REVIEW ARTICLE

# Advances in Radiation Protection in Oral and Dental Radiology: Pragmatic Approaches and Recent Innovations

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Received: 21 October 2023 / Accepted: 16 November 2023

## Abstract

**Purpose:** The utilization of Ionizing Radiation (IR) in diagnostic dental techniques poses inherent risks, especially when patients are exposed to it repeatedly. Therefore, it is crucial to continuously evaluate and improve the measures taken to protect individuals from the potentially harmful effects of ionizing radiation in dental radiology. This study desires to assess the advancements made in recent years regarding ionizing radiation protection measures in the field of dental radiology.

**Materials and Methods:** A thorough review was conducted using prominent databases such as PubMed, Science Direct, and Dentistry and Oral Sciences Source (via EBSCOhost). The primary conclusions and relevant units of measurement are also included. According to the predefined inclusion and exclusion criteria, a total of 26 articles were systematically reviewed for this study.

**Results:** Recent data reveals the urgent need to update radiation protection guidelines to accommodate newer technologies like Cone Beam Computed Tomography (CBCT) and digital imaging. Digital intraoral X-ray technology has shown promising results in significantly reducing radiation exposure. To ensure standardized practices, Diagnostic Reference Levels (DRLs) have been defined for CBCT and must be established for different clinical indications. Moreover, advancements in nanotechnology provide potential opportunities for the production of radiation shielding supplies that are lighter and customizable. These innovative materials can prove invaluable for everyday use, offering enhanced protection during extended periods of physical activity. The review findings suggest that samples with nanostructures are more efficient at reducing X-ray energy. The research findings indicate that the implementation of a nanocomposite shield leads to a notable reduction in radiation dose, with a range of 15 to 35%. Given the increasing frequency of dental CBCT imaging and the unmatched dose levels compared to conventional dental radiography, it is imperative to set DRLs in this domain.

**Conclusion:** This literature review focuses on the most common types of radiation protection in dental radiology, aiming to demonstrate improved techniques for individual protection.

**Keywords:** Dental Radiography; Radiation Safety; X-Ray Shielding; Cone Beam Computed Tomography; Diagnostic Reference Levels.


DOI: https://doi.org/10.18502/fbt.v12i1.17745

## 1. Introduction

X-ray imaging is utilized in various medical fields to identify different ailments. These fields comprise skeletal, vascular, digestive, urinary, neurological, and dental system examinations [1-5]. Radiological exams are commonly utilized in dentistry for a variety of diagnostic and treatment-planning purposes [6]. The two primary types of dental X-ray radiography apparatus are: By inserting an X-ray film within the patient's mouth, intraoral equipment creates an image that contains extensive information about the condition of the patient's teeth, jawbones, and tooth roots as well as the presence of cavities [7, 8]. Dental practices use various extraoral X-ray systems, such as Cone Beam CT (CBCT), panoramic, and cephalometric [9, 10].

The latest advancement in dental radiology is CBCT, which was initially created for the maxillofacial region in 1995 and has been commercially available since 1999. Its widespread use is mainly due to its affordability as a diagnostic technology, allowing for treatment planning and image-guided surgical and operative procedures [11]. Intraoral radiographs are the prevailing method of dental X-ray investigations, with a substantial number of cases recorded globally. For instance, in the United States, the frequency of intraoral radiographs reaches approximately 100 million, while in Canada, it amounts to around 4 million. Similarly, in Europe, the number of intraoral radiographs conducted is estimated to be around 16 million. These statistics highlight the extensive reliance on dental radiography for diagnostic purposes [12]. Depending on the imaging technique, each type of equipment is capable of delivering a variety of radiation dosages.

This type of radiation has the potential to trigger the generation of free radicals within the body, which can subsequently lead to the formation of cytotoxic monomers, tissue hurt, swelling, and other physiological processes [13]. It is important to note that DNA damage can occur through both the impact of free radicals and direct interactions with DNA and these types of damage can give rise to deterministic and stochastic effects resulting from Radiation Exposure (RE) [14, 15]. According to the National Radiation Protection Board (NRPB) and the International Commission on Radiation Protection (ICRP), it is widely reinforced that there is no edge dose below which radiation can be considered entirely safe. In other words, exposure of any tissue to radiation holds the potential to induce malignant changes, further emphasizing the importance of radiation protection measures in dental radiography [16, 17].

Furthermore, protective shielding is one of the most naive ways to avoid unneeded RE to the patient's other organs or the radiologist or technician. Lead has received a lot of attention in X-ray protection since the beginning due to its high atomic number and significant density [18]. Lead can be used alone, in combination with polymers, or as flexible lead aprons and lead sheets for walls. These aprons are quite heavy, making prolonged use uncomfortable. When worn repeatedly, they may potentially cause back pain [19]. These flaws motivate scientists to design eco-friendly nano-composites or look for lead-free shielding materials. In general, binders and additives combined with attenuating heavy metals are used to create non-lead shielding materials [17, 20].

Also, rectangular collimation significantly lowers the dose for intra-oral radiography compared to round collimation. Low-dose protocols in CBCT can reduce radiation dose without compromising image quality. A well-known technique for dose optimization known as Diagnostic Reference Levels (DRLs) has not yet been developed for CBCT and should be modified for various clinical purposes [21]. Making sure diagnostically appropriate radiographic pictures are obtained on the first try without the need for a second try is another strategy to protect the patients. Additionally, proper formal training in dental radiography could lower the frequency of radiological errors [10].

The primary objective of this paper is to offer a comprehensive overview of radiation protection in dental radiology, with a specific emphasis on the introduction of novel X-ray techniques in recent times such as CBCT, digital imaging, and other innovative modalities.

## 2. Materials and Methods

The process of article selection for this comprehensive review was guided by specific inclusion criteria. These criteria ensured that the chosen articles met rigorous standards and contributed to the research objectives. The criteria involved the following aspects:

The articles had to be original, quantitative papers, review papers, theses, conference papers, or ongoing papers written in English. This diverse selection aimed to encompass a broad range of research sources and perspectives in the field of oral radiology. The studies included in this review encompassed both experimental procedures and simulations, utilizing advanced methods such as the Monte Carlo, Geant 4, and Gate methods. This inclusion criterion aimed to incorporate studies that explored various approaches to dose reduction in oral radiology. To ensure a comprehensive search, multiple reputable databases were systematically explored. These databases included PubMed/Medline, Embase, ProQuest, Scopus, Cochrane, and Google Scholar. The search strategy in each database involved the utilization of Mesh keywords and suitable synonyms. The search terms used were as follows: ((radiation protection [Title/Abstract]) AND ((("radiation shielding"[Mesh]) OR dose reduction in oral radiology [Title/Abstract]) OR dental radiology [Title/Abstract])) AND ((Nanocomposite shields [Title/Abstract])). The search was conducted within the time frame of March 2015 to March 2022. In addition to the database search, a manual search was conducted on the reference lists of the identified articles. This approach aimed to identify any relevant articles that may have been missed during the database search. It is important to note that the search was limited to articles published in English, as the review focused on English-language literature to ensure consistency and accessibility. By adhering to these rigorous article selection criteria and employing a comprehensive search strategy, this review aimed to provide an extensive and up-to-date analysis of the approaches to dose reduction in oral radiology, incorporating a wide range of research sources and perspectives. According to the predefined inclusion and exclusion criteria, a total of 26 articles were systematically reviewed for this study.

