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Impact of dental imaging on pregnant women and recommendations for fetal radiation safety: A systematic review

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ABSTRACT

Purpose: This study was conducted to investigate the safety of dental imaging in pregnant women with respect to fetal health.

Materials and Methods: Searches were conducted of the PubMed, Scopus, and Web of Science databases in May 2023. The inclusion criteria encompassed cross-sectional and longitudinal studies that focused on the analysis of diagnostic dental imaging in pregnant women, as well as studies utilizing phantoms to simulate imaging examinations. The exclusion criteria consisted of reviews, letters to the editor, book chapters, and abstracts from scientific conferences and seminars.

Results: A total of 3,913 articles were identified. Based on a review of the titles and abstracts, 3,892 articles were excluded, leaving 21 articles remaining for full-text review. Of these, 18 were excluded, and 4 additional articles were included as cross-references. Ultimately, 7 articles underwent quantitative-qualitative analysis. Three retrospective studies were focused on pregnant women who underwent dental imaging procedures. The remaining 4 studies utilized female phantoms to simulate imaging examinations and represent the radiation doses absorbed by the uterus or thyroid.

Conclusion: Few dental radiology studies have been conducted to determine the safe radiation threshold for pregnant women. Additionally, the reviewed articles did not provide numbers of dental examinations, by type, corresponding to this dose. Dental imaging examinations of pregnant women should not be restricted if clinically indicated. Ultimately, practitioners must be able to justify the examination and should adhere to the "as low as diagnostically acceptable, being indication-oriented and patient-specific" (ALADAIP) principle of radioprotection. ***(Imaging Sci Dent 2024; 54: 1-11)***

KEY WORDS: Pregnancy; Radiography, Dental; Radiography, Panoramic; Cone-Beam Computed Tomography; Radiation Protection

Introduction

Dental imaging is routinely used as a complementary exam. Common modalities include intraoral radiography, panoramic radiography, and cone-beam computed tomography (CBCT), each with distinct characteristics related to radiation dose.[1-3] In the treatment of pregnant women, dental practitioners have expressed concern over the potential adverse effects of ionizing radiation on the fetus.[4] These professionals should understand the deleterious effects of cumulative radiation exposure and implement protective strategies for imaging procedures, particularly CBCT, which delivers relatively high doses of radiation compared to conventional radiographic techniques.[4-7]

The biological impacts of ionizing radiation include both deterministic and stochastic effects. Deterministic effects stem from impairment or loss of organ function due to cellular damage. In contrast, stochastic effects arise from

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changes in cells that retain their capacity to divide. For stochastic effects, no threshold dose is assumed to exist, and the likelihood of their manifestation is believed to increase proportionally with the radiation absorbed. Consequently, the risk of these effects should be minimized by exposing patients to radiation only at the lowest feasible level.[8]

Despite international guidelines specifying maximum doses of ionizing radiation for pregnant women, general dentists continue to express concerns about the potential impact on the fetus from lower doses absorbed in the uterine area during diagnostic dental imaging procedures.[3,9-14] Moreover, the dental literature has long included differing perspectives regarding the use of lead aprons, or shields, to reduce the exposure of pregnant women to ionizing radiation.[1,4,15-21] In this context, the established annual dose limit for the fetus of a pregnant worker who has declared the pregnancy is 1 mSv.[1] This dose, when absorbed by the uterus, is commonly used as a proxy for the radiation absorbed by the embryo or fetus in medical radiation dosimetry.[9] The average organ dose *in utero* for the most frequently performed examinations is 0.4 mSv per radiograph; the use of a protective apron has been shown to halve this dose. According to the findings of Weber et al.,[22] of all diagnostic radiography procedures, dental radiography poses the lowest radiation risk to the fetus. Similarly, Orsini et al.[16] found that radiographic shields for the uterus were superfluous.[16]

However, in the realm of research on the impact of protective lead aprons on fetal safety, particularly in imaging studies of the head and neck areas,[23-25] conflicting opinions have been presented. Researchers are examining the usefulness of lead shields in dental radiography during pregnancy, encountering both ambiguous results and varying practices. Certain studies[19,26,27] have advocated the use of protective lead aprons and thyroid collars to minimize fetal exposure. Moreover, the European guidelines on radiation protection in dental radiology[3] have conveyed that no contraindications prevent pregnant women, or those who may be pregnant, from undergoing dental radiography if it is clinically warranted.[3]

European guidelines have also indicated that the use of a protective lead apron is not necessary in dental radiography.[2] In Finland, the national authority has recommended the use of shields when these devices minimize the patient's radiation exposure. However, the definition of a reasonable dose reduction remains unclear. Thyroid shields are employed in intraoral and cephalometric radiography, but they are not used in panoramic radiography because they can obstruct the primary beam. In CBCT, the decision to use thyroid protection should be made based on local assessment. No evidence presently supports the routine application of abdominal protection in conventional dental radiography or CBCT examination.[2,10] The practices and viewpoints on dental X-rays during pregnancy are similarly inconsistent.

