

Review

Not peer-reviewed version

Beyond Dose: Architecture as an Overlooked Silent Component of the Occupational Exposome in Dental Radiology Within Industrial Clinical Settings

[Ahmed Adel Mansour Kamar](#)*, [Ioannis Mavroudis](#), [Alin Ciobica](#), [Diana Gheban](#)*, [Irina-Luciana Gurzu](#), [Otilia Novac](#)

Posted Date: 29 January 2026

doi: 10.20944/preprints202601.2264.v1

Keywords: occupational dental radiation exposure; dental radiography; radiation protection; thyroid radiosensitivity; cone-beam computed tomography (CBCT); scatter radiation; lightweight or artificial wall construction; industrial dental clinics



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a [Creative Commons CC BY 4.0 license](#), which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Review

Beyond Dose: Architecture as an Overlooked Silent Component of the Occupational Exposome in Dental Radiology Within Industrial Clinical Settings

Ahmed Adel Mansour Kamar ^{1,2,3,*}, Ioannis Mavroudis ^{4,5}, Alin Ciobica ^{6,7}, Diana Gheban ^{7,*}, Irina-Luciana Gurzu ⁸ and Otilia Novac ⁸

- ¹ Medical Department, Gulf of Suez Petroleum Company (GUPCO), Cairo Office, Cairo 11511, Egypt
- ² Department of Orthopedics and Traumatology, Clinical Recovery Hospital (Recuperare), 700661 Iasi, Romania
- ³ Doctoral School of Biology, Faculty of Biology, “Alexandru Ioan Cuza” University of Iasi, 700505 Iasi, Romania
- ⁴ Neurosciences Department, Leeds Teaching Hospitals NHS Trust, Leeds LS1 3EX, UK
- ⁵ Laboratory of Neuropathology & Electron Microscopy, School of Medicine, Faculty of Health Sciences, Aristotle University of Thessaloniki (AUTH), 54124 Thessaloniki, Greece
- ⁶ Department of Biology, Faculty of Biology, “Alexandru Ioan Cuza” University of Iasi, 700505 Iasi, Romania
- ⁷ “Ioan Haulica” Institute, Apollonia University, Păcurari Street 11, 700511 Iasi, Romania
- ⁸ Faculty of Medicine, Grigore T. Popa University of Medicine and Pharmacy, 700115 Iasi, Romania
- * Correspondence: ahmed81kamar@gmail.com (A.A.M.K.); diana.gheban@yahoo.com (D.G.)

Abstract

Dental radiography is a routine part of modern dental care and is usually considered safe because it uses low radiation doses. This belief is mainly based on studies from hospitals and conventional clinics, where dental X-ray rooms are built with verified wall shielding. In real-life practice, however, dental radiology is not always performed in such settings. In many industrial and corporate workplaces, permanent dental clinics are located inside non-hospital buildings with thin, lightweight, or prefabricated walls. In these environments, wall shielding may be absent or not regularly checked. During dental imaging, especially with the increasing use of cone-beam computed tomography (CBCT), scattered radiation may pass beyond the dental room and reach nearby offices or work areas. This means that radiation exposure may affect not only dental staff but also other workers who are not considered radiation workers and are not included in routine monitoring. This narrative review explores occupational radiation exposure from dental radiology in long-term industrial clinical settings with non-standard building design. Special attention is given to indoor scatter radiation, wall construction, and possible effects on the thyroid gland, a radio-sensitive organ. By reviewing available evidence on dental occupational exposure, scatter radiation, thyroid sensitivity, and current radiation protection guidelines, this paper highlights a possible gap between existing safety assumptions and real working conditions. The findings suggest that building design and wall shielding should receive more attention in radiation protection practices for dental clinics operating in industrial settings, together with appropriate monitoring and safety measures.

Keywords: occupational dental radiation exposure; dental radiography; radiation protection; thyroid radiosensitivity; cone-beam computed tomography (CBCT); scatter radiation; lightweight or artificial wall construction; Industrial dental clinics

1. Introduction

Dental radiography is an essential component of modern dental practice and is widely regarded as safe because manufacturers describe it as delivering relatively low radiation doses. This perception is largely based on evidence derived from conventional healthcare facilities, where dental imaging is performed within purpose-built environments that incorporate verified architectural shielding and controlled radiation areas. Under such conditions, occupational exposure of dental healthcare workers is generally reported to remain well below recommended dose limits [1,2].

