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Cone-beam computed tomography in implant dentistry - guidelines, current concepts and limitations for practice

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Abstract

This article issues scientific background of Cone-beam computed tomography (CBCT) and the importance of taking x-rays before and after implant placement in daily practice as a common care. The review will introduce cone-beam computed tomography guidelines, restrictions and intraoperartive issues for instance nerve damage and bleeding incidents. Modern CBCT technology enables specialists to avoid making a wrong diagnosis, which translates into a higher percentage of people with a positive treatment outcome.

Diagnostic radiology is a crucial element of every dental treatment planning. CBCT market is expanding gradually since two decades, there are more than 85 distinct CBCT tools available. CBCT is a three-dimensional (3D) imaging used nowadays in dentistry with increased frequency and offers volumetric data on jaw bones and teeth with relatively low radiation doses and costs. Currently, the greatest advantage of CBCT examinations over radiographs is the fact that the image obtained is presented in a 3D projection and not, as is the case, in 2D. It has the ability to help a wider range of patients, but the use of CBCT also has negative consequences. Routine or excessive use has resulted in increased radiation doses accumulating in the patient's body, which translates into an increased risk of adverse effects. The risk varies according to the age of the patient under study and is directly proportional to it, that is, it is highest for young people and lower for older people. The potential risk is also slightly higher in the female population. For this reason, creating awareness of the mandatory patient safety management of CT scans is a key process by which X-ray exposures can be optimised.

Keywords: Cone-Beam Computed Tomography; Dental Implants; X-Rays; Dentistry

Introduction

Cone-beam computed tomography (CBCT) first has appeared in the European market in 1996 and in the US market in 2001. During the last decade is has grow into being a fundamental diagnostic tool in many dental fields, such as endodontics, orthodontics, oral and maxillofacial surgery. It is roughly calculated that about 78% of oral and maxillofacial surgeons working in a private clinics use CBCT devices from which 59.1% apply CBCT in routine preoperative dental implant planning.

There are several factors that prevent to create complications and supply durable success of dental implants and these are the correct presurgical establishment of quality and quantity of bone and choice of the right implant with the ideal width and length. Research has shown that cross-sectional radiological imaging and especially CBCT demonstrate improved clinical effectiveness in comparison to classical 2D pictures for the assessment of implant poisoning in the bone and its nearby structures. [1,2]

Materials and methods

In order to find the relevant literature included in this article, an electronic search of PubMed database was performed. This review included studies published in English language, with an English language abstract and Polish language.
To create this publication, data were collected from 48 scientific articles, both Polish and English-language. After analysing the content contained in them, 19 articles were rejected, and the information used in the publication entitled: "The use of cone-beam computed tomography in dental implants” came from 29 of them.

Dental implants

A dental implant is a structure that imitates a natural tooth root. It was developed to replace missing teeth. Once implanted, the implant forms a permanent connection with the bone with the aim of transferring the chewing force directly to the bone surface.

There are a few ways to replace missing teeth in patients and one of them is inserting a dental implant. Their use became a commonly-used routine procedure for treating edentulism and they bring many benefits compared to classical fixed partial denture, such as a high success rate, a lower chance of getting caries and root canal issues of neighbouring teeth, increased preservation of bone in the area of a missing tooth/teeth and lower responsiveness of neighbouring teeth.[3]

Dental implant is a device used to bring retention and support for a fixed or removable dental prothesis. They are made of all-plastic materials and inserted into the oral tissues into the bone. [4]

At present, implants are made of biocompatible materials to ensure the success of the integration of the implant into the bone (so-called osteointegration); the use of the aforementioned materials is also responsible for easy absorption by the body. Two types of biocompatible materials are currently used for implants: zirconia and titanium. Zirconia implants are characterised by a high resistance to abrasion and interaction with acidic substances. Another advantage of zirconia implants is that they are aesthetically pleasing; thanks to the use of ceramic material, the colour of the implant largely corresponds to the patient's natural tooth colour. Titanium implants are made of metal, which gives them a high biocompatibility factor, thus ensuring minimal chances of non-integration into the patient's bone. An advantage over zirconia implants for a large number of patients is the lower cost. [5,6]

CBCT in implant dentistry

There continues to be an upward trend in this topic. Unfortunately, apart from the publication, the topic of tomography is still quite modern, resulting in a rather large discordance between the scientific literature and the equipment and software available today. For this reason, research results cannot always be treated according to the same framework, as published guidelines and may apply to a particular piece of equipment and may not necessarily work in the case we are diagnosing. This is also influenced by the fact that there are huge differences in the radiation doses used and the image quality, which are variable depending on the machine model and software selected [16,17].