Pina and Douglass[26] observed that a majority of surveyed dentists in Connecticut were supportive of providing dental care during the second trimester of pregnancy. However, although 97% of the respondents had treated pregnant patients, only 45% reported feeling very comfortable doing so. The various interpretations regarding the use of protective shielding promote confusion among practitioners who aim to adhere to best practices. These practices include the radioprotection guidelines recommended under the "as low as diagnostically acceptable, being indication-oriented and patient-specific" (ALADAIP) principle.[28] Additionally, considerable variation exists across continents concerning the use of rectangular versus circular collimators, which may affect the amount of scattered radiation in the vicinity of the embryo or fetus.

Although the radiation dose delivered to the uterus during a routine dental diagnostic X-ray is minimal, the general consensus is to avoid such X-rays during pregnancy or to postpone them until after delivery.[27] Miller,[27] however, advocated for the use of X-rays when necessary to diagnose and manage a dental emergency at any stage of pregnancy. Dental radiography is notable in that the sheer volume of X-rays conducted ensures the inclusion of some patients who are unaware of their pregnancy. Upon learning that they are pregnant, these patients may express concern about the potential impact of the X-ray procedure on the fetus. If practices were standardized, patients would likely feel more reassured and may be less inclined to make unfounded attributions of cause should their child be born with an illness.

Therefore, the objective of this systematic review was to answer the following questions: Is dental imaging - including periapical radiography, panoramic radiography, and CBCT - safe for pregnant women? What constitutes a safe radiation dose for a pregnant woman? Finally, how many dental imaging examinations can be safely performed during pregnancy?

Materials and Methods

This systematic review complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[29] and was registered with the PROSPERO database of the National Institute of Health

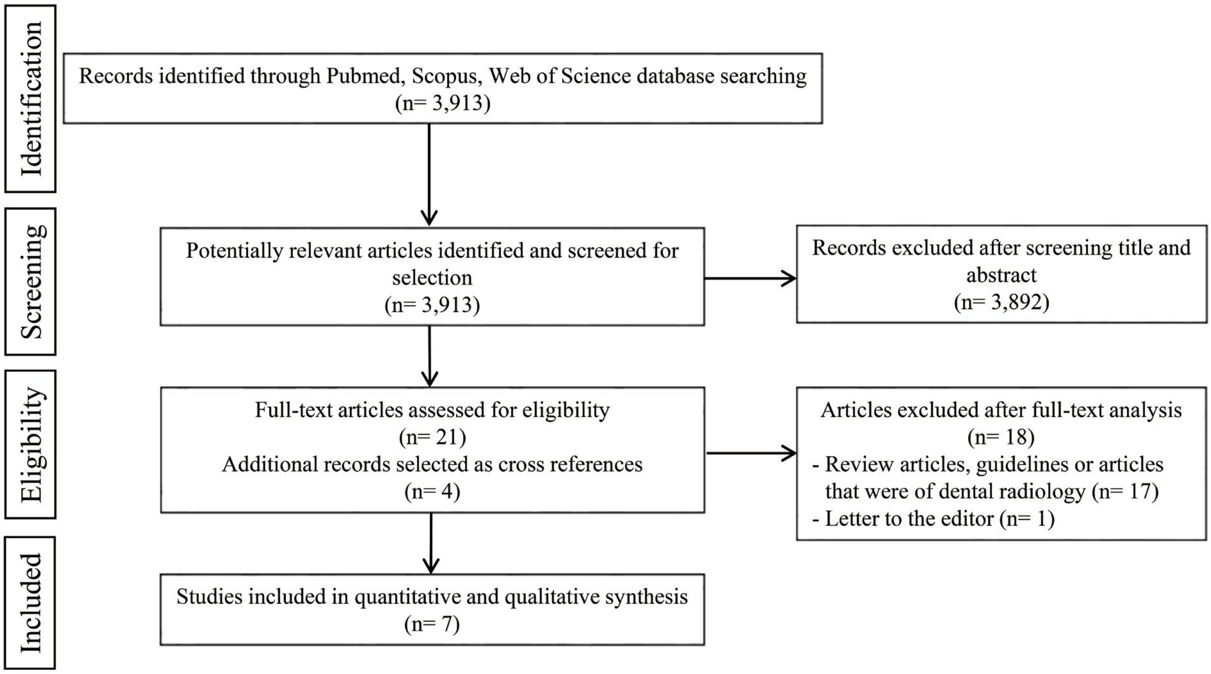

Fig. 1. Flowchart of study selection, aligning with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Research under the protocol number CRD42019131649.

