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Opportunistic investigation of vascular calcification using 3-dimensional dental imaging

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ABSTRACT

Purpose: Given the growing use of cone-beam computed tomography (CBCT) scans, this study assessed radiation exposure from these scans in the context of national guidelines and recommended dose limits.

Materials and Methods: The current literature was reviewed to quantify the benefit of opportunistic diagnosis of carotid artery calcification relative to the potential risk of radiation-induced cancer.

Results: The average radiation from CBCT at its largest field of view and highest resolution possible amounts to a reasonable but still low ionizing radiation exposure. This exposure is comparable to 22 days of background radiation and is notably lower than the radiation exposure from medical CT scans. According to the risk assessment analysis, the risk of stroke events involving internal and external carotid artery calcification (CAC) was 202 and 67 per 100,000 individuals, respectively. In contrast, the estimated risk of radiation-induced cancer associated with CBCT was notably lower, at 0.6 per 100,000.

Conclusion: The present study advocates for a comprehensive assessment of CBCT scans encompassing the areas of the internal and external carotid arteries by a knowledgeable professional, given the potential advantages of early detection of vascular abnormalities. Dental professionals who take scans involving these areas need to be mindful of reporting these findings and refer patients to their primary care physician for further investigation. ***(Imaging Sci Dent 2024; 54: 283-8)***

KEY WORDS: Cone-beam Computed Tomography, Ionizing Radiation, Incidental Findings, Carotid Artery Diseases

Introduction

Cone-beam computed tomography (CBCT) has revolutionized the field of dentistry by providing 3-dimensional (3D) imaging of the dentomaxillofacial region. This advanced imaging technique overcomes the limitations associated with conventional 2-dimensional (2D) radiographs, such as magnification, distortion, superimposition, and misrepresentation of anatomical structures within the intricate head and neck area.[1] As a result, CBCT has found extensive applications across various dental specialties, improving diagnostic accuracy and treatment planning.[2]

While CBCT has advanced the field of dentistry, it is crucial to consider the risk associated with its use due to its higher ionizing radiation exposure compared to conventional 2D imaging modalities. In the current literature, this advanced imaging modality is suggested not as a replacement for conventional methods, but rather as an advanced imaging tool.[3] While CBCT is widely utilized for procedures such as endodontic treatments and implant planning,[4,5] it should be used judiciously and under the "as low as reasonably achievable" (ALARA) principle for ionizing radiation exposure.[6]

The high resolution and larger field of view (FOV) of CBCT often reveal radiographic findings that exceed the initial imaging intent and area of concern.[7] These findings, commonly referred to as incidental findings, occur in 24.6% to 94.3% of CBCT scans.[7-9] While many of these findings are non-threatening, such as calcification of the stylohyoid ligament, some can be serious. One such significant finding that warrants further investigation and referral is the presence of vascular calcifications in the area of the carotid artery.[10] Carotid artery calcification

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(CAC) is a well-known marker of atherosclerosis, and vascular calcification is present in 80%-90% of atheromas.[11] Cardiovascular disease and ischemic stroke pose a significant global health concern, ranking among the leading causes of mortality and disability worldwide.[12] In 2020, estimates suggested the presence of carotid plaques in 21.1% of individuals aged between 30 and 79 years worldwide.[13]

The significance of CAC in the progression of ischemic cardiovascular disease, along with its well-established predictive value for stroke incidents;[14,15] underscores the importance highlighted in the literature for dental professionals to conduct comprehensive examinations of CBCT scans, specifically focusing on these areas that are opportunistically included in the FOV.[16,17]

Acknowledging the increasing number of CBCT scans, this comprehensive literature review was conducted to compare the radiation exposure from these scans with current national radiation guidelines and dose limits, as well as radiations exposure from natural sources. Additionally, recognizing the possible benefits of CAC diagnosis in CBCT scans, the potential advantages of early CAC detection were investigated relative to the risk of radiation-induced cancer associated with these scans. The findings of this study could be pivotal in guiding decision-making regarding the use of CBCT and optimizing radiation dose levels.