Available studies indicate that occupational radiation doses in dentistry are usually low when standard radiation protection measures are applied, and routine intra-oral radiography is therefore often perceived as low risk, with radiation protection relying largely on assumed distance and environmental attenuation [2,3,25]. However, occupational exposure may vary depending on imaging modality, workload, operator position, and, critically, the structural characteristics of the clinical environment in which dental radiology is performed [4].

The safety of dental radiology therefore depends not only on the radiation output of imaging equipment but also on architectural and spatial factors that influence the distribution of scattered radiation within indoor environments. In conventional clinics, these factors are implicitly addressed through hospital-grade construction materials and established radiation protection standards. Less attention has been given to dental clinics operating outside such settings.

In many industrial and corporate organizations, permanent medical and dental clinics are embedded within non-hospital buildings constructed using lightweight or modular architectural materials, such as those found in petroleum, mining, and large industrial facilities. These environments may lack verified lead-equivalent wall shielding, clearly defined controlled radiation areas, or routine personal dosimetry programs, despite continuous long-term operation. As a result, assumptions derived from conventional healthcare facilities may not accurately reflect occupational exposure conditions in these settings.

In facilities constructed with lightweight or artificial walls, scattered radiation generated during dental imaging may extend beyond the dental operatory and reach adjacent offices or workspaces. Consequently, occupational exposure may affect not only dental healthcare workers but also administrative staff, technical personnel, and other employees working in proximity to dental imaging areas. These individuals are typically not classified as radiation workers and are therefore unlikely to be included in routine monitoring or radiation safety training, complicating exposure assessment and risk management.

Occupational exposure in dental practice arises predominantly from scattered radiation during imaging procedures. Cone-beam computed tomography (CBCT), which is increasingly used in implantology, orthodontics, and maxillofacial diagnostics, generates higher radiation doses than conventional intraoral radiography and contributes more substantially to indoor scatter radiation [8–10]. Distance from the radiation source and the presence of effective structural shielding remain key determinants of occupational exposure levels [12].

The thyroid gland is among the most radiosensitive organs in the human body, making chronic low-dose occupational exposure a relevant concern from a public health perspective. Evidence from medical radiation workers and exposed populations suggests that repeated or long-term exposure may be associated with thyroid nodules, functional alterations, and an increased risk of thyroid cancer [5–7]. However, these findings are largely derived from settings with well-characterized exposure conditions and conventional architectural shielding.

Current radiation protection recommendations in dentistry are based on the principles of justification, optimization, and dose limitation and assume that dental clinics are designed with adequate wall thickness and appropriate lead or lead-equivalent shielding [1,13]. These assumptions may not hold in permanent dental clinics embedded within industrial and corporate facilities constructed with lightweight or artificial wall materials, where indoor scatter radiation may extend beyond the dental operatory and expose personnel who are not formally recognized as radiation workers.

The motivation for this review stems from long-term clinical practice across industrial healthcare settings, where dental radiology may operate in non-hospital architectural environments without routinely verified shielding, prompting reflection on whether current safety assumptions adequately address such contexts. Accordingly, this narrative review examines existing evidence on occupational radiation long-term exposure from dental radiology with a particular focus on architectural design, indoor scatter radiation, and potential implications for thyroid health in industrial clinical settings.

Research Question

Do current radiation protection frameworks adequately address the absence of verified wall shielding in long-term dental radiology practice conducted in industrial clinical settings with thin, lightweight, or modular wall construction?

2. Methodology

This study is a narrative review that summarizes published evidence on occupational radiation exposure in dental radiology and its possible implications for thyroid health. A narrative approach was selected because the available literature is heterogeneous, including different study designs, exposure assessment methods, and outcome measures, which limits the feasibility of a systematic quantitative synthesis.

A literature search was conducted using the PubMed, Scopus, and Web of Science databases. The search focused on publications published between 2000 and 2025. Key search terms included combinations of *dental radiography*, *occupational radiation exposure*, *dental staff*, *cone-beam computed tomography (CBCT)*, *scatter radiation*, *radiation protection*, and *thyroid radiation effects*. In addition, the reference lists of relevant articles were manually screened to identify further pertinent studies.