This review included studies on diagnostic dental imaging that faithfully reproduced imaging examinations in pregnant women. The imaging modalities considered were intraoral radiography, panoramic radiography, and CBCT. Additionally, guidelines established by international dental radiology associations were utilized to evaluate the consensus regarding radiation dose and radiographic procedures for pregnant women.

In May 2023, a detailed individual search of the PubMed, Scopus, and Web of Science databases was performed (Fig. 1). The search utilized the following keywords: pregnancy or pregnant or pregnant woman; radiography or dental radiography or intraoral radiographs; panoramic or panoramic radiography or panoramic radiographs; cone beam computed tomography or cone-beam computed tomography or CBCT; and radiation or ionizing radiation or radiation dose. After reviewing the full articles, 4 studies identified through cross-referencing were also selected for inclusion in the sample.

The present study incorporated cross-sectional and longitudinal research that involved dental imaging examinations in pregnant women or simulated these examinations using phantoms representing the uterine area. It also included studies that reported maximum or safe levels of radiation for conducting imaging tests on pregnant women. Selection was limited to studies published in English and conducted on humans, with a requirement that the stage of pregnancy of the patients be explicitly stated. No data restriction filters were applied in the selection of articles.

The aim of this systematic review was to identify articles that could provide answers to the research questions posed. Consequently, certain types of studies were deemed unsuitable. The following categories of articles were excluded from the search: reviews, letters to the editor, book chapters, and abstracts from scientific conferences and seminars. Studies that did not evaluate at least 1 dental imaging diagnostic method (among periapical radiography, panoramic radiography, and CBCT) were omitted. Studies were also excluded if they did not include pregnant women in the sample or if they did not attempt to reproduce the radiation dose in the uterine region.

Initially, 2 authors (T.O.G. and I.L.F.) independently reviewed the titles and abstracts of articles to assess their eligibility based on the inclusion criteria. Following this preliminary assessment, the same authors individually read the full texts of the articles and applied the study's exclusion criteria. In instances of disagreement, a third reviewer (H.L.D.S.) made the final decision regarding the inclusion of papers. The searches for, and selection of, articles deemed relevant to the research were conducted manually by the respective authors. The articles chosen for inclusion were required to describe the characteristics of the exposure dose in pregnant women for each type of dental imaging examination examined (among intraoral radiographs, panoramic radiographs, and/or CBCT).

The quality assessment of the articles selected for this systematic review was based on the Risk of Bias Assessment Tool for Non-randomized Studies (RoBANS), a tool designed to evaluate the risk of bias in non-randomized investigations.[30] This assessment included 6 domains: selection of participants, confounding variables, measurement of exposure, blinding of the outcome assessments, incomplete outcome data, and selective outcome reporting. For each domain, studies were classified as having a low, high, or unclear risk of bias. The last of these classifications was assigned when the information provided was insufficient to definitively determine whether the risk of bias was low or high.

The synthesis strategy was formulated in response to the previously outlined questions. Consequently, a third and final screening was conducted by a researcher who read the full articles to evaluate the scientific findings of the selected studies. Quantitative and qualitative data that potentially addressed these questions were examined.

Results

A search of the PubMed, Scopus, and Web of Science databases yielded 3,913 articles. Upon reviewing the titles and abstracts, the researchers excluded 3,892 articles, yielding 21 articles for full-text review. Following full-text analysis, 18 additional studies were omitted for various reasons: 6 were literature review studies, 5 were guidelines, 1 was a letter to the editor, and 6 did not pertain to dental imaging studies. An additional 4 articles were identified and included from the reference lists. Ultimately, 7 articles were selected for inclusion in this systematic review and subjected to quantitative-qualitative analysis. Fig. 1 presents a flowchart, aligned with the PRISMA 2010 guidelines,[29] describing the process of study selection. Regarding experimental design, 3 of the included studies involved retrospective analyses of women who received dental X-rays during pregnancy, examining outcomes such as newborn health, low birth weight, or stillbirth. The remaining 4 studies utilized female phantoms to measure the radiation doses absorbed at the uterus or thyroid, which could potentially impact the fetus.

In the analysis of risk of bias, the study conducted by Hamilton et al.[15] demonstrated a high risk of bias across all domains, with the exception of participant selection, a domain that relates to the clear presentation of the number of study participants. In fact, the article by Mortazavi et al.[20] was the only study identified as having a high risk of bias in this domain. Concerning the blinding of outcome assessment, all studies lacked clarity in their criteria, as none specified whether blinding of the examiners had been implemented. The studies by Hujoel et al.[21] and Mortazavi et al.[20] were found to have a high risk of bias with respect to confounding variables and the measurement of exposure. Research employing phantoms indicated a low risk of bias for all evaluated items, except the blinding of examiners during outcome assessment (Table 1).