## 3. Results

### 3.1. Shielding

#### 3.1.1. Lead-Based Shielding

The use of shields is a crucial factor in radiation protection in radiology. It is essential to employ shielding for sensitive organs like the gonads, eye lens, breast, and thyroid. Customizing the use of shields based on individual patient requirements is of utmost importance. Proper positioning of these devices on the patient is critical to prevent artifacts and avoid disruption of the X-ray machine's automatic exposure control. Neglecting these precautions can have severe consequences for the patient's well-being [21-23]. Various common radiation protection tools such as rolling shields, ceiling-suspended shields, lead aprons for operators, collars, and lead glasses effectively block a significant portion of scattered radiation [24]. In a recent study conducted in 2022, Anna Kelaranta *et al.* examined the impact of lead shields on reducing absorbed radiation dose in the fetus and breast during dental X-ray examinations. In their study, the researchers employed an anthropomorphic female phantom as a means to assess the levels of RE associated with various dental procedures, namely intraoral, cephalometric, panoramic, and CBCT. The evaluation was conducted in two scenarios: with and without the implementation of

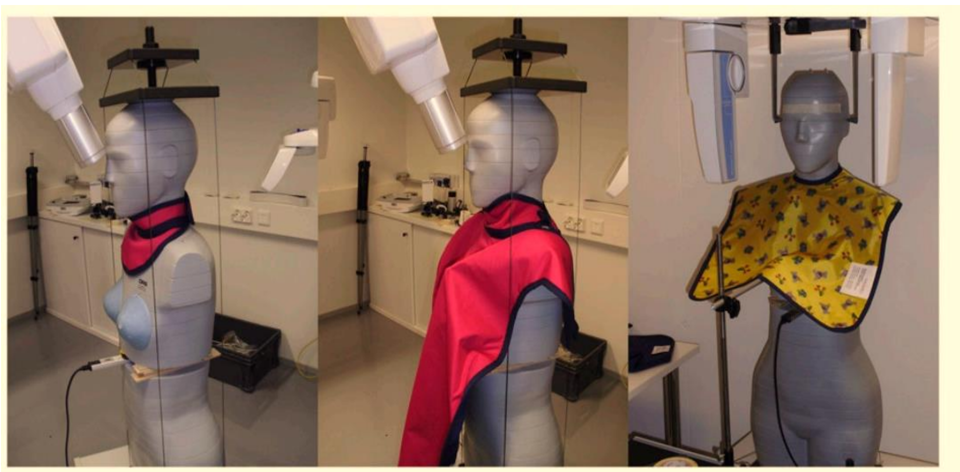

**Figure 1.** The shields were designed for three specific areas: (a) the thyroid, (b) the breast and abdominopelvic region, and (c) the breast and upper abdomen [20]

lead shields. This approach allowed for a comprehensive examination of the effectiveness of lead shields in minimizing RE during these dental procedures (Figure 1) [25].

The researchers concluded that the doses received at the surface of the breast ranged from 0.602 to 75.4 µGy, while the estimated doses for fetuses ranged from 0.009 to 6.9 µGy. When lead shields were used, the fetal doses varied between 0.005 and 2.1 mGy, and the breast doses ranged from 0.002 to 10.4 µGy. In another study conducted by Lifeng Yu *et al.*, they conducted a comprehensive investigation to determine the precise reduction in dose achieved by utilizing lead aprons during pediatric chest CT scans. The researchers assertively emphasized the crucial role played by the distance between the apron and the bottom of the scan range in achieving this decrease [26].

To simulate the RE encountered by a 5-year-old child, the researchers positioned semi-anthropomorphic phantoms representing the head, abdomen, and pelvis near the chest phantom. Following this, a CT scan of the chest region was conducted, and a point dosimeter was employed to measure the radiation dose both within and outside the scanning range. To examine the impact of radiation, a lead apron was placed at varying distances (1, 5, and 10 cm) from the lower boundary of the CT scanning range, and the measurements were repeated accordingly. Subsequently, the researchers calculated the weighted average dose for each measurement position. This meticulous experimental setup allowed for a comprehensive evaluation of the radiation dose and its distribution about the placement of the lead apron, providing valuable insights into radiation protection strategies for young children undergoing CT scans.

Based on the findings of the study, it was discovered that the weighted average dose within the CT scan range was determined to be 1.7 mGy. In contrast, outside the scanning range, the average dose dropped significantly to a mere 0.067 mGy. The introduction of a lead apron proved to be highly effective in reducing the mean dose outside the scanning range. When the apron was positioned at distances of 1, 5, and 10 cm from the bottom of the scan range, the mean dose reduction percentages were calculated as 19.1%, 10.1%, and 4.3%, respectively. These results highlight the importance and effectiveness of utilizing lead aprons in minimizing RE to areas beyond the scanning range, thereby enhancing radiation protection for pediatric patients undergoing CT scans. Taking into account the primary scan, the total percentage dose reduction was 0.7%, 0.4%, and 0.2%, respectively. These findings underscore the importance of employing a lead apron to minimize RE outside the scan range.

It is indeed important to acknowledge the potential health hazards associated with the use of lead as a radiation-shielding material. While lead has traditionally been utilized for its effectiveness in shielding gamma rays and X-rays, its toxicity and heavy nature pose significant risks. The accumulation of lead in the body can lead to chronic and acute health disorders, as it is not efficiently eliminated [27]. Furthermore, understanding the various pathways through which lead can enter the human body is crucial in addressing these concerns.

With the advent of nanotechnology, there is a growing demand for innovative radiation shielding materials that are not only effective but also safe, environmentally friendly, lightweight, and reliable. This has sparked a rapid expansion in radiation-related sectors, including healthcare (such as radiotherapy and medical imaging), nuclear power plants, and industries. As a result, there has been significant progress in the development of fabrication and characterization techniques for novel lead-free composite materials. Polymer micro-composites and nanocomposites, in particular, have emerged as promising options due to their numerous advantages [28]. These materials offer the potential for enhanced radiation shielding capabilities while addressing the drawbacks associated with lead-based alternatives.