Peer-reviewed articles were included if they addressed occupational radiation exposure in dental practice, scatter radiation from dental imaging modalities, architectural or environmental factors influencing exposure, or biological effects of ionizing radiation relevant to thyroid health. International and national radiation protection guidelines were also reviewed to provide context regarding safety assumptions, architectural shielding requirements, and occupational dose limits.

Articles were excluded if they focused exclusively on patient radiation doses, therapeutic radiation exposure, or non-dental imaging modalities, or if they lacked sufficient methodological detail to support interpretation of occupational exposure. The included literature was analyzed qualitatively and synthesized thematically, with particular attention to architectural design, wall construction, indoor scatter radiation, and long-term occupational exposure in non-hospital clinical settings.

The aim of this review was not to provide an exhaustive systematic synthesis, but to identify recurring themes and gaps relevant to architectural design and occupational exposure.

3. Scientific Background: Dental Radiation and Occupational Exposure

Dental radiography uses ionizing radiation to obtain diagnostic images of teeth and surrounding structures. Common techniques include intraoral radiography, panoramic imaging, and cone-beam computed tomography (CBCT). Occupational exposure in dental practice occurs mainly through scattered radiation rather than direct beam exposure [1,2,26]. Although radiation doses in dentistry are generally lower than in other medical imaging fields under standard clinical conditions, occupational exposure may become more relevant in settings where structural shielding is inadequate or radiation safety practices are inconsistently applied [3,25,26].

Several studies have shown that occupational doses for dental healthcare workers and other personnel working in proximity to dental imaging areas usually remain below recommended limits when radiation protection measures are properly applied [2,4]. However, exposure levels vary depending on imaging modality, workload, equipment type, and compliance with safety practices.

CBCT, in particular, produces higher radiation doses than conventional dental radiography and contributes more to scatter radiation within the clinic [9,10]. In facilities with lightweight or artificial wall construction, this increased scatter radiation may extend beyond the imaging room, potentially affecting adjacent indoor areas. The main characteristics of common dental imaging modalities and their relevance for occupational radiation exposure are summarized below in Table 1.

Table 1. Dental imaging modalities and characteristics of occupational radiation exposure.

Dental imaging modality	Common clinical use	Relative radiation dose	Main source of occupational exposure	Key protection measures
Intraoral radiography	Detection of caries, periapical pathology, routine follow-up	Low	Scatter radiation from patient	Proper operator distance, beam collimation, protective barriers
Panoramic radiography	Evaluation of jaws, impacted teeth, general dental assessment	Low to moderate	Scatter radiation within the imaging room	Structural shielding, operator positioning behind barriers
Cone-beam computed tomography (CBCT)	Implant planning, orthodontics, maxillofacial diagnostics	Higher	Increased scatter radiation during image acquisition	Adequate wall shielding, controlled areas, reduced exposure time, staff training

Original table created by the first author AAMK.

4. Occupational Exposure in Dental Clinics

Occupational exposure in dental clinics is influenced by clinic layout, wall materials, shielding quality, operator position, and the broader architectural context in which dental imaging is performed. Radiation scatter can penetrate surrounding areas if structural shielding is insufficient or improperly designed, as demonstrated even for simple intra-oral dental X-ray units under experimental conditions [6,26]. Standard radiation protection models assume adequate wall thickness and the presence of lead or lead-equivalent barriers, which may not always be the case in non-standard or lightweight clinic constructions [1,11]. In clinics constructed with lightweight or artificial wall materials, such as prefabricated panels or modular structures, scatter radiation may penetrate walls more easily than assumed in standard radiation protection models.

Measurements of scatter radiation have demonstrated that distance from the X-ray source and the use of protective barriers significantly reduce occupational exposure [10]. In clinics with limited space or inadequate shielding, dental staff and other personnel working in proximity to dental imaging areas may be exposed to higher cumulative doses, particularly during frequent CBCT use [10].

This risk may be particularly relevant in industrial and corporate healthcare facilities, where dental clinics are embedded within office or field environments and where radiation protection practices may not be routinely audited.