Hamilton et al.[15] presented findings on the rates of exposure to dental radiation among pregnant women, drawing on data from questionnaires collected in a retrospective cross-sectional study conducted in 1980 in the United States.[15] The study included 3,631,460 mothers, categorized into those with liveborn infants (3,612,258) and those with stillborn infants (19,202). The rates of exposure to dental X-rays during pregnancy were 3.6% for the liveborn respondents and 2.4% for the stillborn group. The analysis revealed no significant association with infant birth weight, and no statistically significant differences were found

Table 1. Risk of bias analysis of the 7 studies, assessed with an adapted version of the Risk of Bias Assessment Tool for Non-randomized Studies (RoBANS)

Domain*	Hamilton et al. (1984)[15]	Hujoel et al. (2004)[21]	Buch et al. (2009)[4]	Okano et al. (2009)[24]	Rottke et al. (2013)[25]	Kelaranta et al. (2016)[1]	Mortazavi et al. (2019)[20]
Selection of participants	+	+	+	+	+	+	−
Confounding variables	−	−	+	+	+	+	−
Measurement of exposure	−	−	+	+	+	+	−
Blinding of outcome assessments	?	?	?	?	?	?	?
Incomplete outcome data	−	+	+	+	+	+	+
Selective outcome reporting	−	+	+	+	+	+	+

+: low, −: high, ?: unclear.

between the groups. Regrettably, the data did not specify the trimester during which the X-rays were administered, nor was information provided on the number of X-ray examinations, the radiation dose received, or whether lead apron shielding was used.

Hujoel et al.[21] conducted a population-based case-control study using birth records and dental insurance data from the US state of Washington, spanning from 1993 to 2000.[21] The objective of that study was to investigate the potential impact of dental radiography on infant birth weight. The sample comprised 5,719 infants, with 1,117 displaying low birth weight and 4,468 having normal birth weight. The findings revealed a positive association between dental X-ray exposure during pregnancy and low birth weight. Specifically, thyroid radiation exposure exceeding 0.4 mGy was associated with an adjusted odds ratio (OR) of 2.27 (95% confidence interval [CI]: 1.11-4.66, $P=0.03$) for low birth weight. Notably, over two-thirds of the radiographic examinations (70.5%) occurred in the first trimester, and exposure to radiation levels above 0.4 mGy during this period was linked to low birth weight, with an OR of 3.11 (95% CI: 1.44-6.73). However, the study did not specify details such as the type of dental examination, the radiation dose received by the uterus/fetus, the use of lead apron shielding, the dental device employed, the exposure parameters, or the guidelines followed.

Mortazavi et al.[20] conducted a retrospective cross-sectional analysis of the medical records of 1,200 mothers and their newborns at Shiraz University of Medical Sciences in Iran in 2019. The 1,200 newborns were categorized based on exposure status to assess the impact of ionizing and non-ionizing radiation, from dental radiography among other sources of exposure, on infant birth weight. No significant difference in mean newborn weight was detected between the infants who were exposed to radiation *in utero* and those who were not. However, the study included only 19 mothers who received dental X-rays while pregnant, and it lacked detailed information regarding the type of examination, the radiation dose, the use of lead apron shielding, the type of dental device, the exposure parameters, and the guidelines applied.

In contrast, Buch et al.[4] conducted a cross-sectional study using a RANDO female phantom (Alderson Research Laboratories Inc., Stamford, CT, USA) at the Dental Management Sciences department of the University of Pretoria, South Africa, in 2019. The objective was to assess the radiation dose absorbed by the uterine region during a full-mouth series of periapical and panoramic examinations, both with and without the application of a lead apron. For film-based intraoral X-rays, the measured radiation dose to the uterus was 2.66 μSv without a lead apron and 2.36 μSv with an apron. The radiation dose was marginally lower with digital X-rays, registering at 2.4 μSv without a lead apron and 2.23 μSv with one. For panoramic examinations, the uterine dose received without a lead apron was 7.97 μSv, which was reduced to 2.24 μSv with the use of an apron. The doses absorbed by the uterus were deemed low for both digital full-mouth and panoramic X-rays, although the use of a lead apron during panoramic imaging resulted in a significant further reduction of the absorbed dose. The dental devices used in the study were the Siemens Heliodent intraoral (film; Siemens, Bensheim, Germany), Gendex intraoral (digital; Gendex Dental Systems, Hatfield, PA, USA), and Instrumentarium panoramic (Instrumentarium Dental, Tuusula, Finland) machines. Reference guidelines were not specified.