The ongoing research and development in the field of nanocomposites for radiation shielding purposes highlight the importance of finding alternative materials that can effectively protect against RE. By exploring and harnessing the potential of these new materials, we can contribute to the creation of safer and more sustainable radiation shielding solutions for various applications, ultimately benefiting both individuals and the environment.

#### 3.1.2. Nanocomposites-Based Shielding

To address the limitations of lead sheets, researchers turned to the use of nano-composite sheets

[29]. In 2023, Asadpor *et al.* utilized Geant4 Monte Carlo simulation to evaluate the shielding performance of multi-metal nanoparticle composites in the field of diagnostic radiology. The results may have demonstrated that the multi-metal nanoparticle composites effectively attenuated radiation, thereby reducing the dose received by the surrounding environment. This would suggest that these composites have the potential to be used as effective shielding materials in diagnostic radiology settings. The comparison included highly hydrogenous substances like polyethylene and hydrides, as well as substances like aluminum and complex hydrides with high Z metals that have minimal hydrogen [30]. The study revealed that $LiBH_4$ exhibited the highest shielding efficiency, being 1.2 times more effective than polyethylene. LiH and NH3BH3 also outperformed polyethylene in terms of shielding effectiveness. Composite materials, such as Carbon Fiber Reinforced Plastic (CFRP) and Silicon Carbide (SiC) composite plastic, have emerged as highly favorable choices for spacecraft components. This preference is primarily attributed to their exceptional mechanical strength and remarkable shielding effectiveness, which surpasses that of traditional metals. Studies have indicated that CFRP and SiC composite plastic exhibits a shielding effectiveness that is 1.9 times higher than that of metals. The superior mechanical properties of CFRP, including its high tensile strength and stiffness, make it an ideal choice for structural components in spacecraft. Its lightweight nature also contributes to fuel efficiency and overall spacecraft performance. Moreover, CFRP offers excellent resistance to corrosion, which is crucial for prolonged space missions. On the other hand, SiC composite plastic possesses exceptional thermal and mechanical properties, including high-temperature resistance, strength, and stiffness. These characteristics make it suitable for applications in extreme environments, such as space. Additionally, SiC composite plastic has demonstrated superior radiation shielding effectiveness compared to metals, offering enhanced protection against cosmic radiation and other forms of space-based radiation [31].

Furthermore, a study conducted in Turkey in 2022 explored the incorporation of Graphene Oxide (GO) as a nanomaterial into various fabrics, enabling the fabrication of radiation-shielding constituents that could potentially replace lead. The study described the creation of a nano-GO composite material for protection against X-rays. The material in question exhibits crucial characteristics that are essential for daily usage in clinical textiles. These include air and water permeability, lightweight, and flexibility. These attributes make it highly suitable for practical and regular use in various clinical settings. In comparison to traditional lead aprons, the utilization of nano-coated Graphene Oxide (GO)-composite fabrics as shielding material offers a practical and reliable alternative [17].

The study conducted by Nurul Z *et al.* focused on investigating the impact of $Bi_2O_3$ particle sizes and the addition of starch to $Bi_2O_3$ -PVA complexes for X-ray guarding purposes across various X-ray energy series. The research findings indicated that the presence of starch helped mitigate the dependency of the $Bi_2O_3$ particle size effect on the density of the PVA background. This improvement in the comparability of particle sizes enhanced the efficiency of X-ray shielding [32, 33]. In a separate study, Le Yu *et al.* explored the development of cutting-edge Pb-Free X-ray shielding using insubstantial bismuth titanate ($Bi_4Ti_3O_{12}$) nanocomposite. The researchers adopted an eco-friendly material engineering and processing approach to create the BTO-ER composite, which exhibited promising characteristics as a novel, lightweight, free-toxic, and high-performance X-ray protection material. The D-65BTO-ER composite demonstrated remarkably low X-ray transmission tenets of only 2.55% and 5.65% at X-ray energies of 80 and 100 kVp, in turn. Growing the number of BTO particles in the composite led to enhanced X-ray attenuation capabilities due to increased densities, thicknesses, and the narrow size effect on the polymer. Notably, the 2 mm thick BTO-ER composite, with a low mass per unit area of 0.004 $g/mm^2$, provides 0.35 mm Pb comparable attenuation at X-ray energies of 80 and 100 kVp, making it a promising lead-free material for X-ray protection applications. These significant findings emphasize the potential of BTO-based composites as a leading alternative for X-ray shielding, replacing hazardous Pb-based materials with safe, reasonable, and environmentally friendly X-ray protective clothing [20, 34].

### 3.2. Digital Imaging and Dose Reduction

The implementation of digital imaging in oral radiology has greatly advanced the experimental training of dentists. Digital imaging, particularly for intraoral radiography, offers numerous advantages such as improved X-ray handling, enhanced storage capabilities, time savings, and reduced radiation dosage. Contemporary education indicates that as digital receptor equipment continues to evolve, the image quality and spatial resolution are becoming comparable to, and even surpassing, that of film imaging. Consequently, patient doses are expected to decrease as digital detectors necessitate shorter exposure periods [21].

When film is used for imaging, it is recommended to use E-speed class films instead of D-speed class films. E-speed films are more cost-effective, reduce dosage by 40-50%, and provide comparable image quality. They fall within the same category as D-speed films in terms of instant filming and radiation dose, with E-speed films receiving a dose four to six times higher. The development of digital technology allows for a 50% reduction in RE compared to conventional screen-film systems, without compromising image quality. Digital systems offer equivalent or improved diagnostic performance, along with other advantages. However, there is a possibility of overexposure without a detrimental effect on image quality. Technologies for digital radiography imaging can produce satisfactory image quality across a wide range of exposure limits and are suitable for various clinical applications [35].

According to a 2020 study conducted in the United States, around 85% of dental offices have adopted digital intraoral X-ray equipment, significantly reducing exposure. Although digital panoramic X-rays still expose certain anatomical regions continuously as the machine rotates around the patient's head, they still contribute to reduced RE. Meanwhile, CBCT, which combines multiple images to create a 3D perspective, has been steadily making its way into general dental practices [36].

To demonstrate the notable variations in radiation dosages, it is worth noting that a complete mouth series consisting of 18 intraoral images taken with digital receptors or E- and F-speed film, utilizing rectangular collimation, is equivalent to an exposure of 4.3 days of background radiation. However, in the USA, where circular collimation is more commonly employed, a full-mouth series corresponds to an exposure of 21 days of background ionizing radiation. It is important to mention that for dentists who do not utilize digital technology and opt for the slower D film speed, the same series would result in an exposure equivalent to 47 days of background radiation. These findings emphasize the substantial differences in radiation dosage based on the type of imaging technology and collimation technique used in dental practices [37].

