ORIGINAL ARTICLE

Risk Assessment of Genotoxicity and Cytotoxicity of Cone Beam Computed Tomography Exposure: A Systematic Review

Marini Arisandy,[1] Dwi Putri Wulansari[2] and Barunawaty Yunus[2]

[1]*Oral and Maxillofacial Radiology Specialist Program, Faculty of Dentistry, Hasanuddin University, Makassar, Indonesia*
[2]*Department of Oral Maxillofacial Radiology, Faculty of Dentistry, Hasanuddin University, Makassar, Indonesia*

ABSTRACT

Objective. The aim of this study was to qualitatively review the effects of genotoxicity and cytotoxicity on buccal mucosal epithelial cells after cone beam computed tomography (CBCT) exposure focusing on DNA damage and cell changes.

Methods. A literature search was carried out in PubMed, Wiley, Google Scholar, and Semantic Scholar for articles published in the last five years. In vivo studies that analyzed the DNA damage and cell changes on buccal mucosal epithelial cells, before and several days after CBCT exposure were included in this review. This review was prepared according to the PRISMA checklist for systematic review and the risk of bias was assessed using the Quality Assessment of Diagnostic Accuracy Studies tool.

Results. A total of four studies were included in this review. The risk of bias analysis showed that all studies had generally good methodological quality. All the studies used buccal epithelial cells to analyze micronucleus (MN) as a parameter for DNA damage (genotoxicity), three of the studies also analyzed cytotoxicity using pyknotic nucleus and three studies analyzed karyolysis and karyorrhexis. All the studies consistently reported a significant increase in MN frequency, and cytotoxic effect were more evident before and 10-15 days after CBCT exposure.

Conclusion. This study demonstrated a significant impact on DNA and cell damage in oral mucosal cells following CBCT examination. The effect of ionizing radiation from CBCT has a more pronounced impact on cell damage than DNA damage.

Keywords: CBCT, cytotoxicity, genotoxicity, buccal mucosal epithelial cells

INTRODUCTION

Dental imaging procedures are essential for the diagnosis of disease, the identification of injuries, the planning of treatment, and the subsequent follow-up.[1,2] Cone beam computed tomography (CBCT) has become a reliable imaging technique in oral maxillofacial radiology. In contrast to conventional computed tomography (CT), CBCT has become popular due to its cost-effectiveness and lower radiation dosage. Providing high-quality, three-dimensional (3D) images of the specific area of interest is one of the numerous benefits of CBCT. This imaging technology features volumetric analysis based on its shorter scan time.[3,4] The application of CBCT in various oral health-related fields is extensive. In the maxillofacial region, it is particularly beneficial for detecting abnormalities or disease of the hard tissue. Furthermore, it substantially supports dental treatment planning.[4–10]

Paper presentation – 11th IKARGI National Symposium Jakarta, July 12, 2024, Aston Kartika Grogol Hotel and Conference Center.

Corresponding author: Dwi Putri Wulansari
Department of Oral Maxillofacial Radiology
Faculty of Dentistry
Hasanuddin University
Jalan Perintis Kemerdekaan KM 10, Tamalanrea,
Makassar, South Sulawesi, Indonesia
Email: dwiputri@gmail.com
ORCiD: https://orcid.org/0000-0001-5445-8197

However, CBCT imaging releases a higher effective dose than conventional dental radiography.[2,6,11] Batool et al (2024) reported that after panoramic radiation exposure, the frequency of micronuclei (MN) was statistically significantly increased.[9] Karabas et al. (2019) reported that panoramic radiograph caused karyorrhexis, karyolysis, pyknosis and DNA damage in oral mucosal cells.[12] CBCT emits ionizing radiation (IR), which is known to cause biological damage, including cell and DNA damage.[13–15] Exfoliated buccal mucosal cells serve as a non-invasive model to assess radiation-induced cytotoxicity and genotoxicity. As a major barrier in the oral cavity, these cells can reflect genotoxic damage, including MN formation, chromosome fragments containing DNA form, caused by carcinogenic agents.[15–18] One of the most important criteria for evaluating MN in exfoliated buccal cells is counting the nucleus and cells with intact borders. Some studies used Tolbert's criteria for identifying MN as follows: (a) its diameter should be less than one-third of the main nucleus but large enough to identify the shape and color; (b) it has the same texture and coloration as the main nucleus; (c) it has the same focal plane as the nucleus; (d) it is smoothly rounded like a membrane; (e) it is separated from or slightly overlaps with the main nucleus.[19–21]

Individuals with a high presence of MN may accumulate mutations and, as a result, develop health problems such as cancer.[15,22] The MN test is advantageous when determining chromosome aberrations and sister chromatid exchanges because it analyzes chromosome mutations in cytological materials easily and efficiently.[14,23] The markers of cytotoxicity, which are pyknosis, karyorrhexis, and karyolysis, indicate the condition of the cells and describe radiation damage.[18,20] This paper aims to qualitatively review the effects of genotoxicity and cytotoxicity on buccal mucosal epithelial cells after CBCT examination causing DNA damage and cell changes over a period of 10-15 days. To achieve this aim, the study seeks to answer spesific question which has more impact after CBCT exposure, DNA or cell damage?