Okano et al.[31] conducted a cross-sectional study using a RANDO female phantom (Alderson Research Laboratories Inc.) at the School of Dentistry, Showa University, Tokyo, Japan in 2009. Radiophotoluminescence glass dosimeters were embedded in various organs and tissues, including the uterus. The study employed 2 different CBCT systems: the 3D Accuitomo (Morita, Kyoto, Japan) and the CB MercuRay (Hitachi, Tokyo, Japan). The results from these systems were then compared to those obtained with multislice computed tomography (CT). The doses absorbed by the uterus ranged from 0.05 to 0.16 μGy using the 3D Accuitomo and were measured at 1.46 μGy for the CB MercuRay. The 3D Accuitomo dose was not only lower than that of the CB MercuRay, but it also was much lower than the conventional CT dose (2.74 μGy). The International Commission on Radiological Protection guidelines served as the reference for this study. However, the article did not include an analysis of the impact of lead apron shielding on dose absorption.

In 2013, Rottke et al.[32] conducted a cross-sectional study at the Dental Diagnostic Center in Freiburg, Germany, utilizing a RANDO full-body phantom (Alderson Research Laboratories Inc.) equipped with 110 thermoluminescent dosimeters at 55 different sites, including the uterine area. Two distinct panoramic radiography devices were used: the SCANORA 3D (Soredex, Tuusula, Finland) and the ProMax 3D (Planmeca, Helsinki, Finland). Each device was tested using 2 protocols: one without lead shielding, resulting in uterine absorbed doses ranging from 31.8 to 39.0 μGy for the SCANORA 3D and 19.8 to 75.6 μGy for the ProMax 3D, and another with a standard adult lead apron, which produced uterine absorbed doses ranging from 35.9

Table 2. Details regarding the 7 articles selected for this review, including authors, publication year, country, study type, sample type, dental examination performed, radiation dose, use of lead apron shielding, dental imaging device employed, exposure parameters, and international guidelines applied

Authors (year)	Country	Type of study	Type of sample	Dental exam	Dental device	Exposure parameters	Uterine/fetal radiation dose		Guidelines
							With lead apron	Without lead apron	
Hamilton et al.[1] (1984)	United States	Retrospective cross-sectional	Questionnaires and vital records from NNS-NFMS	Not specified	Not specified	Not specified	Not specified		None
Hujoel et al.[21] (2004)	United States	Population-based case-control	Dental insurance records from WDS and birth certificates	Full-mouth periapical Bitewing Periapical Panoramic	Not specified	Not specified	>0.4 mGy* 0.1-0.4 mGy* (Not specified)		None
Buch et al.[4] (2009)	South Africa	Cross-sectional	RANDO female phantom	Full-mouth periapical Panoramic	Siemens Heliodent: film Gendex: digital Instrumentarium: panoramic	70 kVp, 7 mA, 0.16-0.2 s 65 kVp, 7 mA, 0.16-0.25 s Not specified	2.36 μSv 2.23 μSv 2.24 μSv	2.66 μSv 2.40 μSv 7.97 μSv	None
Okano et al.[24] (2009)	Japan	Cross-sectional	RANDO female phantom	CBCT	3D Accuitomo CB MercuRay	80 kV, 5 mA 120 kV, 15 mA	0.05-0.16 μGy Not specified		ICRP
Rottke et al.[25] (2013)	Germany	Cross-sectional	RANDO Full-body phantom	Panoramic	SCANORA 3D ProMax 3D	68 kV, 13 mA, 19 s 73 kV, 8 mA, 15 s	31.8-39.0 μGy 19.8-75.6 μGy	35.9-53.8 μGy 17.3-85.4 μGy	EADMFR
Kelaranta et al.[1] (2016)	Finland	Cross-sectional	ATOM adult female phantom	Intraoral Panoramic Cephalometric CBCT	Planmeca ProX Planmeca Pro-Max 2D S2 Planmeca ProMax cephalostat Planmeca ProMax 3D Mid	60-70 kV, 6-7 mA, 0.1-0.2 s 66 kV, 8 mA, 15.8 s 66 kV, 10 mA, 6.4 s 90 kV, 10 mA, 12-27 s	0.009-0.553 μGy 0.04 μGy 0.69 μGy 0.80-2.11 μGy	0.0-0.017 μGy 0.11 μGy 0.71 μGy 2.64-6.93 μGy	EADMFR
Mortazavi et al.[21] (2019)	Iran	Retrospective cross-sectional	Maternal and neonate screening program	Not specified	Not specified	Not specified	Not specified		None

NNS-NFMS: National Natality and Fetal Mortality Surveys - 1980, WDS: Washington Dental Service, CBCT: cone-beam computed tomography, ICRP: International Commission on Radiological Protection, EADMFR: European Academy of DentoMaxilloFacial Radiology, *: estimated dental-related thyroid exposure to 53.8 μGy for the SCANORA 3D and 17.3 to 85.4 μGy for the ProMax 3D. No statistically significant differences were found in the absorbed doses regarding the use of lead apron shielding for either device. The guidelines followed in this study were those of the European Academy of Dento MaxilloFacial Radiology.