CBCT radiation doses in comparison with guidelines and suggested dose limits

Humans are constantly exposed to radiation from various natural sources, which encompass cosmic, terrestrial, inhalation, and ingestion-related factors.[18] The biological risk of this radiation is assessed by measuring the effective dose absorbed by the body. The quantity of background radiation differs across various regions, with an annual average of 2.4 mSv worldwide, 3 mSv in the United States, and 1.8 mSv in Canada.[19] Beyond this background radiation, additional radiation exposure is incurred through activities such as air travel and medical diagnostic imaging. The average radiation exposure for cross-Canada air travel, for instance, is 20 μSv.[20]

The radiation exposure from different medical imaging procedures exhibits significant variation. However, it should be noted that there are no limits for ionizing radiation exposure on diagnostic imaging.[21] Procedures such as positron emission tomography-computed tomography (CT) scans and spine CT scans involve high levels of radiation, with respective exposures of 22.7 mSv and 8.8 mSv.[22] In contrast, procedures such as bone dosimetry and dental X-rays involve much lower radiation levels, with exposures of 1 μSv and 5 μSv, respectively.[22]

The effective dose for CBCT scans has been quantified in numerous studies across various dental specialties. It is influenced by the patient's size and age, machine parameters such as scan time, voxel size, resolution, peak kilovoltage, and milliamperage, as well as the purpose and location of the scan.[23] Ludlow et al.[23] reported a broad spectrum of doses ranging from 5 to 1073 μSv, with an average value of 212 μSv for large-FOV scans and 84 μSv for small-FOV scans. In another study, the median effective dose for small, medium, and high heights of FOV was reported as 29 μSv, 65 μSv, and 118.65 μSv, respectively.[24]

Comparing the reported doses with the annual background radiation and the dose limits for the public as per the guidelines and recommendations of Canada, the United States, and the International Commission on Radiological Protection (ICRP), which is 1 mSv,[20,21,25,26] it becomes evident that the average radiation from CBCT at the largest FOV, which is 212 μSv, constitutes one-fifth of the annual dose limit. This is equivalent to 22 days of background radiation and is 41 times lower than the radiation from cervical spine CT scans (8.8 mSv).[22] Moreover, the implementation of low-dose CBCT scans, achieved by modifying exposure settings and limiting the FOV across various specialties, has been demonstrated to effectively reduce the dose for the patient while maintaining high scan quality.[27,28]

To quantify the risk of radiation, the available literature that measured the lifetime risk of cancer or death from CBCT scans was reviewed. It is crucial to note that the causal relationship between radiation-induced cancer and advanced dental imaging remains unknown. The majority of studies used the Biological Effects of Ionizing Radiation (BEIR) VII model from the National Research Council to estimate the risk.[29] Pauwels et al. showed that the incidence of cancer attributed to radiation varies by age, with a rate of 2.7 per million for individuals older than 60, and 9.8 per million for those aged 8 to 11, and the average risk stands at 6.0 per million, based on skin dosimetry. Notably, the risk is on average 40% higher for female patients.[30] A study on orthodontic patients reported a higher risk of death due to radiation exposure among younger and female patients. Specifically, the risk was 2.6 per million for 10-year-old females and 1.9 per million for 10-year-old males. In contrast, the risk decreased to 1.04 per million for 30-year-old females and 0.89 per million for 30-year-old males.[31] Similarly, Jha et al. conducted a study on orthodontic patients and highlighted the impact of age and sex on the risk of cancer. They reported that the risk of cancer for children (aged 5 and 10 years) under a median exposure setting was 16 times greater than the risk for adults (aged 20, 30, and 40 years).[32]

Quantitative assessment of CBCT benefits in the detection of CAC versus carcinogenic risks