METHODS

Protocol and Registration

This study was designed to assess the effect of genotoxicity and cytotoxicity after CBCT examination on buccal mucosal epithelial cells according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement. The ethical exemption was registered by The Health Research Ethics Committee Faculty of Dentistry Hasanuddin University (Number: 246).

Study Design

This study involved in vitro (buccal mucosal cells) and in vivo (patients) studies that evaluate genotoxicity and cytotoxicity after CBCT exposure. The included studies should answer the research question according to the PICO (Population, Intervention, Comparison, and Outcome) is determined as follows: Population: Patients undergoing CBCT; Intervention: Exposure to CBCT; Comparison: Before exposure and several days after CBCT examination; and Outcome: Genotoxicity and cytotoxicity outcomes.

Eligibility Criteria

Based on the PICO, inclusion and exclusion criteria are established.

Inclusion criteria

a. CBCT scans in human participants.
b. Studies measuring genotoxicity and or cytotoxicity before and after CBCT exposure.
c. Used oral/buccal mucosal tissue to analysis of genotoxicity and cytotoxicity outcomes
d. Observational study (prospective or retrospective), prospective experimental study, case-control studies
e. Articles in English with full-text access
f. Articles in the last 5 years

Exclusion criteria

a. Animal experiments were performed in vitro
b. Review articles, case reports, pilot study
c. Non-English literature
d. No full-text access

Information Sources and Search Strategy

Article searches were conducted on four different databases (PubMed, Willey Online, Semantic Scholar, and Google Scholar) to find articles regarding the genotoxicity and cytotoxicity effects on buccal mucosal epithelial cells during the CBCT examination period in the last five years. The search was updated in all databases until 20 May 2024, and no additional studies were found for inclusion in this review. All data obtained were exported to Mendeley, and duplicates were removed. The search method is modified for each database, and the results are shown in Table 1.

Selection Process and Data Extraction

Early stage, the authors filtered all articles from databases and the entire article will be read if it meets the qualifying criteria. First author (MA) screened all studies. Second author (DPW) If there are any discrepancies, a third author (BY) will adjudicate them. Subsequently, the abstract and title are initially assessed, the systematic review will include articles that meet the eligibility criteria.

Data Collection

The first author, publication year, country, subjects, sex, age, CBCT machine, CBCT scanning parameter, time of sampling, the mean and standard deviation (SD) in the frequency of the MN cell, and cell changes as primary outcomes are all evaluated in full text. Articles that have been considered potential are assessed in detail.

Risk of Bias in Individual Studies

The included study methodology was evaluated using the QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies-2) instrument against the standards decided upon by the raters based on prior agreement and implemented uniformly across investigations.

RESULTS

Study Selection

The attached flow chart details the study identification process based on inclusion and exclusion criteria (Figure 1). A total of 450 articles ware obtained from four databases, a total of 367, after removing duplicates. Study selection is continued by reading the title and abstract, and a total of 357 articles were excluded because they were irrelevant to the topic. Animal studies, abstracts, and articles for the conference were excluded from the general review. The remaining seven full-text papers were extensively reviewed; however, three of them were excluded due to their inconsistent research procedures and incomplete data. Palla et al. implemented the same methodology, employing CT as an instrument.[20] Belmans et al. study different biomarkers (γH2AX and 53BP1 foci).[17] Althouki et al. used the same method, but the populations are children, which cannot be compared with adult subjects because they have different cell turnover times.[16]

Study Characteristics

Four studies were conducted in two countries. A study were conducted in India, and the others were in Iran. All studies were conducted in the last five years (2019-2024) and English full text. All the studies used buccal epithelial cells to analyzed MN as a parameter for DNA damage (genotoxicity) three of which studies also analyzed cytotoxicity using pyknotic nucleus and three of which studies also analyzed karyolysis and karyorrhexis (Table 2). All the studies compared the variable before and 10-15 days after CBCT exposure.

Synthesis of Results

A total of 120 people were exposed to CBCT examination with a mean patient age of 35.03±5.78 years. Four studies used various CBCT devices and CBCT settings with the smallest (8x11 cm) and largest (10x10 cm) field of view (FOV) sizes. Buccal mucosal cell sampling was performed before and 10-15 days after exposure. The samples were examined in microscopic fields at a magnification of 400x for the presence of MN and cell changes. All studies confirmed the increase of micronuclei and cell changes after CBCT exposure are shown in Table 3.