In a study conducted by Khaled Al Khalifa *et al.*, the researchers aimed to identify the optimal mixtures of goal and filter resources for different X-ray tube voltage sets, taking into consideration their impact on image quality and radiation dose. For this investigation, various Digital Mammography (DM) imaging methods were utilized, along with breast-equivalent phantoms. The results of the study indicated that for compressed breast thicknesses of 6 cm with 20% glandular tissue and 80% adipose tissue, the Tungsten (W)/Rhodium (Rh) combination yielded the most favorable outcomes. This particular combination offered good image quality while minimizing RE. Therefore, it is strongly recommended to implement this mixture whenever feasible. In situations where the W/Rh combination is not possible, the Rh/Rh or Molybdenum (Mo)/Rh combinations are the next best alternatives. It is important to note that the imaging machine automatically selects the appropriate filter based on the thickness and density of the breast, ensuring optimal results in terms of image quality and radiation dose [38].

Another study by Simabuguro *et al.* compared the equivalent and effective dosages of various digital radiography techniques (panoramic, lateral cephalometric, and periapical) with CBCT. The researchers found that the doses generated by digital radiography in orthodontic settings were lower than the effective doses delivered by CBCT. However, the radiation output of the orthodontic set was higher in certain areas during periapical evaluations. It is important to adhere to the ALARA principle and to use tomographic images instead of radiography only under very limited circumstances. For restricted areas, it is preferable to use a single periapical radiograph rather than a full periapical examination [39].

In a study conducted by Praskalo *et al.*, intraoral X-ray radiography was performed in Bosnia and Herzegovina for the extraction of adult patients' incisors, premolars, and molars, both maxillary and mandibular. The results indicated that devices with digital image receptors had lower dose descriptor values compared to devices with film-based image receptors. The average air kerma values for film-based intraoral devices ranged from 0.98 mGy for mandibular incisors to 2.9 mGy for maxillary molar examinations. On the other hand, average dosimetric quantity values for digital systems ranged from 0.38 mGy for mandibular incisors to 0.96 mGy for maxillary molars, which were significantly lower than those for analog systems [40]. These findings provide evidence that the use of procedures with digital image receptors is essential for reducing dose descriptor values compared to film-based image receptors.

### 3.3. Diagnostic Reference Levels (DRLs)

To optimize radiological practices and reduce radiation dose, both the European and International Basic Safety Standards define DRLs. It is essential to conduct a local review if a patient receives an unusually high or low dose of radiation during an X-ray procedure. While there are published DRLs for different X-ray modalities, recent literature has not established any for CBCT and dental Multi-Detector Computed Tomography (MDCT) examinations. Given the increasing use of CBCT in dental radiology and the potential for high patient radiation doses, it is crucial to establish CBCT DRLs. Ideally, DRLs should be set for numerous experimental signs to ensure patient safety [21].

In a study conducted in 2021, the surface-absorbed dosages of crucial organ regions, specifically the thyroid and parotid glands, were studied. The researchers, Zamani *et al.*, assessed Dose Area Product (DAP) values and constructed a local DRL for panoramic radiography. The study included data from 201 patients, comprising 141 adults and 60 children (5–10 years old), from six radiology clinics in the Yazd province. TLD dosimeters (GR-200) were implemented to determine the surface absorbed dosage in the thyroid and parotid gland regions for each patient. The DRL values were computed using DAP values in accordance with the ICRP recommendation. The local DRL values for the adult and child groups were measured as 99.7 and 73.4 mGy.cm2, respectively. The study found that the use of higher radiation parameters resulted in higher surface absorbed dose values in the adult group [41].

In a separate study conducted by Jose *et al.*, the researchers focused on determining the regional DRLs for dental radiography in Tamil Nadu. The investigation involved examining the impact of routine adult exposure to various types of X-ray devices, including intraoral, panoramic, cephalometric, and dental CBCT machines. The team evaluated the DRLs by considering two parameters: incident air kerma (Ka, i) and Kerma Area Product (PKA). To measure air kerma, a calibrated RTI black Piranha 557 dosimeter was utilized for all dental units. The study calculated the third quartile values for adult intraoral (mandibular molar), panoramic, cephalometric, and CBCT radiation based on the median, resulting in values of 1.5 mGy, 116 mGycm$^2$, 40 mGycm$^2$, and 532 mGycm$^2$, respectively. These values represent the recommended upper limit of RE for each type of dental radiography procedure. It is noteworthy that the DRLs proposed in this study align with those reported in other countries such as Germany, Greece, the UK, Japan, and Korea. This consistency suggests a global understanding and agreement on the acceptable levels of RE in dental radiography. By establishing regional DRLs, this study provides valuable guidelines for dental practitioners in Tamil Nadu to ensure that radiation doses are kept within safe limits while maintaining diagnostic image quality. These findings contribute to the ongoing efforts to promote radiation safety and optimize dental radiographic procedures for the benefit of patients and healthcare professionals. The findings indicate a requirement for effective dose management and optimization of radiation dosage in dental facilities across the state. Additionally, the study discovered that the use of digital detectors in dental facilities does not necessarily lead to reduced exposure levels [42].

A study conducted by Zamani *et al.* in 2019 investigated the DRLs in CT of adults based on the criteria of volume average CTDI and Dose Length Product (DLP) in the Yazd province. The study included six multi-layer CT scanners and seven standard techniques spread over the province. At least 20 patients who were at least 18 years old were sampled for each approach at each facility. The suggested DRLs for CT scans were given in terms of the CTDI and the DIP. The proposed DRLs for different parts of the body were slightly lower than those recommended for other medical investigations.

In a study conducted by Praskalo *et al.* in 2019, data was presented to support the adjustment of the currently valid DRL for intraoral dental X-ray radiography in Bosnia and Herzegovina. The study encompassed the measurement of 41 intraoral X-ray systems, including 20 systems with digital image sensors and 21 film-based systems. To assess patient dosage, incident Ki and PKA were utilized as descriptors. The findings of the study revealed that the third quartile values for both types of devices, film-based and digital image sensors, were lower than the existing national DRL. Specifically, the third quartile values were 3.5 mGy for film-based systems and 1.2 mGy for digital image sensor systems, whereas the current national DRL stood at 7.0 mGy, based on the Q3 data. This suggests that the radiation doses used in intraoral dental X-ray radiography can be reduced without compromising diagnostic quality (Figure 3). Furthermore, the study emphasizes the importance of establishing national DRLs for other dental radiographic procedures such as panoramic radiography and dental cone beam computed tomography. These procedures, along with intraoral X-ray radiography, play a vital role in dental diagnostics and involve patient exposure. Implementing national DRLs in these areas would be crucial for future research and for ensuring that radiation doses are optimized while maintaining diagnostic accuracy. The data presented in this study provides valuable insights and highlights the need for regular assessment and adjustment of DRLs to promote radiation safety and improve patient care in dental radiography [43].