Limitations of CBCT

Despite CBCT's quick entry into the dental sector, there are still some issues with it at the moment. These issues might be connected to the "cone-beam" projection geometry, detector sensitivity, or contrast resolution. Poor soft tissue contrast, noise, and artefacts all impair the quality of CBCT pictures.

Any distortion or mistake in the image unrelated to the picture under study is called an artefact. This reduces the quality of CBCT images and makes it more difficult to see the structures in the dento-alveolar area. Beam hardening (which causes streaks, dark bands, and cupping artefact), patient motion (which causes the reconstructed image to become jagged), scanner motion (which causes circular or ring-shaped artefacts), and cone beam motion (which causes partial volume averaging, undersampling, and cone-beam effect) can all cause artefacts. [7,8]

Low soft tissue contrast: Compared to traditional CT scanners, CBCT devices exhibit much lower soft tissue contrast. The contrast resolution of CBCT is limited by three factors: increased noise in the images, the divergence of the x-ray beam, and various intrinsic artefacts based on flat-panel detectors. [9,10]

Another disadvantage of CBCT is that there is still a great deal of variability between the instruments available on the market, which is reflected in the range of effective doses. This affects the results of studies and published reports. The doses used in them can differ significantly from the doses used in the most modern machines. The main differences affecting results are caused by differences noted in the range of detectors, scanning times and available fields of view (FOV). Currently, units with smaller FOVs and dramatically reduced effective radiation doses make up the bulk of machine production. The aim of this is to reduce the radiation dose to which the patient

undergoes the examination by using the smallest possible diagnostically acceptable field of view. Having a guideline, in the form of criteria that allow selection to be made among patients referred for CBCT, can help the specialist to perform the examination, only in a group of patients likely to benefit from the diagnostic aids used. It also allows the use of tomography to be adapted to given situations where 2D radiography has not been able to provide an answer to the question for which framing was performed [11]. The American Academy of Oral and Maxillofacial Radiology (AAOMR), has concluded that it is beneficial to perform cross-sectional imaging in patients who have a dental implant. They also point out that the decision to order a CBCT examination should be guided by the diagnostic data and the planned treatment, in order to avoid exposing the patient to unnecessarily high radiation doses. This can be achieved by limiting the field of view to the implant site only and the adjacent area also requiring CBCT diagnosis [12]. An additional fact supporting the validity of the recommendations of the American Academy of Oral and Maxillofacial Radiology is the fact that high-resolution scans are in most cases not required during the planning of implant treatment, examples being the evaluation of bone dimensions, the general assessment of bone quality and the visualisation of adjacent structures. In general, low-dose protocols are sufficient. European guidelines relating to the safety and efficacy of a new and emerging dental X-ray modality (SEDENTEXCT) point out that CT images often cover an area not included in the part under diagnosis, the entire volume should be assessed and not just limited to the region that is the main indication for examination. It cannot be disputed that CBCT plays a significant role in dental imaging and, in many situations, has a positive impact on the results of ongoing treatment. [13]
However, the effects of excessive use of CBCTs should not be overlooked and always take into account both aspects. Computed tomography machines first appeared on the market after the late 1990s . Since then, they have been widely used in diagnostics, which has revolutionised treatment planning and the evaluation of the performance of procedures. The main advantage of using CBCT in dental implantology is the ability to obtain accurate volumetric imaging data of the maxillofacial region, which translates into increased success and patient safety during surgery, by increasing the chance of a proper diagnosis and more accurate preoperative planning [14].