Quality Assessment and Risk of Bias in Research

This study used the QUADAS-2 tool for quality assessment and risk of bias in the research which showed homogeneity for the qualitative systematic review. (Figure 2)

Table 1. Strategy Searches Used for the Four Electronic Databases

Database of Published Trials	Search Strategy	Articles found
Pubmed Searched on 20 May 2024	("genotoxicity" OR "DNA damage") AND ("cytotoxicity" OR "cell viability" OR "cell damage" OR "apoptosis") AND ("CBCT" OR "cone beam computed tomography" OR "cone beam CT")	9
Wiley Online Library Searched on 20 May 2024	("genotoxicity" OR "DNA damage") AND ("cytotoxicity" OR "cell viability" OR "cell damage" OR "apoptosis") AND ("CBCT" OR "cone beam computed tomography" OR "cone beam CT")	7
Semantic Scholar Searched on 20 May 2024	("genotoxicity" OR "DNA damage") AND ("cytotoxicity" OR "cell viability" OR "cell damage" OR "apoptosis") AND ("CBCT" OR "cone beam computed tomography" OR "cone beam CT")	256
Google Scholar Searched on 20 May 2024	("genotoxicity" OR "DNA damage") AND ("cytotoxicity" OR "cell viability" OR "cell damage" OR "apoptosis") AND ("CBCT" OR "cone beam computed tomography" OR "cone beam CT")	178
Pubmed Updated Searched on 7 March 2025	("genotoxicity" OR "DNA damage") AND ("cytotoxicity" OR "cell damage") AND ("CBCT" OR "cone beam computed tomography" OR "cone beam CT")	9

Table 2. Summary of Characteristics of Included Studies

Author (year of publication)	Country	Samples	Design study	Outcomes
Mounika G et al. (2021)[25]	India	30 (Sex NA)	Longitudinal observational experimental	MN, Pyknotic
Ghadikolaei et al. (2023)[26]	Iran	30 (13 males; 17 females)	Observational experimental	MN, Pyknosis, Karyolysis, Karyorrhexis
Jahanshahiafshar et al. (2023)[19]	Iran	30 (13 males; 17 females)	Prospective observational experimental	MN, Pyknosis, Karyolysis, Karyorrhexis
Mosavat et al. (2022)[27]	Iran	30 (15 males; 15 females)	Observational	MN, Pyknosis, Karyolysis, Karyorrhexis

MN – Micronucleus

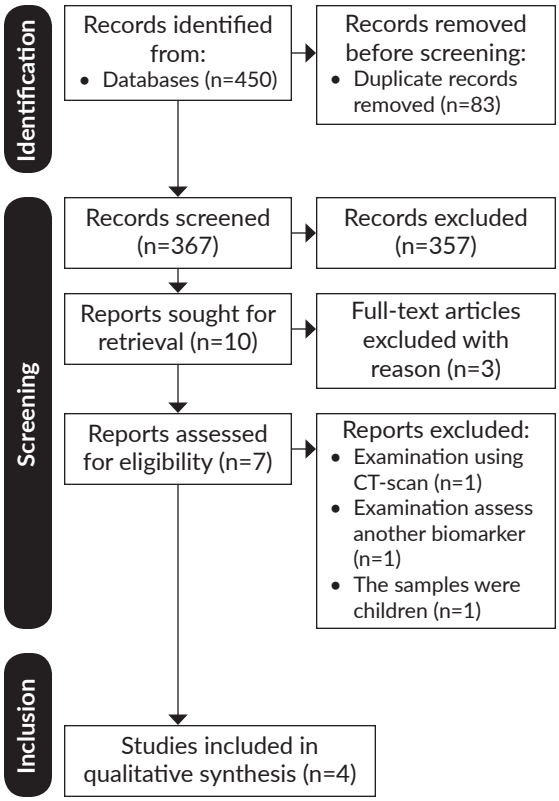

Figure 1. Flowchart of systematic search and study selection strategy.