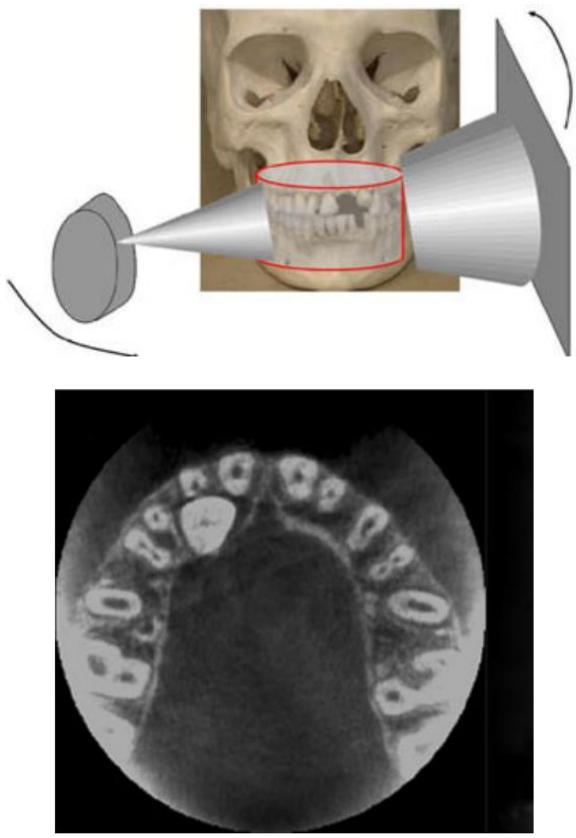

**Figure 2.** Illustration of Extraoral dental technique cone beam CT (Up), Cone beam examination of the right impacted canine reveals resorption of the neighboring incisors, not seen on the panoramic image (Bottom) [41]

In another study, Asgharzadeh *et al.* measured Dose-Width Product (DWP) amounts for dental panoramic radiography and developed a local DRL. The study involved five panoramic equipment in five radiography clinics in Kashan, Iran. Exposure parameters for each patient were extracted to investigate the DWP values. The dose received by the thyroid gland and the lens of the eye was calculated using thermoluminescent dosimeters. The local DRL for panoramic radiography was determined to be 250 $mGycm^2$. The study also found that there was a significant variation in the DWP values among the different panoramic equipment, indicating the need for standardization and optimization of radiation doses in dental radiography. In summary, the establishment of DRLs is crucial in ensuring patient safety and optimizing radiation doses in dental radiology. Studies have been conducted to determine DRLs for various dental imaging modalities, including panoramic radiography, CBCT, and intraoral radiography. These studies have provided valuable data on radiation doses and have proposed local DRL standards based on different parameters such as DAP, incident air kerma (Ka, i), PKA, CTDI, and DLP. The findings of these studies highlight the importance of effective dose management and the need for standardization and optimization of radiation doses in dental radiography [44].

### 3.4. Cone-Beam CT (CBCT)

To overcome some limitations of traditional CT scanning technology, cranial CBCT was developed. In craniofacial CBCT scans, the object being examined

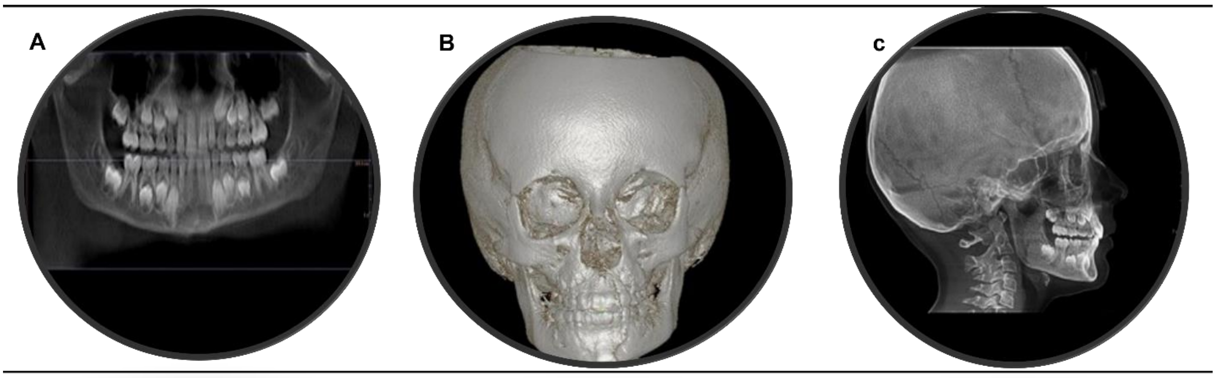


**Figure 3.** Seven-year-old patients underwent CBCT examination with a low-dose protocol with the following parameters: FOV 240 × 190 mm, images with normal resolution, 5 mA, absorption time 15 seconds, and 80 kV: notice the good quality of the panoramic (a), images (b), and 3D (c) cephalometric [43]

is captured as the radiation passes through a two-dimensional retractor. This small distinction allows for the entire region of interest to be recorded with just one rotation of the radiation source, unlike a standard CT device that requires stacking multiple slices to create a complete image (Figure 2). Additionally, compared to traditional fan-shaped CT machines, cone beam technology produces a more focused beam and significantly reduces scatter radiation. This leads to a lower requirement for X-ray tube power during volumetric scanning, while still maintaining high-quality imaging [45]. The scope of the Field Of View (FOV) plays a crucial role in determining the patient dose in CBCT and is directly associated with image quality due to X-ray dispersion. Therefore, when selecting a CBCT machine, it is important to consider the various FOVs offered by the vendor [21]. In a study accompanied by Yeung *et al.* in 2021 [10], the rejection rates of radiographic images in Dentom-axillofacial radiology were examined. The study found that the mean CBCT reject rate was lower at 2.77% (223/8060) compared to intra-oral and extra-oral imaging methods.

In a study conducted by Beatrice Feragalli *et al.*, the researchers aimed to evaluate picture quality and RE in dental and maxillofacial imaging examinations using CBCT. The study involved the use of five alternative acquisition protocols to assess image quality and RE. One of the protocols involved lowering the kilovolt peak (kVp) from 95 to 80 kVp, resulting in a decrease in the DAP from 1556 to 1013 mGy $cm^2$, representing a reduction of approximately 35%. The reference protocol utilized a large FOV, high-resolution images, 95 kVp, 5 mA, and an acquisition duration of 24 seconds, resulting in a DAP value of 1556 mGy $cm^2$. Furthermore, the study explored the impact of altering the FOV by conducting scans with smaller FOVs. Two scans were performed with FOVs of 160 x 140 mm and 120 x 90 mm, respectively. By analyzing the different acquisition protocols, the study aimed to optimize CBCT imaging techniques, ensuring high-quality images while minimizing RE to patients. The findings of this research contribute to the ongoing efforts to enhance the safety and effectiveness of dental and maxillofacial imaging examinations using CBCT [46]. In situations where a thorough assessment of the maxillofacial region is necessary to determine the appropriate cure, CBCT conducted with a low-dose protocol has actual small RE and produces high-quality images [47].