5. Mechanistic Pathways Linking Ionizing Radiation and Thyroid Dysfunction

Ionizing radiation affects biological tissues primarily through the generation of reactive oxygen species (ROS), leading to oxidative stress and potential damage to DNA, proteins, and cellular membranes [5,12]. The thyroid gland is particularly vulnerable to such effects because normal thyroid hormone synthesis physiologically involves oxidative processes, resulting in a higher baseline oxidative burden within thyroid cells [5].

Radiation-induced oxidative stress may contribute to DNA damage, mitochondrial dysfunction, and chronic inflammatory responses in thyroid tissue. Over time, these processes have been associated with thyroid nodules, functional alterations, and an increased risk of malignant transformation in exposed populations [5,7]. Under conditions of repeated or long-term exposure,

even low-dose radiation may therefore have biological relevance, particularly when protective factors such as adequate shielding are insufficient.

5.1. *Thyroid Sensitivity to Low-Dose Ionizing Radiation: Redox Imbalance*

The distinctive radiosensitivity of the thyroid gland is closely linked to its intrinsic redox biology. Thyroid hormone biosynthesis depends on hydrogen peroxide generation by dual oxidase enzymes (DUOX1 and DUOX2), which is required for thyroid peroxidase-mediated iodination reactions [19]. As a result, thyrocytes function under conditions of sustained ROS production and rely on tightly regulated antioxidant systems to maintain redox balance.

Low-dose ionizing radiation induces additional ROS through radiolysis of intracellular water [20]. Although such exposure does not usually cause acute cytotoxicity, repeated or long-term exposure may shift the intracellular redox balance toward a pro-oxidative state. This redox imbalance can affect cellular components, disrupt signaling pathways, and impair mitochondrial function, further amplifying oxidative stress within thyroid tissue [21–24].

Collectively, these mechanisms provide biological plausibility for subtle thyroid functional disturbances reported in chronically exposed occupational groups. However, these molecular pathways are presented to support mechanistic understanding rather than to imply direct causality in dental occupational settings, as direct exposure–outcome studies in industrial clinical environments remain limited.

6. Human Evidence from Occupational and Medical Radiation Studies

Epidemiological studies of medical radiation workers have reported associations between occupational radiation exposure and thyroid abnormalities, including nodules and increased cancer risk [3,7,14]. An overview of the available human evidence linking radiation exposure to thyroid-related outcomes is summarized in Table 2. Although most evidence derives from settings with better-characterized exposure levels, recent reviews suggest that chronic occupational exposure may affect thyroid structure and function [4,5].

Meta-analyses and pooled studies have demonstrated an increased risk of thyroid cancer following external radiation exposure, with risk magnitude influenced by dose, duration of exposure, and age at exposure [3,14]. Data specific to personnel with occupational exposure to dental imaging remain limited, highlighting the need for further investigation in this occupational group.

Table 2. Summary of human evidence linking radiation exposure to thyroid-related outcomes.

Study type	Population studied	Type of radiation exposure	Thyroid-related outcome	Main conclusion
Narrative and systematic reviews	Healthcare and medical radiation workers	Chronic occupational exposure	Thyroid nodules, functional alterations	Long-term radiation exposure may affect thyroid structure and function
Meta-analyses	Occupationally exposed adults	External ionizing radiation	Increased thyroid cancer risk	Thyroid cancer risk increases with cumulative radiation dose
Cohort and pooled studies	Medical radiation workers and exposed populations	Repeated diagnostic or occupational exposure	Structural and malignant thyroid changes	Risk depends on dose, duration, and age at exposure
Dental exposure studies	Dental healthcare workers	Low-dose occupational exposure	Limited direct data	Evidence is limited; further focused research is needed

Original table created by the first author AAMK.

7. Occupational Risk Management and Regulatory Gaps

Radiation protection in dentistry is based on the principles of justification, optimization, and dose limitation [11,15]. Current guidelines emphasize equipment quality assurance, operator training, appropriate positioning, and structural shielding [15]. When these measures are applied, occupational doses are generally low.