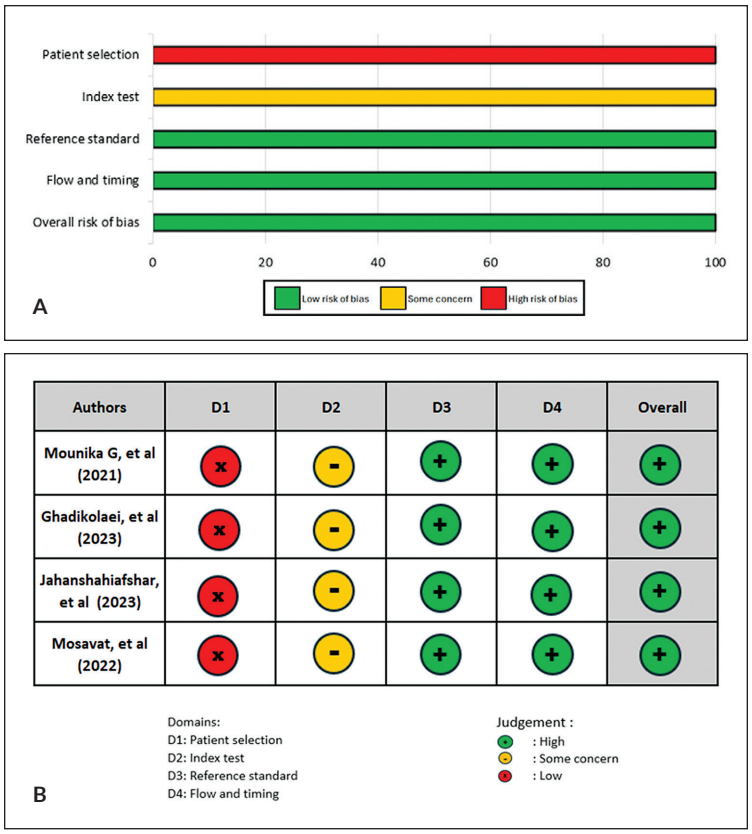

Figure 2. (A) Risk of bias graph. **(B)** Risk of bias summary.

DISCUSSION

IR can induce harmful biological effects by altering cell functionality, causing mutations leading to malignancy, or directly triggering cell death through DNA damage, facilitated by its ability to release energy upon ionization, which disrupts molecular structures and releases ions, electrons, and other types of radiation.[25,26] This study investigated the cytotoxicity and genotoxicity in patients subjected to CBCT, focusing on the formation of MN and other cellular alterations in buccal mucosal cells. The standardized scanning protocol for CBCT included parameters such as kVp, mA, time, and FOV. Cells were collected immediately before and 10-15 days after exposure to IR, considering the buccal epithelial cell turnover rate of 7-16 days. Consistent with previous studies, the buccal mucosa was the preferred site for cell collection due to its high turnover rate, accurately reflecting cytotoxic changes and genomic instabilities.[3,19,24,25]

Table 3 shows that the increase in MN ranged from 23%-93% after 10-15 days after exposure with average increase in MN after CBCT exposure of 47.7%. While the increase in cell damage ranged from 25%-101% with an average increase of 59.3%.The formation of MN and cytotoxicity markers have been used to assess the genetic effects of dental radiography.[2] The epithelial cells of the buccal mucosa are a valuable resource for rapidly identifying of genotoxic effects. The frequency of MN occurrence will indicate DNA/chromosomal damage. Numerical chromosome defect can be caused by clastogen, which trigger chromosolam breaks, aneugens, which disrupt spindle formation, leading to acentric fragments or misaligned chromosomes.[27]

Farhadi et al. (2017) reported an increase the percentage of micronucleus after CBCT examination of ±17%, and there was no correlation between the age and gender of participants in MN.[28] Anasofia et al (2022) reported an increase in MN occurred after 12 hours after head CT exposure significantly showed an increase in MN more than CBCT.[29] Jahanshahiafshar et al (2023) compared the frequency of MN after exposure to CBCT and Multi-detector Computed Tomography (MDCT), and significantly showed a higher increase in MN after MDCT exposure.[19] CBCT generally delivers 10-12 times lower radiation than head CT or MDCT.[17,30]

IR causes complex DNA damage, both directly through DNA strand breaks and indirectly through the formation of free radicals. This damage triggers various clinical manifestations, including hematopoietic disorders, increased risk of carcinogenesis, and chronic inflammation and fibrosis in organs such as the lungs, skin and kidneys. Local effects such as xerostomia and impaired wound healing may also