Recently, Kuramoto *et al.* conducted a quantitative evaluation of the impact of additional Copper-filters (Cu-filters) on the radiation dose and Contrast-to-Noise Ratio (CNR) in dental CBCT. They acquired CBCT images of a phantom containing aluminum, air, and bone equivalent material with homogeneous properties. The researchers calculated the CNRs based on the voxel values of each homogeneous material and measured the $CTDI_{vol}$ using standard polymethyl methacrylate CTDI test objects. The findings indicated a trend of higher CNR with increasing tube voltage and tube current across all homogeneous materials. However, the CNR decreased as the thickness of the Cu-filter increased. The study also observed that the $CTDI_{vol}$ increased with higher tube voltage and tube current, while it decreased with increasing Cu-filter thickness. When the CNR was fixed at 9.23 of BEM with an exposure setting of 90 kV/5 mA without a Cu-filter, the $CTDI_{vol}$ at 90 kV with Cu-filters was found to be 8.7% lower compared to that without a Cu-filter. These results highlight the potential of incorporating Cu-filters to reduce patient dose while maintaining image quality. The study underscores the importance of optimizing exposure settings and considering the use of Cu-filters in dental CBCT to achieve a balance between radiation dose reduction and adequate image quality [48].

In a-2019 study conducted by Shokri *et al.*, the researchers investigated the effects of CBCT exposure factors, specifically mA and FOV, on metal artifacts of dental implants in different bone densities. This experimental study was carried out in vitro and included a total of 27 bone blocks with varying densities. These bone blocks were categorized into nine type 1, nine type 2 and 3, and nine type 4, representing different levels of bone density. These bone blocks were incorporated into wax models of the mandible. The blocks were scanned using a Cranex3D imaging system with FOVs of 4x6 $cm^2$ and 6x8 $cm^2$, and mA settings of 4 and 10 during hole preparation and after implant insertion. The gray values of the bone blocks were recorded before and after implantation. Results showed that regardless of bone density, narrow FOVs generally exhibited fewer artifacts compared to larger FOVs ($P > 0.05$). Metal artifacts were not affected by changes in mA ($P > 0.05$). Type 4 bone demonstrated more artifacts compared to other bone types ($P < 0.05$), while no substantial differences were experiential between type 1 and types 2 and 3 ($P > 0.05$) [49]. Another study assessed the optimization of effective dose and its impact on image quality and diagnostic efficiency in dental CBCT. The study concluded that although CBCT exposes patients to higher doses of radiation, traditional radiography remains a more sensitive diagnostic method. Therefore, there is a risk of overexposure unless the benefit to the patient is proven. Furthermore, concerns have been raised that increased diagnostic sensitivity may lead to a loss of specificity, resulting in an overrepresentation of diseases. This underscores the importance of developing a dedicated CBCT "natural atlas" to accurately diagnose pathological conditions. Moreover, the limitations of traditional radiography in depicting the three-dimensional anatomy of teeth and related structures restrict its usage. Therefore, CBCT is recommended when traditional radiography fails to provide accurate diagnostic information [50]. In a recent study conducted at the Sweden Faculty of Dentistry in 2020, researchers aimed to evaluate a low-dose strategy for CBCT imaging of the Temporomandibular Joint (TMJ). A group of 34 adult patients who required TMJ CBCT imaging participated in the study. These patients underwent two examinations using two different scanning protocols: the manufacturer's suggested protocol and a low-dose procedure where the tube current was decreased to 20% of the default protocol. For each scanning protocol, three sets of images were reconstructed: the default protocol, the low-dose protocol, and the processed low-dose protocol which utilized a noise reduction method. The results of the study indicated that the low-dose CBCT protocol for TMJ assessment using the specific CBCT device employed in this investigation was diagnostically equivalent to the manufacturer-recommended protocol. However, the low-dose protocol delivered a significantly lower radiation dosage, which was approximately five times lower than that of the default protocol. These findings highlight the potential of implementing a low-dose strategy in TMJ CBCT imaging, as it maintains diagnostic accuracy while significantly reducing patient exposure to radiation. Such an approach can contribute to the overall efforts aimed at optimizing radiation doses in dental imaging, ensuring patient safety without compromising the quality of diagnostic information obtained [51].

## 4. Conclusion

In conclusion, the discussion highlighted the recent advancements in technology, particularly CBCT and digital imaging, along with the associated concerns regarding radiation protection. It is evident that existing radiation protection rules for dental radiology need to be revised to accommodate these modern technologies. Looking ahead, the establishment of CBCT Dose Reference Levels (DRLs) for various clinical purposes is imperative in the near future. Furthermore, the introduction of new X-ray shielding materials with nanocomposite coatings offers promising solutions. These materials maintain important properties alike air and water permeability, lightweightness, and flexibility. The nano-coating provides practical and reliable shielding decreasing 15-35% radiation, serving as a viable substitute for Pb-aprons. The findings of this discussion emphasize the importance of regular training for all personnel in correct positioning techniques. This training is crucial to improve patient care in dental radiography. Moreover, the implementation of DRLs and advanced shielding measures have shown promising outcomes, leading to reduced patient doses. Overall, it is highly recommended that the dental radiology field embraces these advancements and incorporates them into practice. By revising radiation protection rules, establishing CBCT DRLs, utilizing innovative X-ray shielding materials, and providing ongoing training, the field can enhance patient care, minimize radiation exposure, and achieve better outcomes.

## References

1- Ali Tarighatnia, Asghar Mesbahi, Amir Hossein Mohammad Alian, Evin Koleini, and Nader Nader, "An analysis of operating physician and patient radiation exposure during radial coronary angioplasties." *Radiation protection dosimetry,* Vol. 182 (No. 2), pp. 200-07, (2018).

2- Ali Tarighatnia, Golshan Mahmoudi, and Nader D Nader, "Radiation Exposure Aspects during Trans-Radial Angiography and Angioplasty." *Frontiers in Biomedical Technologies,* (2023).

3- Ali Tarighatnia, L Pourafkari, A Farajollahi, AH Mohammadalian, M Ghojazadeh, and ND Nader, "Operator radiation exposure during transradial coronary angiography." *Herz,* Vol. 43 (No. 6), pp. 535-42, (2018).

4- Ali Tarighatnia *et al.*, "Radiation exposure levels according to vascular access sites during PCI." *Herz,* Vol. 44 (No. 4), pp. 330-35, (2019).