However, existing regulations largely assume conventional, hospital-grade clinic designs and may not adequately address dental clinics embedded within industrial or corporate facilities constructed with non-standard architectural materials [6,16,17]. Limited guidance exists on radiation protection requirements for lightweight or modular clinics, where shielding performance may differ from traditional facilities. This represents a potential gap in occupational risk management.

In industrial and corporate settings, dental clinics may operate as permanent healthcare units without being subject to the same level of architectural radiation safety assessment applied in hospital environments. In such facilities, wall construction materials may lack verified lead-equivalent shielding, and the physical separation between dental imaging areas and surrounding offices may be insufficient. As a result, scatter radiation may extend beyond the dental operatory and affect adjacent indoor workspaces, exposing personnel who are not formally recognized as radiation workers. These structural and organizational shortcomings represent a potential gap in occupational radiation protection that cannot be mitigated solely through procedural or administrative measures.

8. Discussion and Recommendations

Dental radiographic equipment is generally regarded as safe because manufacturers describe it as emitting relatively low radiation doses in technical specifications and operator manuals. This has contributed to a widespread perception among dental practitioners that dental radiology is safe when used within conventional clinical environments [1,12]. This perception of safety is largely based on dental clinics operating within conventional buildings constructed with thick concrete or masonry walls that provide substantial passive radiation shielding [11]. In such environments, scatter radiation is effectively attenuated by structural materials, reinforcing the assumption of minimal occupational and environmental risk. However, this assumption does not hold in clinics constructed with lightweight or artificial wall materials. In these settings, even low-dose scatter radiation may penetrate surrounding structures and extend into adjacent indoor areas. Therefore, reliance on nominally low radiation output alone is insufficient to ensure safety when architectural shielding is inadequate.

Available evidence indicates that occupational radiation exposure in dental clinics is strongly influenced by the physical and architectural conditions under which dental imaging is performed [2,6]. While exposure levels are generally well controlled in conventional healthcare facilities with verified structural shielding, this assumption may not apply to clinics operating in environments with non-standard architectural design. In such settings, inadequate wall shielding and insufficient physical separation of imaging areas may permit scatter radiation to extend beyond the dental operatory, increasing the potential for unintended occupational exposure [10].

The high radiosensitivity of the thyroid gland, combined with long-term occupational activity in these environments, underscores the importance of prioritizing effective engineering controls as the foundation of radiation protection [3–5,14]. Verification of wall construction materials, assessment of lead-equivalent shielding, and appropriate spatial planning of dental imaging areas should be considered essential components of occupational risk management. Procedural measures and radiation safety training, while important, cannot compensate for deficiencies in structural radiation protection [11].

Future research should place greater emphasis on evaluating radiation transmission through lightweight or artificial wall materials commonly used in industrial and corporate facilities. Studies assessing indoor scatter distribution and long-term thyroid-related outcomes in personnel working

within or adjacent to dental imaging areas are particularly needed to inform evidence-based updates to radiation protection guidelines [3,4,17,18].

Occupational Radiation Exposure in Permanent Industrial Healthcare Facilities with Non-Standard Architecture

In many industrial sectors, including petroleum and energy industries, permanent medical and dental clinics are integrated within administrative offices and field facilities constructed using lightweight or prefabricated materials. Although these clinics may operate continuously for decades, their architectural design often does not incorporate verified lead-equivalent shielding or adequate physical separation between dental imaging areas and surrounding workspaces [6,16,17].

As a result, scatter radiation generated during dental imaging procedures may penetrate surrounding structures and extend into adjacent indoor areas [8–10]. This exposure may affect not only dental healthcare workers but also other personnel working nearby who are not formally considered radiation workers. Existing radiation protection frameworks largely assume hospital-grade construction with inherent structural shielding and therefore may underestimate occupational and environmental exposure risks in these industrial settings [15–17]. Addressing this gap requires explicit consideration of architectural design and wall shielding performance in radiation protection guidance for dental clinics operating outside conventional healthcare facilities.

9. Conclusions

Dental radiographic equipment is designed to operate at relatively low radiation doses and is generally considered safe when used in appropriately constructed clinical environments. However, this perceived safety depends strongly on the presence of adequate architectural radiation shielding. When dental radiology is performed in industrial or corporate clinical settings constructed with thin, lightweight, or artificial wall materials, these assumptions may not fully apply.