Table 3. Individual Characteristics of Included Studies

Author	Total Samples	Range of Age; Mean Age (years)	CBCT Device	CBCT Settings	Time of sampling	Biomarker	Mean value pre-exposure	Mean value 10-15 days after exposure	*p*-value	Outcomes
Mounika et al.[24]	30 (Sex NA)	23–50; 36,17 ± 7,65	I MAX Touch 3D CBCT	FOV: 9.3 x 8.3 cm^2 mAs: 9 mA kV: 76 kVp Time: 8 s	Before exposure; 15 days after exposure	MN Pyknotic	11.27 8.83	13.90 11.03	0.000 0.001	The increase in the frequency of pyknotic in cells was greater than the increase in micronucleus in cells after exposure.
Ghadikolaei et al.[25]	30 (13 males; 17 females)	26–46; 34,23 ± 7,75	X MIND (ACTEON Olgiate Olona Italy)	FOV: 8 x 11 cm^2 mAs: 8mA kV: 90 kVp (man); 85kVp (woman) Time: 8 s	Before exposure; 10-12 days after exposure	MN Cytotoxic changes	34.00 5.00	42.00 8.00	<0,001 <0,001	Cytotoxic changes were significantly higher than the increase of MN in cell.
Jahanshahiafshar et al.[19]	30 (13 males; 17 females)	21–50 ; 34,7 ± 7,72	X MIND (ACTEON Olgiate Olona Italy)	FOV: 8 × 11 cm^2, mAs: 8 mAs kV: 90 kVp (man); 85 kVp (woman) Time: NA	Before exposure; 12 days after exposure	MN Cytotoxic changes	34.17 4.67	42.70 7.07	0.001 <0.001	Cytotoxic changes were significantly higher than the increase of MN in cell.
Mosavat et al.[26]	30 (15 males; 15 females)	20–50; 35	3030 Alphard VEGA scanner (Asahi, Japan)	FOV: 10 x 10 cm^2 kV: 80 kVp mAs: 4 mA Time: 17 s	Before exposure; 10 days after exposure	MN Cytotoxicity	5.13 0.81	7.67 1.82	<0.0005 <0.0005	Cytotoxic changes were significantly higher than the increase of MN in cell.

NA – Not Applicable, MN – Micronucleus, FOV – Field of View

occur, especially in radiation exposures such as CBCT.[31,32] In addition, radiation to the brain can cause cognitive impairment, memory degradation, and the risk of neurodegeneration such as dementia. When DNA damage is not properly repaired, genetic mutations, micronucleus formation, and cellular transformation may occur, increasing the risk of cancer and other cellular disorders. This combination of direct and indirect effects exacerbates cellular damage and accelerates chronic inflammatory processes.[33,34]

Frequencies of pyknosis, karyolysis, and karyorrhexis cells for cell death were evaluated to monitor cytotoxicity.[28,29,35–37] Despite IR known cytotoxicity and their ability to induce cell death through necrosis and apoptosis and this is supported by similar findings from other studies support the cytotoxic effects of this radiation, underscoring the need for imaging procedures to be performed with precise clinical indications and radioprotection measures.[29,37,38] Researches indicate that prolonged exposure to cytotoxic agents may cause chronic cellular damage, uncontrolled proliferation, hyperplasia, and eventual tumor formation by disrupting normal cell growth and apoptosis.[14,39] Assessing the genotoxic and cytotoxic changes following conventional dental radiation helps us to reinforce the importance of evaluating the side effects of radiation.[27]

Minimizing radiation dose of CBCT is critical for patient and operator safety. The ALARA (as Low as Reasonably Achievable) and ALADA (as Low as Diagnostically Acceptable) principles are the main guidelines, focusing on using the lowest possible radiation dose that still produces quality diagnostic images. Some of the measures to reduce CBCT dose include selecting an appropriate FOV according to clinical needs, optimally setting parameters such as mAs and kVp, and using protective equipment such as lead aprons and thyroid collars to protect areas of the body that do not need to be exposed. In addition, CBCT should be used as an adjunctive technique when conventional 2D radiography does not provide enough diagnostic information.[40–43]

Limitation

The number of studies analyzed was limited, so generalization of the findings to a wider population may not be accurate. In addition, there were variations in the methodology of each study, including differences in study design, sample size, and methods of analyzing genotoxicity and cytotoxicity, which may affect the consistency of the results. The evaluation time span of only 10-15 days after CBCT exposure is also a limitation, as it does not provide an overview of the long-term impact of CBCT radiation on cellular changes. In addition, all studies analyzed were from two countries, India and Iran, so the results may not fully reflect the global population.

CONCLUSION

This review suggests that CBCT exposure exhibits genotoxic and cytotoxic effects on mucosal epithelial cells with cytotoxic effects being more pronounced than DNA damage. Although CBCT is a highly accurate tool for detecting oral abnormalities or diseases, clinicians should be aware of its potential risks and should use judiciously when conventional

techniques are ineffective. Future research should focus on refining radiation safety protocols and further evaluating the long-term effects of CBCT exposure on cell health.

Statement of Authorship

All authors certified fulfillment of ICMJE authorship criteria.

Author Disclosure

All authors decraled no conflicts of interest.

Funding Source

None.