CBCT scans have been proven to effectively detect vascular calcifications, and its image quality for calcifications has been found to be comparable to that of conventional CT.[33-35] However, these imaging modalities are not considered to be the standard of care for CAC. Thus, CBCT scans may be a valuable tool for the early and opportunistic detection of soft tissue calcifications, particularly in asymptomatic patients who are receiving 3D scans for dental procedures. The reported rates of significant incidental findings vary widely, from 0.3% to 31.4%, across different studies, largely due to varying classifications of conditions.[10] CAC is detected in 5.7% to 17.6% of general scans,[9,36] and the prevalence of this finding escalates with age, with scans of adults aged 40 years and older revealing calcifications in up to 63% of cases.[37]

According to the most recent report from the Canadian Chronic Disease Surveillance System, the age-standardized incidence rate of stroke in Canada for those aged 20 and older is 270 per 100,000.[38] Notably, 87% of these stroke events are ischemic, primarily associated with atherosclerosis.[39] Bos et al. showed that the presence of intracranial CAC increased the risk of stroke by 4.64 times. They also highlighted that intracranial CAC contributed to 75% of strokes, while extracranial CAC contributed to 25%.[14] Additionally, a significant correlation was noted between the presence of calcifications in both the extracranial and intracranial portions of the carotid artery—specifically, if calcification was detected in the extracranial part of the ICA, there was an increased likelihood of observing similar calcification in its intracranial segment.[33]

Drawing upon the findings of Bos et al.[14] and data from the Canadian Chronic Disease Surveillance System, it can be inferred that calcification in the intracranial and extracranial carotid arteries contributes to 202 and 67 strokes per 100,000 individuals, respectively in Canada. Taking into account the 15% 30-day mortality rate for ischemic stroke,[40] it is estimated that internal and external CAC contribute to 30 and 10 deaths per 100,000 individuals, respectively. These conditions are potentially detectable by CBCT scans, and by identifying these entities, dental professionals can effectively contribute to the prevention of stroke events. Moreover, the predictive value of carotid atherosclerosis and calcification in cardiovascular disease and coronary artery disease augments the importance of these findings.[41]

In terms of radiogenic cancer risk from medical imaging, real mortality and morbidity data have been previously employed for high-dose procedures, such as head CT and abdominal CT, enabling the establishment of a benefit-to-risk ratio.[42,43] When comparing the risk of ischemic stroke events with the risk of radiation-induced cancer or death from CBCT, the risk of stroke in adults is considerably higher. Specifically, the risk of stroke events involving internal and external CAC stands at 202 and 67 per 100,000 individuals, respectively. In contrast, the risk of radiation-induced cancer is estimated to be 0.6 per 100,000,[30] which is notably lower than the risk of stroke associated with CAC. Furthermore, the estimated risk of death is 30 and 10 per 100,000 for internal and external CAC, respectively, and 0.1 per 100,000 for radiation from CBCT.

There are several limitations in this comparison, such as uncertainties in predicting cancer risk and comparing different populations; however, it could provide a broad overview of reported statistics. Moreover, from the perspective of stroke prevention, the comparison is constrained by the assumption of 100% prevention of stroke upon diagnosis of CAC, which is not realistic. However, previous studies have indicated that solely adopting a healthy lifestyle can reduce the risk of stroke by 80%, underscoring the importance of early diagnosis.[44]

In addition to utilizing mortality and morbidity data, some studies have suggested employing disability-adjusted life years (DALYs) as an index to quantify excess cancer risk resulting from radiation exposure.[45] DALYs serve as a metric for assessing the impact of a disease on a population by integrating mortality (years of life lost due to premature mortality) and morbidity (years lived with disability) into a unified measure.[46] Shimada et al.[47] reported that the DALY loss for all cancers in Japan per 1 Gy per person was 0.84 years in men and 1.34 years in women, with the loss decreasing as age increases.[47]