5- Karen Panetta, Rahul Rajendran, Aruna Ramesh, Shishir Paramathma Rao, and Sos Agaian, "Tufts dental database: a multimodal panoramic x-ray dataset for benchmarking diagnostic systems." *IEEE journal of biomedical and health informatics,* Vol. 26 (No. 4), pp. 1650-59, (2021).

6- Kiana Nikeghbal, Zahra Zamanian, Shoaleh Shahidi, Gianrico Spagnuolo, and Parisa Soltani, "Designing and fabricating nano-structured and micro-structured radiation shields for protection against CBCT exposure." *Materials,* Vol. 13 (No. 19), p. 4371, (2020).

7- Vinita Chauhan and Ruth C Wilkins, "A comprehensive review of the literature on the biological effects from dental X-ray exposures." *International journal of radiation biology,* Vol. 95 (No. 2), pp. 107-19, (2019).

8- Alenka Matjasic, "DIAGNOSTIC REFERENCE LEVELS IN DENTAL RADIOLOGY: A SYSTEMATIC REVIEW: Diagnostične referenčne ravni v dentalni radiologiji-Sistematični pregled literature." *Medical Imaging and Radiotherapy Journal,* Vol. 38 (No. 2), pp. 22-29, (2021).

9- Touko Kaasalainen, Marja Ekholm, Teemu Siiskonen, and Mika Kortesniemi, "Dental cone beam CT: An updated review." *Physica Medica,* Vol. 88pp. 193-217, (2021).

10- Andy Wai Kan Yeung and Natalie Sui Miu Wong, "Reject rates of radiographic images in Dentomaxillofacial radiology: a literature review." *International Journal of Environmental Research and Public Health,* Vol. 18 (No. 15), p. 8076, (2021).

11- William C Scarfe, Z Li, W Aboelmaaty, SA Scott, and AG Farman, "Maxillofacial cone beam computed tomography: essence, elements and steps to interpretation." *Australian dental journal,* Vol. 57pp. 46-60, (2012).

12- K Horner, "Radiation protection in dental radiology." *The British journal of radiology,* Vol. 67 (No. 803), pp. 1041-49, (1994).

13- Manish Mittal, Mohammad Rizwan Siddiqui, Khiem Tran, Sekhar P Reddy, and Asrar B Malik, "Reactive oxygen species in inflammation and tissue injury." *Antioxidants & redox signaling,* Vol. 20 (No. 7), pp. 1126-67, (2014).

14- ME Lomax, LK Folkes, and P O'neill, "Biological consequences of radiation-induced DNA damage: relevance to radiotherapy." *Clinical oncology,* Vol. 25 (No. 10), pp. 578-85, (2013).

15- Reza Malekzadeh, Ali Tarighatnia, Parinaz Mehnati, and Nader D Nader, "Reduction of Radiation Risk to Cardiologists and Patients during Coronary Angiography: Effect of Exposure Angulation and Composite Shields." *Frontiers in Biomedical Technologies,* (2022).

16- Avdeesh Shetty, Fabiana T Almeida, Seema Ganatra, Anthea Senior, and Camila Pacheco-Pereira, "Evidence on radiation dose reduction using rectangular collimation: a systematic review." *International dental journal,* Vol. 69 (No. 2), pp. 84-97, (2019).

17- Serhat Süha Türkaslan, Şule Sultan Ugur, Banu Esencan Türkaslan, and Nicholas Fantuzzi, "Evaluating the X-ray-shielding performance of graphene-oxide-coated nanocomposite fabric." *Materials,* Vol. 15 (No. 4), p. 1441, (2022).

18- JE Ngaile, CBS Uiso, P Msaki, and R Kazema, "Use of lead shields for radiation protection of superficial organs in patients undergoing head CT examinations." *Radiation protection dosimetry,* Vol. 130 (No. 4), pp. 490-98, (2008).

19- E Mansouri, A Mesbahi, R Malekzadeh, A Ghasemi Janghjoo, and Murat Okutan, "A review on neutron shielding performance of nanocomposite materials." *International Journal of Radiation Research,* Vol. 18 (No. 4), pp. 611-22, (2020).

20- Parinaz Mehnati, Reza Malekzadeh, and Mohammad Yousefi Sooteh, "New Bismuth composite shield for radiation protection of breast during coronary CT angiography." *Iranian Journal of Radiology,* Vol. 16 (No. 3), (2019).

21- Virginia Tsapaki, "Radiation protection in dental radiology–Recent advances and future directions." *Physica Medica,* Vol. 44pp. 222-26, (2017).

22- M Vuolo *et al.*, "Exploring innovative radiation shielding approaches in space: a material and design study for a wearable radiation protection spacesuit." *Life sciences in space research,* Vol. 15pp. 69-78, (2017).

23- Reza Malekzadeh, Vahid Sadeghi Zali, Okhtay Jahanbakhsh, Murat Okutan, and Asghar Mesbahi, "The preparation and characterization of silicon-based composites doped with BaSO4, WO3, and PbO nanoparticles for shielding applications in PET and nuclear medicine facilities." *Nanomedicine Journal,* Vol. 7 (No. 4), pp. 324-34, (2020).

24- Aida Khaleghi Fard, Amir Hossein Mohammad Alian, Leili Pourafkari, Morteza Ghojazadeh, Ali Tarighatnia, and Alireza Farajollahi, "Impact of pelvic and rad-board lead shields on operator and patient radiation dose in trans-radial coronary procedures." *Radiation protection dosimetry*, Vol. 187 (No. 1), pp. 108-14, (2019).

25- Anna Kelaranta, Marja Ekholm, Paula Toroi, and Mika Kortesniemi, "Radiation exposure to foetus and breasts from dental X-ray examinations: effect of lead shields." *Dentomaxillofacial Radiology,* Vol. 45 (No. 1), p. 20150095, (2016).

26- Lifeng Yu, Michael R Bruesewitz, Thomas J Vrieze, and Cynthia H McCollough, "Lead shielding in pediatric chest CT: effect of apron placement outside the scan volume on radiation dose reduction." *American Journal of Roentgenology,* Vol. 212 (No. 1), pp. 151-56, (2019).

27- Abdulrhman Hasan Alsaab and Sadek Zeghib, "Study of Prepared Lead-Free Polymer Nanocomposites for X- and Gamma-ray Shielding in Healthcare Applications." *Polymers,* Vol. 15 (No. 9), p. 2142, (2023).

28- Parinaz Mehnati, Reza Malekzadeh, Baharak Divband, and Mohammad Yousefi Sooteh, "Assessment of the effect of nano-composite shield on radiation risk prevention to Breast during computed tomography." *Iranian Journal of Radiology,* Vol. 17 (No. 1), (2020).

29- Parinaz Mehnati, Reza Malekzadeh, and Mohammad Yousefi Sooteh, "Application of personal non-lead nano-composite shields for radiation protection in diagnostic radiology: A systematic review and meta-analysis." *Nanomed. J,* Vol. 7 (No. 3), pp. 170-82, (2020).