REFERENCES

1. Salman BN, Rafieyan S, Rahimipour K, Bayat N. Genotoxic and cytotoxic effects of dental radiographic modalities on buccal mucosal cells in children. J Child Sci. 2023 Aug;13(1):E113-7. doi:10.1055/s-0043-1772206.
2. Chauhan V, Wilkins RC. A comprehensive review of the literature on the biological effects from dental X-ray exposures. Int J Radiat Biol. 2019 Jan;95(2):107-19. doi:10.1080/09553002.2019.1547436. PMID: 30496029.
3. Basha S, Essawy M. Genotoxic and cytotoxic effects of cone beam computed tomography on exfoliated buccal epithelial cells. Iosr-Jdms. 2018 Mar;17(3):66-70. doi:10.9790/0853-1703056670.
4. Mubarak H, Tajrin A, Gazali M, Nurwahida, Rahman FUA. Impacted mandibular third molars: A comparison of orthopantomography and cone-beam computed tomography imaging in predicting surgical difficulty. Arch Craniofacial Surg. 2024 Oct;25(5): 217-23. doi:10.7181/acfs.2024.00297. PMID: 39501730. PMCID: PMC11540487.
5. Yang P, Xuan B, Li G, Qi S. Does cone-beam computed tomography examination increase the micronuclei frequency in the oral mucosa exfoliated cells? A systematic review and meta-analysis. BMC Oral Health. 2023 Feb;23(1):127. doi:10.1186/s12903-023-02832-3. PMID: 36841769. PMCID: PMC9960480.
6. Marcu M, Hedesiu M, Salmon B, Pauwels R, Stratis A, Oenning ACC, et al. Estimation of the radiation dose for pediatric CBCT indications: a prospective study on ProMax3D. Int J Paediatr Dent. 2018 May;28(3):300-9. doi:10.1111/ipd.12355. PMID: 29356184.
7. Carlin V, Artioli AJ, Matsumoto MA, Filho HN, Borgo E, Oshima CTF, et al. Biomonitoring of DNA damage and cytotoxicity in individuals exposed to cone beam computed tomography. Dentomaxillofacial Radiol. 2010 Jul;39(5):295-9. doi:10.1259/dmfr/17573156. PMID: 20587654. PMCID: PMC3520249.
8. Ikbal M, Shen YW, Ruslin M, Fuh LJ, Hsu JT. Assessment of sagittal root position, alveolar bone concavity, and labial bone perforation in the mandibular anterior tooth region for immediate implant placement. J Dent Sci. 2023 Feb;18(3):1227-34. doi:10.1016/j.jds.2023.01.034. PMID: 37404638. PMCID: PMC10316510.
9. Batool SA, Chaudhry S, Munir N, Inayat N, Suleman G, Ahmed AR, et al. Micronuclei as an indicator of genotoxic change in epithelial cells of buccal mucosa after panoramic radiographs. Technol Health Care. 2024;32(4):2825-36. doi:10.3233/THC-240072. PMID: 38995741.
10. Yunus B, Dwi P. A symmetric mandible identification using cone beam computed tomography (CBCT). 2019 Apr;4(1):36-38. doi:10.15562/jdmfs.v4i1.666.
11. Vogiatzi T, Menz R, Verna C, Bornstein MM, Dagassan-Berndt D. Effect of field of view (FOV) positioning and shielding on radiation dose in paediatric CBCT. Dentomaxillofacial Radiol. 2022 Sep;51(6):20210316. doi:10.1259/dmfr.20210316. PMID: 35762346. PMCID: PMC10043625.
12. Karabas HC, Ozcan I, Sener LT, Guler SD, Albeniz I, Erdem TL. Evaluation of cell and DNA damage induced by panoramic radiography. Niger J Clin Pract. 2019 Aug;22(8):1041-8. doi:10.4103/njcp.njcp_675_18. PMID: 31417045.
13. Anbumeena S, Kannan A, Krithika CL, Vasanthi V. Genotoxic and cytotoxic biomonitoring in patients exposed to panoramic dental radiography: Comparison between five different age groups. J Indian Acad Oral Med Radiol. 2021 Jan-Mar;33(1):16-21. doi:10.4103/jiaomr.jiaomr_124_20.