CBCT is currently conquering the diagnostic market due to its small size, reasonable dose, low cost and ease of use. Currently, specialists have 85 different CBCT models to choose from. Among these are hybrid systems, otherwise known as multimodal, that is, for combined 2D (panoramic and/or cephalometric) and 3D (CT) imaging. In addition to diagnostic use, CBCTs are also used for other purposes, such as pre-operative planning, also referral for rehabilitation. The growing interest in CBCTs has also translated into the software market for planning and guiding surgical procedures, resulting in its apparent growth in recent years. The increased interest has also left its mark on the number of publications produced in recent times related to the use of CBCTs in dental laboratories [15].

What radiation dose is used during a dental examination using CBCT?

It is very important to establish the relationship between the radiation dose and the quality of the image obtained. Reducing the radiation dose to a low level would be a great and simple solution to significantly reduce the risk of malfunctions. Unfortunately, very low radiation doses could render the images diagnostically useless, which would affect the diagnostic process The dentist should set radiation doses according to the ALADAIP (As Low as Diagnostically Acceptable being Indication-oriented and Patient-specific) principle, i.e. as low as diagnostically acceptable, indication-oriented and patient-specific to which the traditional ALARA principle has evolved; avoiding exposure to radiation [18].

Current thinking is that the effective doses for cone-beam CT should be significantly lower than those used for spiral CT, which is considered one of the major advantages of CBCT. Two to a maximum of 10 panoramic images are recommended. The currently available machines used for cone-beam CT vary considerably in terms of their design and the software used, which also translates into the radiation dose levels used for diagnosis. Radiation doses should range from approximately 10 μSv to 1,000 μSv, which is equivalent to 2-200 panoramic images [19].

In the latest generation of CBCT machines, the range of radiation doses is characterised by a very wide range of parameter settings, which also translates into a difference in the output dose and the quality of the image obtained during the examination. A number of guidelines and low-dose protocols have been created to enable professionals to use appropriate doses. CBCT equipment manufacturers have also introduced low-dose protocols, which can be as low as the dose values of panoramic images. Despite the above-mentioned guidelines and protocols, there is still a need for research aimed at determining the required image quality for diagnosis, pre-operative planning and during implant surgery. When carrying out the above-mentioned examinations, specialists are directed to balance the radiation dose against the image quality requirements. It should also be taken into account that medical imaging is constantly evolving, and therefore the currently recognised radiation dose advantage of CBCT in relation to the performance of multi-slice CT is relative and may change with improvements in the technology currently used. The radiation doses used for multi-row CT compared to those used for CBCT may even be at a lower level. This depends on the generation of the machine used to perform the CT scan and the exposure protocol used. The advances shown above in the optimisation of the radiation dose used in 2D and 3D imaging technology make it clear that the amount of dose used during the examination of a patient, as well as the risk of adverse effects, are elements that, with the current access to technology, can change dynamically and therefore need to be monitored frequently as well as re-questioned [20]. Furthermore, the specialist should individually adjust the dose level to the indications as well as the specific requirements of the patient. The dentist can fully follow the ALADIP principles to appropriately adjust the radiation dose in terms of optimisation and the prevention of adverse effects in daily medical practice, only if it sets doses according to a dose monitoring strategy during the recovery process or during the diagnostic process [21].

Parameters affecting the quality of the image obtained during a CBCT examination

The quality of the image obtained from a CBCT examination can vary significantly, primarily depending on the exposure protocols as well as, to a very large extent, the radiation dose ranges used during the examination. It is generally accepted that the images resulting from the use of cone tomography have a high spatial resolution, while with regard to the size of the voxels of the reconstructed CBCT datasets, these are in the range between 0.08 and 0.4 mm. Voxels with smaller sizes are particularly used diagnostically, in cases where diagnostic images of small anatomical structures, such as root canals or periodontal tissues, need to be obtained during the examination process [22]. A key factor in the situation of integrated virtual planning is the difference observed in terms of segmentation accuracy. This includes, among other things, models of the jawbone or the production of radiographic and surgical templates, but also applies to further prosthetic models. It should be 200 μm, depending on the type of CBCT machine and with regard to the settings of the tomograph parameters [23].