30- Nikan Asadpour, Reza Malekzadeh, Saeed Rajabpour, Soheila Refahi, Parinaz Mehnati, and Ahmad Shanei, "Shielding performance of multi-metal nanoparticle composites for diagnostic radiology: an MCNPX and Geant4 study." *Radiological Physics and Technology,* Vol. 16 (No. 1), pp. 57-68, (2023).

31- Masayuki Naito *et al.*, "Investigation of shielding material properties for effective space radiation protection." *Life sciences in space research,* Vol. 26pp. 69-76, (2020).

32- Nurul Z Noor Azman *et al.*, "Effect of Bi 2 O 3 particle sizes and addition of starch into Bi 2 O 3–PVA composites for X-ray shielding." *Applied Physics A,* Vol. 122pp. 1-9, (2016).

33- Parinaz Mehnati, Reza Malekzadeh, Mohammad Yousefi Sooteh, and Soheila Refahi, "Assessment of the efficiency of new bismuth composite shields in radiation dose decline to breast during chest CT." *The Egyptian Journal of Radiology and Nuclear Medicine,* Vol. 49 (No. 4), pp. 1187-89, (2018).

34- Le Yu, Pei Lay Yap, Alexandre Santos, Diana Tran, and Dusan Losic, "Lightweight bismuth titanate (Bi4Ti3O12) nanoparticle-epoxy composite for advanced lead-free X-ray radiation shielding." *ACS Applied Nano Materials,* Vol. 4 (No. 7), pp. 7471-78, (2021).

35- Mr Kunal Pise, Mr Suhas Tivaskar, Mr Anurag Luharia, Rajasbala Dhande, and Aniket Pathade, "Assessment Of Radiation Dose In Digital Radiography System-A Review Article." *Journal of Pharmaceutical Negative Results,* pp. 69-75, (2022).

36- Roberto Molteni, "The way we were (and how we got here): fifty years of technology changes in dental and maxillofacial radiology." *Dentomaxillofacial Radiology,* Vol. 50 (No. 1), p. 20200133, (2021).

37- Caroline C Rodgers, "Low-dose X-ray imaging may increase the risk of neurodegenerative diseases." *Medical hypotheses,* Vol. 142p. 109726, (2020).

38- Khaled Alkhalifah, Akram Asbeutah, and Ajit Brindhaban, "Image quality and radiation dose for fibrofatty breast using target/filter combinations in two digital mammography systems." *Journal of Clinical Imaging Science,* Vol. 10(2020).

39- Lillian Atsumi Simabuguro Chinem, Beatriz de Souza Vilella, Cláudia Lúcia de Pinho Maurício, Lucia Viviana Canevaro, Luiz Fernando Deluiz, and Oswaldo de Vasconcellos Vilella, "Digital orthodontic radiographic set versus cone-beam computed tomography: an evaluation of the effective dose." *Dental press journal of orthodontics,* Vol. 21pp. 66-72, (2016).

40- Jovica Praskalo, Adnan Beganović, Jovana Milanović, and Koviljka Stanković, "Intraoral dental x-ray radiography in Bosnia and Herzegovina: Study for revising diagnostic reference level value." *Radiation protection dosimetry,* Vol. 190 (No. 1), pp. 90-99, (2020).

41- H Zamani, AA Parach, SH Razavi, M Shabani, Gh Ataei, and MH Zare, "Estimating the radiation surface dose and measuring the dose area product to provide the diagnostic reference level in panoramic radiography." *International Journal of Radiation Research,* Vol. 19 (No. 4), pp. 963-70, (2021).

42- Amal Jose, A Saravana Kumar, KN Govindarajan, and Sunil Dutt Sharma, "Assessment of regional diagnostic reference levels in dental radiography in Tamil Nadu." *Journal of Medical Physics,* Vol. 47 (No. 1), p. 86, (2022).

43- Hamed Zamani, Hamidreza Masjedi, Reza Omidi, and Mohammad Hosein Zare, "Establishment of local diagnostic reference levels for common procedures of computed tomography in Yazd province." *Radiation protection dosimetry,* Vol. 188 (No. 2), pp. 222-31, (2020).

44- Akbar Aliasgharzadeh, Davood Khezerloo, Bagher Farhood, Mehran Mohseni, Habiballah Moradi, and Tohid Mortezazadeh, "Measuring the dose–width product and proposing the local diagnostic reference level in panoramic dental radiography: a multi-center study from Iran." *Oral Radiology,* Vol. 37pp. 80-85, (2021).

45- Amit Kumar, Sonam Vig, and Angad Sharma, "Impact of recent advances in radiology on orthodontic diagnosis and treatment planning-A review." *Journal of Advanced Medical and Dental Sciences Research,* Vol. 9 (No. 11), pp. 74-78, (2021).

46- Bart Vandenberghe, Reinhilde Jacobs, and Hilde Bosmans, "Modern dental imaging: a review of the current technology and clinical applications in dental practice." *European radiology,* Vol. 20pp. 2637-55, (2010).

47- Parinaz Mehnati, M Yousefi Sooteh, Reza Malekzadeh, Baharak Divband, and Soheila Refahi, "Breast conservation from radiation damage by using nano bismuth shields in chest computed tomography scan." *Iran Red Crescent Med J,* Vol. 6 (No. 1), pp. 46-50, (2019).

48- Beatrice Feragalli *et al.*, "Cone beam computed tomography for dental and maxillofacial imaging: technique improvement and low-dose protocols." *La radiologia medica,* Vol. 122pp. 581-88, (2017).

49- Taku Kuramoto *et al.*, "X-ray dose reduction using additional copper filtration for dental cone beam CT." *Physica Medica,* Vol. 81pp. 302-07, (2021).

50- Abbas Shokri, Mohammad Reza Jamalpour, Atefeh Khavid, Zeinab Mohseni, and Masoud Sadeghi, "Effect of exposure parameters of cone beam computed tomography on metal artifact reduction around the dental implants in various bone densities." *BMC medical imaging,* Vol. 19pp. 1-10, (2019).

51- Margarete B McGuigan, Henry F Duncan, and Keith Horner, "An analysis of effective dose optimization and its impact on image quality and diagnostic efficacy relating to dental cone beam computed tomography (CBCT)." *Swiss dental journal,* Vol. 128 (No. 4), pp. 297-316, (2018).

52- Durer Iskanderani, Mats Nilsson, Per Alstergren, Xie-Qi Shi, and Kristina Hellen-Halme, "Evaluation of a low-dose protocol for cone beam computed tomography of the temporomandibular joint." *Dentomaxillofacial Radiology,* Vol. 49 (No. 6), p. 20190495, (2020).