14. Lorenzoni DC, Fracalossi ACC, Carlin V, Ribeiro DA, Sant'Anna EF. Mutagenicity and cytotoxicity in patients submitted to ionizing radiation : A comparison between cone beam computed tomography and radiographs for orthodontic treatment. Angle Orthod. 2013 Jan;83(1):104-9. doi:10.2319/013112-88.1. PMID: 22656641. PMCID: PMC8805537.
15. Baudin C, Bernier MO, Klokov D, Andreassi MG. Biomarkers of genotoxicity in medical workers exposed to low-dose ionizing radiation: Systematic review and meta-analyses. Int J Mol Sci. 2021;22(14):7504. doi:10.3390/ijms22147504. PMID: 34299125. PMCID: PMC8304237.
16. Altoukhi DH, Alaki S, El Ashiry E, Nassif O, Sabbahi D. Genotoxicity and cytotoxicity of cone beam computed tomography in children. BMC Oral Health. 2021 Sep;21(1):1-9. doi:10.1186/s12903-021-01792-w. PMID: 34481467. PMCID: PMC8418710.
17. Belmans N, Gilles L, Vermeesen R, Virag P, Hedesiu M, Salmon B, et al. Quantification of DNA Double Strand Breaks and Oxidation Response in Children and Adults Undergoing Dental CBCT Scan. Sci Rep. 2020 Feb;10(1):1-13. doi:10.1038/s41598-020-58746-5. PMID: 32034200. PMCID: PMC7005754.
18. Wulansari DP, Arsyad A, Rieuwpassa IE, Hamrun N, Hasyim R. Analysis of genotoxic and cytotoxic effects of oral mucosa in smokers and non-smokers after exposed to digital intraoral radiography. J Dentomaxillofacial Sci. 2019 Dec;4(3):159-162. doi:10.15562/jdmfs.v4i3.961
19. Jahanshahiafshar Z, Ghorbani H, Seyedmajidi M, Nabahati M, Gorji KE, Seyedmajidi S, et al. Genotoxic and Cytotoxic Effects of Cone Beam Computed Tomography and Multidetector Computed Tomography on Exfoliated Buccal Epithelial Cells. Iran J Med Sci. 2023 Nov;48(6):572-581. doi:10.30476/ijms.2023.96522.2807. PMID: 38094288. PMCID: PMC10715117.
20. Palla S, Rangdhol V, Uma AN, Devy SA, Shekar V. The genotoxic and cytotoxic effects of CT scan on buccal epithelial cells. J Cytol. 2020 Oct-Dec;37(4):189-192. doi:10.4103/JOC.JOC_120_19. PMID: 33776259. PMCID: PMC7984523.
21. Zehra SAFI O. Micronucleus scoring: An available approach in the evaluation of genomic damage in exfoliative cervicovaginal cells. Ann Cytol Pathol. 2020 Jun;5(1):064-067. doi:10.17352/acp.000018.
22. Silva-Júnior FMR da, Tavella RA, Fernandes CLF, Mortola AS, Peraza GG, Garcia EM. Genotoxic risk in health-care professionals occupationally exposed to low doses of ionizing radiation. Toxicol Ind Health. 2020;36(5):356-370. doi:10.1177/0748233720932081. PMID: 32539670.
23. Chitra P, Prashantha G, Rao A, Jois HS. In Vivo Evaluation of Micronucleus Frequencies in Buccal Mucosal Cells of Orthodontic Patients with and Without Fluoride Use. J Indian Orthod Soc. 2022;56(3):274-281. doi:10.1177/03015742211037307. PMID: 32338522. PMCID: PMC8982669.
24. Mounika G, Sridevi K, Krishnaveni B, Kumar N, Naidu H, Sahi B. Evaluation of genomic damage from buccal epithelial cells in patients subjected to cone beam computed tomography. J Indian Acad Oral Med Radiol. 2021 Oct-Des;33(4):372-378. doi:10.4103/jiaomr.jiaomr_83_21.
25. Ghadikolaei RF, Ghorbani H, Seyedmajidi M, Gorji KE, Moudi E, Seyedmajidi S. Genotoxicity and cytotoxicity effects of x-rays on the oral mucosa epithelium at different fields of view: A cone beam computed tomography technique. Casp J Intern Med. 2023 Winter;14(1):121-127. doi:10.22088/cjim.14.1.121. PMID: 36741479. PMCID: PMC9878913.