Utilizing data from the study of Shimada et al., a study calculated the justification factor for various imaging methods.[48] In an example closely related to the present study, the ratio of benefit to detriment for head CT in relation to mild stroke/transient ischemic attack was examined. The author concluded that radiological examinations considered to provide information that assists in patient management are likely to be quantitatively justified, and the justification factor tends to increase with age at exposure. An explanation for this is that the survival time is shorter than the latency period for radiation-induced cancers.[48]

Considering the relatively low radiation risk of CBCT for patients older than 30 years, and the higher prevalence of CAC findings in these patients, the benefit-to-risk ratio tends to be particularly favourable for older patients. Patients over the age of 65 were found to be 5.01 times more likely to exhibit vascular pathologies than patients aged between 41 and 65. Furthermore, compared to patients aged between 16 and 40, this likelihood increased significantly to 13.39 times.[49]

Therefore, CBCT scans with a medium to large FOV for adults, encompassing the carotid artery areas, offer opportunities for investigating vascular calcifications that should be carefully further investigated. Dental professionals performing scans of these areas should be aware of their responsibility to report these findings and refer patients to their primary care physician for further clinical investigation. This approach could lead to the early detection and treatment of serious findings and potentially improve health outcomes.

The appropriateness of each dental imaging modality and the prescription of radiographs should be a constant consideration for dental professionals when choosing between 2D and 3D radiographs, and the potential risks associated with ionizing radiation exposure must always be weighed against its potential benefits. When prescribing advanced imaging such as CBCT, dental providers should be aware of the responsibility to report all radiographic findings in the imaged volume and, if necessary, refer the patient for further evaluation.[50] This ensures comprehensive patient care and adherence to professional standards of care.

Discussion

CBCT has emerged as a valuable tool in dental imaging, offering distinct advantages and considerations. This study aimed to comprehensively compare CBCT radiation exposure with current guidelines and dose limits. Additionally, given the high prevalence of incidental findings in CBCT scans, some of which indicate serious conditions requiring further investigation, this review evaluated the benefits of early detection of CAC against the potential increased cancer risk from these scans.

According to this review, the ionizing radiation dose of dental CBCT scans is notably lower than that of common CT scans, positioning it as a safer alternative. However, it should not be regarded as a direct substitute for conventional dental radiographs due to its higher radiation dose. Furthermore, employing lower dose parameters and small FOV scans for younger patients is essential for substantially reducing ionizing radiation exposure and the risk of radiation-induced cancer. This goal can be achieved by limiting the FOV through collimation, selecting the largest voxel size appropriate for treatment requirements, opting for lower dose settings, and employing thyroid shields.[51] Ultimately, this approach will bring radiation levels closer to those of 2D radiographs while maintaining high quality. This approach aligns with the concept of "as low as diagnostically acceptable" (ALADA),[52] which is a modification of "as low as reasonably achievable" (ALARA). ALADA underscores the optimization of radiation exposure by balancing image quality with reduced radiation dose, prioritizing patient safety while ensuring diagnostic efficacy.

In contrast, opting for CBCT with a larger FOV can be reasonable for older adults, offering the potential benefits of early detection of significant findings such as vascular abnormalities and improved treatment planning without significantly increasing radiation risk to patients. Comparatively, a full-mouth radiograph series using films delivers a similar radiation dose equivalent to a limited FOV CBCT scan, highlighting the value of CBCT.[53]

It is crucial to educate dentists about their medical-legal responsibilities and the interpretation of all radiographic findings from CBCT scans, including awareness of the potential consequences related to overlooking a finding requiring further action. Referring CBCT volumes to oral and maxillofacial radiologists for a complete evaluation of the volume, if necessary, ensures comprehensive patient care and optimizes the benefits of CBCT technology in dental practice. A multi-professional approach is essential in complex cases and to interpret larger FOV scans.

Conflicts of Interest: None

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