This review highlights that insufficient wall shielding and limited physical separation of dental imaging areas can allow scattered radiation to extend beyond the dental operator. Under such conditions, occupational exposure may affect not only dental healthcare workers but also other personnel working in nearby indoor spaces who are not routinely considered in radiation protection programs. Reliance on low nominal radiation output alone may therefore be insufficient to ensure occupational safety in non-standard architectural environments.

Taken together, the findings suggest that architectural design and wall construction should be more explicitly considered in radiation protection practices for dental radiology, particularly in long-term industrial clinical settings. Greater attention to shielding verification, spatial layout, and exposure monitoring may help bridge the gap between current safety assumptions and real-world working conditions. Future research and guidance should further examine how non-hospital architectural environments influence chronic occupational exposure and how radiation protection frameworks can better address these settings.

Author Contributions: Conceptualization, A.A.M.K.; literature search and data collection, A.A.M.K., I.M., O.N., and I.-L.G.; data interpretation and synthesis, A.A.M.K., A.C., and D.G.; drafting of the manuscript, A.A.M.K.; critical revision of the manuscript for important intellectual content, I.M., A.C., D.G., O.N., and I.-L.G.; supervision, A.C., and I.-L.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The authors thank George Catalin Morosan (Grigore T. Popa University of Medicine and Pharmacy, Iasi, Romania) for his constructive comments and critical perspective, which helped improve the clarity, structure, and framing of this manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The views expressed are those of the authors and do not necessarily reflect those of affiliated institutions. No employer had any role in the writing, interpretation, or decision to submit this manuscript. The first author’s institutional affiliation with an industrial organization did not involve access to internal exposure data, facility-specific measurements, or employer-provided information, and the manuscript is based exclusively on publicly available literature.

Abbreviations

The following abbreviations are used in this manuscript:

ALARA	As Low As Reasonably Achievable
CBCT	Cone-Beam Computed Tomography
CT	Computed Tomography
DNA	Deoxyribonucleic Acid
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
mSv	Millisievert
NCRP	National Council on Radiation Protection and Measurements
ROS	Reactive Oxygen Species
DUOX	dual oxidase
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

References

1. Benavides E, Krecioch JR, Connolly RT, Aps JKM, Yeung AWK, Horner K. Optimizing radiation safety in dentistry: clinical recommendations and regulatory considerations. *J Am Dent Assoc.* 2024;155(4):280-293. doi:10.1016/j.adaj.2023.12.002
2. Almuqrin AH, Al-Ehaideb A, Al-Faleh W, Al-Dakhil L, Al-Qarni A. Occupational and patient effective radiation doses in dental imaging procedures. *Appl Radiat Isot.* 2021;176:109899. doi:10.1016/j.apradiso.2021.109899
3. Qu H, He C, Xu H, Li J, Zhang Y, Wang Y. Occupational radiation exposure and risk of thyroid cancer: a meta-analysis. *Oncol Lett.* 2024;27(2):14570. doi:10.3892/ol.2024.14570
4. Andreadi A, Andreadi S, Cerilli M, Giordano D, Pivonello R, Simeoli C. Occupational radiation exposure and thyroid nodules in healthcare workers: a review. *Int J Mol Sci.* 2025;26(13):6522. doi:10.3390/ijms26136522
5. Ludlow JB, Davies-Ludlow LE, White SC. Patient risk related to common dental radiographic examinations: the impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation. *J Am Dent Assoc.* 2008;139(9):1237-1243. doi:10.14219/jada.archive.2008.0339. PMID:18762634.
6. Shatskiy I. Effective doses and radiation risks from common dental radiographic, panoramic and CBCT examinations. *Radiat Prot Dosimetry.* 2021;195(3-4):296-305. doi:10.1093/rpd/ncab069. PMID:34086952.
7. Hart D, Wall BF. UK population dose from medical X-ray examinations. *Br J Radiol.* 2004;77(917):969-977. doi:10.1259/bjr/27477110
8. Pauwels R. Cone beam CT for dental and maxillofacial imaging: dose matters. *Radiat Prot Dosimetry.* 2015;165(1-4):156-161. doi:10.1093/rpd/ncv381
9. Ludlow JB, Timothy R, Walker C, Hunter R, Benavides E, Samuelson DB, et al. Effective dose of dental CBCT—a meta-analysis of published data and additional data for nine CBCT units. *Dentomaxillofac Radiol.* 2015;44(1):20140197. doi:10.1259/dmfr.20140197
10. Yang C-C. Characterization of scattered X-ray photons in dental cone-beam computed tomography. *PLoS One.* 2016;11(3):e0149904. doi:10.1371/journal.pone.0149904.
11. Rehani MM, Frush DP. Radiation protection in diagnostic radiology: progress and challenges. *Br J Radiol.* 2010;83(988):507-522. doi:10.1259/bjr/46551182.

12. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med.* 2007;357(22):2277-2284. doi:10.1056/NEJMra072149
13. Linet MS, Slovis TL, Miller DL, Kleinerman R, Lee C, Rajaraman P, et al. Cancer risks associated with external radiation from diagnostic imaging procedures. *CA Cancer J Clin.* 2012;62(2):75-100. doi:10.3322/caac.21132
14. Ron E, Lubin JH, Shore RE, Mabuchi K, Modan B, Pottern LM, et al. Thyroid cancer after exposure to external radiation: a pooled analysis of seven studies. *Radiat Res.* 1995;141(3):259-277. doi:10.2307/3579003
15. American Dental Association. X-rays/radiographs: radiation safety and guidelines for dental imaging. Available from: <https://www.ada.org/resources/ada-library/oral-health-topics/x-rays-radiographs>
16. Australian Radiation Protection and Nuclear Safety Agency. Radiation Protection Series C-7: Code for Radiation Protection in Dental Exposure. ARPANSA; 2025. Available from: <https://www.arpansa.gov.au>
17. International Atomic Energy Agency. Radiation protection in dental radiology. IAEA Safety Reports Series; 2022. Available from: <https://www.iaea.org/publications/14720>
18. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. UNSCEAR 2010 Report. United Nations; New York. Available from: <https://www.unscear.org>
19. Kochman J, Jakubczyk K, Bargiel P, Janda-Milczarek K. The influence of oxidative stress on thyroid diseases. *Antioxidants (Basel).* 2021;10(9):1442. doi:10.3390/antiox10091442.
20. Song, Y.; Driessens, N.; Costa, M.; De Deken, X.; Detours, V.; Corvilain, B.; Maenhaut, C.; Miot, F.; Dupuy, C. Roles of hydrogen peroxide in thyroid physiology and disease. *J. Clin. Endocrinol. Metab.* 2007, 92, 3764–3773. <https://doi.org/10.1210/jc.2007-1083>
21. Azzam, E.I.; Jay-Gerin, J.-P.; Pain, D. Ionizing radiation-induced metabolic oxidative stress and prolonged cell injury. *Cancer Lett.* 2012, 327, 48–60. <https://doi.org/10.1016/j.canlet.2011.12.012>
22. Spitz, D.R.; Azzam, E.I.; Li, J.J.; Gius, D. Metabolic oxidation/reduction reactions and cellular responses to ionizing radiation. *Cancer Metastasis Rev.* 2004, 23, 311–322. <https://doi.org/10.1023/B:CANC.0000031769.14795.bc>
23. Ma, Q. Role of Nrf2 in oxidative stress and toxicity. *Annu. Rev. Pharmacol. Toxicol.* 2013, 53, 401–426. <https://doi.org/10.1146/annurev-pharmtox-011112-140320>
24. Yakes, F.M.; Van Houten, B. Mitochondrial DNA damage is more extensive and persists longer than nuclear DNA damage in human cells following oxidative stress. *Proc. Natl. Acad. Sci. USA* 1997, 94, 514–519. <https://doi.org/10.1073/pnas.94.2.514>
25. Horner K, Eaton KA. Radiation protection in dental radiology. *Br Dent J.* 2016;221(9):519–524. doi:10.1038/sj.bdj.2016.780
26. Leadbeatter J, Diffey J. Evaluation of radiation exposure to operators of portable hand-held dental X-ray units. *Phys Eng Sci Med.* 2021;44:377–385. doi:10.1007/s13246-021-00985-5

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.