26. Mosavat F, Mahdavi N, Safari S. Cytotoxicity, genotoxicity, and immunohistochemical expression of p53 in the oral mucosal epithelium of adults following cone-beam computed tomography. Mutat Res Genet Toxicol Environ Mutagen. 2022 Jul-Aug: 879–80. doi: 10.1016/j.mrgentox.2022.503496. PMID: 35914862.
27. Lau YS, Chew MT, Alqahtani A, Jones B, Hill MA, Nisbet A, et al. Low dose ionising radiation-induced hormesis: Therapeutic implications to human health. Appl Sci. 2021 Sep;11(19). doi:10.3390/app11198909.
28. Farhadi S, Jolehar M, Babaeiha K. Evaluation of Micronucleus Frequency and Related Factors in the Buccal Mucosa of Cone Beam Computed Tomography-Exposed Subjects. J Res Dent Maxillofac Sci. 2017 Jun;2(3):10-5. doi:10.29252/jrdms.2.3.10.
29. Elizondo-Plazas A, Martinez-de-Villarreal LE, Cárdenas-Ramos SG, Rojas-Patlan L, Velasco-Sepulveda BH, Elizondo-Riojas G, et al. Effects of ionizing radiation in DNA: Defining the immediate and cumulative genetic damage induced by head computed tomography. Int Res J Public Environ Heal. 2022 Dec;9(5):148-155. doi:10.15739/irjpeh.22.018.
30. Sudhaa Mani M, Ahamed YS. Ambiga P, Sivaraman G, Gokulapriya S, Balan N. On the qui vive - Genotoxic and cytotoxic changes following the conventional dental radiograph. J Indian Acad Dent Spec Res. 2019:23;22-6.
31. Mavragani IV, Nikitaki Z, Kalospyros SA, Georgakilas AG. Ionizing radiation and complex DNA damage: From prediction to detection challenges and biological significance. Cancers (Basel). 2019 Nov; 11(11):1789. doi:10.3390/cancers11111789. PMID: 31739493. PMCID: PMC6895987.
32. McBride WH, Schaue D. Radiation-induced tissue damage and response. J Pathol. 2020 Apr;250(5):647–55. doi: 10.1002/path.5389. PMID: 31880369. PMCID: PMC7216989.
33. Vitti ET, Parsons JL. The radiobiological effects of proton beam therapy: Impact on DNA damage and repair. Cancers (Basel). 2019 Jul;11(7):946. doi: 10.3390/cancers11070946. PMID: 31284432. PMCID: PMC6679138.
34. Najafi M, Motevaseli E, Shirazi A, Geraily G, Razaeyan A, Norouzi F, et al. Mechanisms of inflammatory responses to radiation and normal tissues toxicity: clinical implications. Int J Radiat Biol. 2018 Mar;94(4):335-56. doi:10.1080/09553002.2018.1440092
35. Fenech M, Knasmueller S, Bolognesi C, Holland N, Bonassi S, Kirsch-Volders M. Micronuclei as biomarkers of DNA damage, aneuploidy, inducers of chromosomal hypermutation and as sources of pro-inflammatory DNA in humans. Mutat Res Rev Mutat Res. 2020 Oct-Dec;786:108342. doi:10.1016/j.mrrev.2020.108342. PMID: 33339572.
36. Da Fonte JBM, De Andrade TM, Jr RLCA, De Melo MDFB, Takeshita WM. Evidence of genotoxicity and cytotoxicity of X-rays in the oral mucosa epithelium of adults subjected to cone beam CT. Dentomaxillofacial Radiol. 2018 Feb;47(2):20170160. doi: 10.1259/dmfr.20170160. PMID: 29091472. PMCID: PMC5965904.
37. Angelieri F, Yujra VQ, Oshima CTF, Ribeiro DA. Do dental X-rays induce genotoxicity and cytotoxicity in oral mucosa cells? A critical review. Anticancer Res. 2017 Oct;37(10):5383-5388. doi:10.21873/anticanres.11964. PMID: 28982846.
38. Pereira R, Sabri H, Pereira P, Wang HL. Associated risks with periodontal x-rays or CBCT scans: Are there any? Clin Adv periodontics. 2023 Jul;14(2):121-6. doi:10.1002/cap.10261. PMID: 37470472.
39. Averbeck D, Candéias S, Chandna S, Foray N, Friedl AA, Haghdoost S, et al. Establishing mechanisms affecting the individual response to ionizing radiation. Int J Radiat Biol. 2020 Mar;96(3):297-323. doi:10.1080/09553002.2019.1704908. PMID: 31852363.
40. Nagi R, De A. Cone beam computed tomography: Systematic review on Justification of exposure based on ALADA principle. SAR J Dent Oral Surg Med. 2021 Jan;2(1):7-21.
41. Distefano S, Cannarozzo MG, Spagnuolo G, Bucci MB, Lo Giudice R. The "Dedicated" C.B.C.T. in dentistry. Int J Environ Res Public Health. 2023 May;20(11):5954. doi: 10.3390/ijerph20115954. PMID: 37297558. PMCID: PMC10252385.
42. Yeung AWK, Jacobs R, Bornstein MM. Novel low-dose protocols using cone beam computed tomography in dental medicine: A review focusing on indications, limitations, and future possibilities. Clin Oral Investig. 2019 Jun;23(6):2573-81. doi:10.1007/s00784-019-02907-y. PMID: 31025192.
43. Jha N, Khan FI. Radiation safety guidelines for 3D CBCT imaging: A dental review. Oral Health Maxillofac Res. 2024 Apr-Jun;1(2): 13-5. doi:10.61577/ohmr.2024.100010.