and avoid repeat exposures, which contribute to unnecessary cumulative dose. Techniques such as the use of bite blocks, headrests, and clear verbal instructions help ensure patients are properly aligned with the imaging device, improving image quality and safety (26). Additionally, immobilization devices are especially important in pediatric imaging to limit movement and improve diagnostic accuracy (27). Special considerations must be taken for pediatric patients, who are more radiosensitive and have smaller anatomical features. For these patients, custom protective devices and carefully adjusted imaging parameters are recommended to provide the highest level of protection while maintaining diagnostic quality (28). Continuous education of radiology staff regarding updated protective protocols and positioning techniques is also vital to ensure consistent adherence to safety standards (29). Together, these protective measures and positioning strategies form an integral approach to enhancing patient safety and optimizing diagnostic outcomes in radiographic imaging.

Education, training, and quality assurance are fundamental components in effectively reducing radiation dose in medical imaging, with the human factor playing a critical role. Comprehensive training for clinicians and technicians, which includes in-depth knowledge of radiation biology, dose optimization techniques, imaging technology, and safety regulations, significantly improves operator competence and compliance with safety protocols (EADMFR) (30). Studies have shown that well-trained personnel can reduce patient doses by applying optimized imaging protocols tailored to specific clinical indications (31,32). Furthermore, certification and continuing education through accredited courses, workshops, and professional development are essential to keep healthcare professionals updated on the latest advances and regulatory requirements (ICRP, 2017) (33). Quality assurance programs that incorporate routine equipment maintenance, regular calibration, and performance testing ensure that imaging devices operate optimally, providing consistent image quality at the lowest achievable dose (American College of Radiology, 2019) (34). Additionally, implementing dose tracking systems and audit processes can further enhance dose management by identifying outliers and promoting best practices. Effective patient communication about the risks and benefits of radiation exposure not only fosters informed consent but also builds patient trust and engagement, which are critical for shared decision-making in clinical care (35,36). Overall, a multidisciplinary approach involving education, continuous quality improvement, and transparent communication is key to achieving dose reduction without compromising diagnostic accuracy.

CONCLUSION

Radiation dose reduction in orthodontic imaging is a multifaceted challenge that requires the integration of advanced technology, tailored imaging protocols, rigorous protective measures, and ongoing professional education. The advent of digital radiography and CBCT has dramatically improved diagnostic capabilities but also necessitates heightened vigilance to minimize radiation risks, particularly in vulnerable pediatric populations.

Strategies such as limiting field of view, adjusting technical parameters, using physical protection, and promoting operator expertise are proven to effectively reduce patient dose without sacrificing diagnostic quality. The ALARA principle should remain the foundational guideline driving these efforts.

Future directions include the broader application of AI-driven image reconstruction and adaptive exposure controls that promise to further enhance dose efficiency. Additionally, establishing international standardized guidelines and promoting awareness among practitioners will be critical in safeguarding patients while optimizing orthodontic care.

REFERENCES

1. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am. 2008 Jul;52(4):707–30.
2. Isaacson KG, Thom AR, Horner K, Whaites E. Radiographic imaging for the orthodontist. 2nd ed. London: British Orthodontic Society; 2015.
3. Pauwels R, Beinsberger J, Collaert B, Theodorakou C, Rogers J, Walker A, et al. Effective dose range for dental cone beam computed tomography scanners. Eur J Radiol. 2012 Feb;81(2):267–71.
4. Silva MA, Wolf U, Heinicke F, Bumann A, Visser H, Hirsch E. Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation. Am J Orthod Dentofacial Orthop. 2008 May;133(5):640.e1–5.
5. White SC, Pharoah MJ. Oral radiology: principles and interpretation. 8th ed. St. Louis: Mosby Elsevier; 2019.
6. Panneerselvam E, O'Neill J, Lee R. Radiographic exposures in orthodontics: a survey of practice. Br J Radiol. 2019;92(1098):20190179.
7. Ludlow JB, Walker C. Assessment of phantom dosimetry and image quality of i-CAT FLX cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2013 Nov;144(5):802–17.
8. Kaya S, Güngör K, Peker S, Aras A, Tuncel B. Comparison of radiation doses and image quality of digital panoramic, lateral cephalometric, and CBCT imaging. Angle Orthod. 2021 Jan;91(1):81–7.
9. ICRP Publication 103. The 2007 Recommendations of the International Commission on Radiological Protection. Ann ICRP. 2007;37(2–4):1–332.
10. SEDENTEXCT Project. Radiation protection: cone beam CT for dental and maxillofacial radiology (Evidence-based guidelines). Luxembourg: European Commission; 2012.
11. Horner K, O'Malley L, Taylor K, Farquharson D, Creanor S. Justification and optimisation principles in dental radiology: from ALARA to ALADAIP. Dentomaxillofac Radiol. 2020;49(5):20190436.