Kelaranta et al.[1] conducted a cross-sectional study in Helsinki, Finland, to evaluate the radiation doses received by the uterus and breasts during various dental X-ray examinations.[1] An anthropomorphic female phantom (ATOM 702-D; CIRS, Norfolk, VA, USA) was used for several dental X-ray imaging studies, including intraoral (ProX, Planmeca) panoramic (ProMax 2D S2, Planmeca), cephalometric (ProMax cephalostat, Planmeca), and CBCT (ProMax 3D Mid, Planmeca), both with and without lead shields. Furthermore, Kelaranta et al.[1] also analyzed the radiation dose to the uterus/fetus based on the presence of lead apron shielding. The findings showed that for panoramic X-rays, the dose was 0.11 μGy without shielding and 0.04 μGy with shielding. For cephalometric X-rays, the dose was 0.71 μGy without shielding and 0.69 μGy with shielding. In CBCT scans with a small field of view (FOV), the dose was 2.64 μGy without shielding and 0.80 μGy with it, while for a medium FOV, the dose was 3.75 μGy without shielding and 1.10 μGy with it. For a large FOV, the dose was 4.52 μGy without lead apron shielding and 1.28 μGy with shielding. Finally, for an extra-large FOV, the dose was 6.93 μGy without shielding and 2.11 μGy with shielding. Despite the observed decrease in radiation doses with the use of lead shielding, the authors concluded that the application of such protection was not necessary. As with the study by Rottke et al.,[32] the authors referenced the guidelines of the European Academy of DentoMaxilloFacial Radiology.

Table 2 presents data on various aspects of the selected studies, including the publication year, country, study type, sample type, dental examination performed, radiation dose received by the pregnant women, radiation dose received by the uterus/fetus (with and without lead apron shielding), the imaging device and parameters used, and the international guidelines applied. The articles unanimously indicated that dental imaging in pregnant women should be conducted only when it is clinically justified.[1,32] However, none of the articles reported the type of collimation employed or the number of dental examinations equivalent to the maximum safe radiation dose.

The authors of this systematic review conducted a comparative analysis (Table 3) to assist general dentists in determining when to request imaging studies for pregnant patients.[33,34] Table 3 provides the average effective dose values for each imaging examination. For intraoral radiography (full mouth), D-speed film had an associated dose of 388 μSv, F-speed/PSP film a dose of 171 μSv, and CCD sensor imaging a dose of 85 μSv. The effective dose for extraoral panoramic radiography was 9 to 24 μSv. Finally, CBCT was associated with the following effective dose ranges: large FOV, 68-1073 μSv; medium FOV, 45-860 μSv, and small FOV, 19-652 μSv. Notably, these authors considered an annual total radiation limit of 1 mSv (equivalent to 1 mGy or 1000 μGy) for pregnant women. This enabled the calculation of the number of each examination that can be undergone without exceeding the annual radiation limit. Consequently, the table includes these annual maximums, representing the number of each examination a pregnant woman could receive in a year while remaining under the radiation

Table 3. Comparison of effective dose and annual dose received by pregnant women across several dental examinations[27,31]

Dental exam	Effective dose (μSv)	Maximum annual number of exams of that type for pregnant women, while remaining under the 1-mSv dose limit	Is this modality tolerated by pregnant women?
Intraoral (1 exam)			
D speed film	27.7	36	Yes
F speed film/PSP	12.21	81	Yes
CCD sensor	6.07	164	Yes
Extraoral			
Panoramic	9-24	41-111	Yes
CBCT			
Small FOV	19-652	1-52	Yes
Medium FOV	45-860	1-22	Yes
Large FOV	68-1073*	0*-14	Considered

CBCT: cone-beam computed tomography, FOV: field of view, *: exceeds the annual dose limit of 1000 μSv for pregnant women limit. The present analysis indicates that the most restrictive exam in terms of the risk of exceeding the limit is large-FOV CBCT, with the annual limit for pregnant women falling between 14.7 and 0.93 CBCT exams. This means that large-FOV CBCT was the only imaging procedure to display an index below zero, suggesting that 1 imaging study could potentially provide an annual radiation dose surpassing the acceptable limit for pregnant patients.

Discussion

The most frequently performed imaging examinations in dental clinics include intraoral and panoramic radiography, as well as CBCT. Each of these utilizes ionizing radiation, which generates free radicals in the human body. The potential harm from ionizing radiation varies based on the dosage received and the body's response, with effects that can manifest immediately or over a longer period.[1] However, many researchers contend that imaging exams employing low doses of radiation, such as intraoral radiography, expose patients to negligible risk of radiation harm.[1] Consequently, it is crucial to establish protocols that define the maximum safe dosage values and the corresponding limits on the number of dental imaging procedures for pregnant women, to prevent adverse effects on the developing fetus.[1,35]

In the context of dental imaging in pregnant women, Buch et al.[4] discussed the radiation dose of full-mouth periapical examinations using conventional films and digital radiographs. They described this dose as minimal, equivalent to approximately half a day of natural background radiation when considering the radiation that directly reaches the uterine region. These researchers found no significant difference in radiation exposure to the uterus between patients with and without lead shielding. Nevertheless, they emphasized that the dental surgeon must take responsibility for safeguarding the pregnant patient from radiation exposure, while not disregarding the potentially harmful stochastic effects of even low-level radiation, as encountered in intraoral and panoramic radiographs.[4] In countries where circular collimators are used, radiation protection shields are recommended. Overall, dental imaging procedures are always justified when the clinical condition of the patient - whether pregnant or not - necessitates the examination,[16] particularly in instances of dental pain. The complications arising from poor oral health may pose a greater risk to the fetus than the extremely low levels of ionizing radiation.[1]

Hujoel et al.[21] related ionizing radiation from X-rays to low birth weight in newborns. They suggested that this condition may be connected to radiation exposure within the mother's thyroid region during pregnancy, potentially leading to hormonal changes.[15,21] In 2005, however, Brent[36] challenged this link, citing the negligible impact of human growth hormone on the fetus. Specifically, this hormone typically becomes physiologically active only several months after birth, with the exception of cases involving mothers with a history of severe hypothyroidism. Therefore, although the epidemiological study demonstrated a valid statistical association, the underlying hypothesis and primary conclusion may be flawed. The high risk of bias with regard to confounding variables supports this skepticism. Nevertheless, further investigation into the thyroid area in pregnant women is warranted to protect fetuses and avert potential harm to newborns. These studies should consider both low and high doses of radiation across all trimesters of pregnancy. The urgency of such research is heightened in countries where X-ray machines with circular collimators are in use, as these devices expose patients to radiation across a larger area.[15,20,21]

Research by Mortazavi et al.[20] contradicted the conclusion of Hujoel et al.[21] and Hamilton et al.[15] that exposure to radiation from dental radiographic examinations may increase the risk of low birth weight in newborns. Their study found no correlation between the weight of newborns and the performance of dental radiographic examinations among pregnant women, indicating that such examinations do not affect newborn weight. Additionally, Hamilton et al.[15] found no significant association between exposure to dental X-rays during pregnancy and the occurrence of stillbirth. In the present review, a high risk of bias was identified for certain aspects of the experimental designs used in the studies by Hamilton et al.[15] and Mortazavi et al.,[20] potentially limiting the validity of these associations. Additionally, no CBCT examinations, which involve a higher dose of exposure, were conducted on the pregnant women in those studies. Further research is recommended, utilizing phantoms that simulate the dimensions of a pregnant abdomen to replicate the radiation dose from various CBCT devices and protocols in the uterine region.[31] The cross-sectional design employed in this type of study has been deemed satisfactory in terms of conception and methodological approach, particularly with respect to the safety of the outcomes. However, the inclusion of phantoms that better mimic the size of the abdomen during pregnancy could enrich future research findings.

Dental professionals worldwide can rely on guidelines that specify the types of X-ray equipment available on each continent and the appropriate radiation levels for various dental examinations, including intraoral and panoramic radiography as well as CBCT.[3,9-14] These guidelines encompass regulatory protocols for each dental specialty and promote the principle of As Low as Diagnostically Acceptable (ALADA), which advocates for the use of the minimal radiation dose possible while still achieving an image resolution sufficient for adequate diagnosis.[3,9-14,37] Only 3 articles used any such guidelines to contextualize their findings regarding the risks associated with dental imaging in pregnant women.[1,29,32] The authors noted that international and European guidelines for protection in dental radiology can vary and emphasized the necessity for specific measures to safeguard patients and professionals from ionizing radiation.[10,12,13] Additionally, their investigations sought to determine a safe radiation dose for dental imaging procedures (intraoral, panoramic, and CBCT), with and without the use of lead aprons to shield the uterine area. The findings indicated that the radiation doses involved were substantially lower than recommended maximums for pregnant women.[1,31,32,33] Accordingly, Kelaranta et al.,[1] Okano et al.,[31] and Rottke et al.[32] concluded that lead aprons were unnecessary in this context, as were other radiation protection shields. This stance may be acceptable in European countries, where X-ray units are equipped with rectangular collimators that limit the area of patient exposure to radiation.