REFERENCES

12. European Commission. Radiation Protection No. 172: Cone Beam CT for dental and maxillofacial radiology—evidence-based guidelines. Luxembourg: Office for Official Publications of the European Communities; 2012.
13. Abdelkarim A, Jerrold L. Clinical considerations and potential liability associated with the use of ionizing radiation in orthodontics. American journal of orthodontics and dentofacial orthopedics. 2018 Jul 1;154(1):15-25.
14. International Atomic Energy Agency. Optimization in dental radiology – FAQs for health professionals. Vienna: IAEA; 2015 (cited 2025 Nov 1). Available from: https://www.iaea.org/resources/rpop/health-professionals/dentistry/optimization
15. Shina LO, Hajee SI. Dose optimization of cone beam computed tomography: measurement of parotid absorbed dose and image quality assessment. J Med Life. 2025;18(3):214-222.
16. Pauwels R, et al. Effective radiation dose and eye lens dose in dental cone beam CT: effect of field of view and angle of rotation. Dentomaxillofacial Radiology. 2014;43(1):20130325.
17. Matenine D, Schmittbuhl M, Bedwani S, Després P, de Guise JA. Iterative reconstruction for image enhancement and dose reduction in diagnostic cone beam CT imaging. Journal of X-ray Science and Technology. 2019 Oct;27(5):805-19.
18. American Academy of Pediatric Dentistry. *Best Practice Guideline: Prescribing Dental Radiographs for Infants, Children, Adolescents, and Individuals with Special Health Care Needs.* Chicago: AAPD; 2022.
19. FDI World Dental Federation. *Policy Statement – Radiation Safety in Dentistry.* Adopted by FDI General Assembly September 13, 2014
20. Otaka Y, Harata Y, Izawa M. Use of a rectangular collimator and detector holder in portable intraoral X-ray devices: dose and operator exposure reduction study. *J Indian Acad Oral Med Radiol.* 2023;35(2):119-23.
21. White SC, Pharoah MJ. *Oral Radiology: Principles and Interpretation.* 7th ed. St Louis: Mosby/Elsevier; 2014.
22. Horner K, O'Malley L, Taylor K, Glenny AM. Guidelines for clinical use of CBCT: a review. Dentomaxillofacial radiology. 2015 Jan 1;44(1):20140225.
23. Båth M, Söderman C, Börjesson M. The effect of thyroid shielding in dental radiography: a dosimetric study. *Dentomaxillofac Radiol.* 2020;49(3):20190451.
24. National Council on Radiation Protection and Measurements (NCRP). *Radiation protection in dentistry and oral & maxillofacial imaging.* Bethesda (MD): NCRP; 2019. Report No.: 177.
25. Meyer L, Connolly M, Hilgers R, Khoo E. Reevaluating the use of lead aprons in panoramic and CBCT imaging: balancing protection and practicality. *J Dent Radiol.* 2021;48(2):65–72.
26. White SC, Pharoah MJ. *Oral radiology: principles and interpretation.* 8th ed. St. Louis: Elsevier; 2014.
27. American Academy of Pediatric Dentistry (AAPD). *Guideline on prescribing dental radiographs for infants, children, adolescents, and persons with special health care needs.* Chicago (IL): AAPD; 2012.
28. Horner K, O'Malley L, Taylor K, Glenny AM. Guidelines for clinical use of dental cone beam computed tomography (CBCT): update 2019. *Eur J Radiol.* 2019;114:46–54.
29. Brennan PC, McEntee MF. Radiology staff education and adherence to radiation protection protocols: a review. *Radiography.* 2019;25(1):e1–e7.
30. Matzen LH, Berkhout E. Cone beam CT imaging of the mandibular third molar: a position paper prepared by the European Academy of DentoMaxilloFacial Radiology (EADMFR). Dentomaxillofacial Radiology. 2019 Jul 1;48(5):20190039.
31. Paolicchi F, Faggioni L, Bastiani L, Molinaro S, Caramella D, Bartolozzi C. Real practice radiation dose and dosimetric impact of radiological staff training in body CT examinations. *Insights into Imaging*. 2013;4(2):239-44.
32. National Research Council. Tracking Radiation Exposure from Medical Diagnostic Procedures: Workshop Report. Washington, DC: The National Academies Press; 2012.
33. International Commission on Radiological Protection. *Patient and Staff Radiological Protection in Cardiology.* ICRP Publication 135. Ann. ICRP. 2017;46(1):1-48
34. American College of Radiology. ACR Position Statement on Quality Control and Improvement, Safety, Infection Control and Patient Education. Jan 9 2019
35. Rehani MM. Patient radiation exposure and dose tracking: a perspective. J Med Imaging (Bellingham). 2017;4(3):031206.
36. Brenner DJ, Hall EJ. Computed tomography — an increasing source of radiation exposure. N Engl J Med. 2007;357:2277-2284.

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