The recommended radiation doses for pregnant women undergoing radiographic examinations, such as intraoral and panoramic radiographs, differ from those for CBCT.[4,33,36] These guidelines dictate the selection of the collimated area and protocols based on the specific indication for the tomographic examination, which can vary across continents. Kelaranta et al.[1] reported estimated fetal doses ranging from 0.009 to 6.9 μGy without a lead shield and from 0.005 to 2.1 μGy with a shield. Both of these dose ranges are considered safe, as they fall below the threshold associated with any risk of radiation exposure to the fetus, especially when compared to radiological exams of the abdominopelvic region.[13] Other studies have reported lower uterine doses than those found by Kelaranta et al.,[1] such as the findings of Buch et al.[4] regarding intraoral and panoramic radiography. However, the results of Buch et al.[4] were higher than those identified by Okano et al.[31] for CBCT images. Notably, Rottke et al.[32] reported radiation exposure doses ranging from 17.3 to 85.4 μGy, without advising the use of a lead apron for pregnant patients. The present authors assessed the safe dose for pregnant women in light of these guidelines. In comparison, Hujoel et al.[21] reported that a dose exceeding 0.4 mGy, which is approximately 5 times higher than the maximum dose posited by Rottke et al.,[32] could result in low infant birth weight. This conclusion warrants caution, as the amount of background radiation exposure during pregnancy is around 0.9 mGy, including exposure to the thyroid gland.[36,38] The present analysis identified a high risk of bias in the measurement of exposure, supporting previous critiques. Additionally, the lack of a defined maximum exposure dose in the study by Hujoel et al.[21] represents another point of contention.

The estimated fetal dose from a standard single intraoral dentomaxillofacial radiology digital examination is approximately 6-7 μGy.[32] From a biological perspective, deterministic effects are not a concern at this level. For instance, embryonic death, which can occur with exposure at 0-9 days, has a threshold dose of about 100 mGy, a value that is roughly 14,000 times higher than the fetal doses provided by dental imaging. Similarly, the threshold for mental retardation and microcephaly, associated with exposures at 8-25 weeks, is 300 mGy, making the fetal doses from dentomaxillofacial imaging approximately 42,000 times lower. Studies have not identified a risk of childhood cancer induction from *in utero* radiation at doses below 10 mGy. The excess absolute risk is calculated at 6% per Gy. By approximating the fetal dose to 10 μGy, this corresponds to an additional 6 cases of cancer per billion examinations.[36] Given the negligible increase in the risk of cancer-related death in children due to exposure, lead shielding has been deemed unnecessary.[1,9-14]

At present, the annual dose limit for the fetus of a worker who has declared a pregnancy is set at 1 mSv (1 mGy), which, when compared to the radiation exposure from a single dental examination without lead shielding, carries a risk of 0.7% (less than 1%).[1] Furthermore, the application of lead aprons has been shown to reduce the fetal dose by 39% to 97%, leading the authors to suggest that inquiring about pregnancy may be unnecessary in dental radiology.[1,39] Fetal doses from intraoral, panoramic, and cephalometric examinations without lead shields constitute 0.1% to 10% of the maximum fetal doses observed in CBCT.[1] However, none of the studies reviewed described the relationship between the dose limit and the number of specific dental examinations permitted.

Beyond the fundamental radioprotection measures that should be taken for pregnant women, one must not overlook additional precautions during dental imaging procedures that can safeguard patients in general from ionizing radiation exposure. Such measures include utilizing a rectangular collimator for intraoral X-ray devices and employing image receptors of higher sensitivity. For panoramic radiographs, it is advisable to use the minimal beam intensity and incorporate automatic exposure control. Furthermore, CBCT protocols should prioritize lower doses of ionizing radiation, in continuous alignment with the radioprotection guidelines endorsed by the ALADAIP principle. Lastly, the indication for an imaging examination should be carefully assessed before proceeding, ensuring that its execution is fully justified.[31,37]

Thus, the present study provides newly summarized information regarding the number of dental imaging examinations pregnant women can receive relative to the recommended annual limit of ionizing radiation exposure. Although this threshold has been documented in various international guidelines, it alone does not enable a straightforward interpretation of the permissible number of imaging procedures for dentists who recommend and conduct these examinations. Accordingly, the present findings serve as a crucial reminder for dental clinicians to exercise caution when prescribing imaging tests, with the aim of consistently mitigating the potential impact of cumulative stochastic radiation doses that may pose risks to pregnant patients and their developing fetuses.[27,31]

Based on the results of this systematic review, it can be concluded that dental imaging examinations for pregnant women should not be restricted in cases with a proper clinical indication, as the health benefits outweigh the minimal potential risk. Furthermore, no evidence was found to suggest the necessity of using a lead apron or thyroid shield. In the field of dental radiology, while some articles have established safety protocols regarding radiation dose, the estimated number of dental imaging examinations acceptable specifically for pregnant women has not been previously addressed. Ultimately, since dental imaging does not pose risks to the fetus - such as fetal growth retardation or death - and considering the limited evidence linking it to low birth weight, no justifiable reason exists to delay or avoid radiographic exams during pregnancy. Finally, it is imperative to adhere to the principle of justification for the examination and to follow the ALADAIP guidelines for radioprotection, which are particularly crucial for pregnant women undergoing procedures involving ionizing radiation.

Conflicts of Interest: None

References

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