However, segmentation accuracy of 200 μm is not always achieved. Often there are inaccuracies of a greater degree, and these can even reach values of 1,000 μm or more. When multislice CT is used, a better quality of contrast resolution is at the specialist's disposal, which translates into fewer errors in relation to cone tomography. Another disadvantage that occurs when performing the examination with CBCT is the lack of diagnostically clear soft tissue contrast, which unfortunately translates into a reduced diagnostic potential and consequently leads to a more difficult application in terms of soft tissue integration, resulting in less accuracy during the preoperative planning process. Another disadvantage of CBCT is the inapplicability of Hounsfield units, resulting in the impossibility of comparing grey values between examinations carried out on different patients as well as on the same patient over time. This unfortunately leads to a lack of a standardised distribution of grey values, which greatly complicates the use of cone tomography in the process of clinical bone density assessment, but is also not without impact on the process of monitoring bone density changes. Hounsfield units (HU), which are widely used in medical computed tomography, are unfortunately not applicable to the examination process using CBCT due to the disadvantage shown above [24].

Unfortunately, the lack of standardisation for HUs, is for most machines used in CBCT their main problem. In the field of dental implantology, in a purely surgical context, the actual relevance of this problem can be questioned, due to the location of the implant. Given that in current implantology, it is more advantageous to have bone that is both healthy and well vascularised for the implant procedure, rather than bone that is hardened, dense and poorly vascularised. As a result, instead of CBCT for the clinician, bone structural analysis, among other things available in dedicated μCT software, may be more useful. Therefore, bone structural analysis has been found to be useful in the cone-beam CT imaging process, and for this reason, the researchers hypothesise that it may have clinical potential when performing a preoperative assessment of a patient's bone quality. Another disadvantage of CBCT is the varying degree of expression of artefacts, which largely interferes with an adequate examination result. Artefacts most often arise as a result of the patient's ear and dense materials, and also not infrequently, there is a combination of both factors mentioned above [19].

Guidelines of CBCT in implant dentistry

The guidelines used in the CBCT approach are mainly based on consensus but also come from a rather limited methodological approach.In a recent systematic review addressing the guidelines of CBCT used in dental implantology, all guidelines published up to the date of the publication were collected and reviewed. It included both indications and limitations of the use of cone-beam tomography in implantology. The current key set of guidelines is still the set of 20 principles, which was published by the European Academy of Dental and Maxillofacial Radiology (EADMFR) in 2009. The aforementioned set was created to bring together basic standards to enable the adoption of national procedures, both within and outside European countries. The guidelines contained in points one to eight speak to the rationale for the use of cone tomography, while points nine to 15 were written to generalise dose optimisation, based on the requirements for obtaining an adequate diagnostic image. The points contained between sixteen and twenty address the question of the appropriate level of both competence and prior training with regard to performing examinations by cone tomography. In the case of diagnostics, we distinguish between several types of diagnostics,

including diagnostic views in the area of the teeth and jawbone, in addition to larger and other anatomical areas [25].
Depending on the area, the requirements for diagnostic evaluation also differ; teeth and jawbone can be viewed and diagnosed by non-specialist doctors who have received the appropriate training for this procedure, while the other anatomical areas mentioned can only be diagnosed by specialist doctors. A more recent publication, for which the sedentex CT guidelines were used, further elaborates on both the principles and strategies for optimising examinations, using CBCT, during the oral floor implant procedure. This publication presents the current EDA guidelines relating to the topic of the use of diagnostic imaging in the field of dental implantology. These guidelines are based on the conclusions drawn at the consensus workshop organised by the European Society of Osseointegration in 2011 and include a revision of the guidelines that were written by the European Society of Osseointegration in 2002. Also published at a similar time are the guidelines relating to the placement of oral implants and the applicability of CBCT, which were developed by the American Academy of Oral and Maxillofacial Radiology, with a revision of the guidelines presented, by the Academy, in 2000 [26].
Both revisions were carried out, due to the advancing sophistication of technology in the field of CBCT and the role it has begun to play in the diagnostic process in recent years, especially with regard to the field of implant dentistry.
The main difference that can be noted between the guidelines is that the EDA places more emphasis on appropriate and specialized training in CBCT examinations [27].

Computed tomography of the teeth - what does it involve?

Dental specialists make extensive use of CT scans of the jaw and/or mandible for treatment planning in various areas. CT scans are used in implant dentistry, dental surgery, periodontics, orthodontics and endodontics, among others. Computed tomography of the tooth is an examination that uses X-rays to image tissue in three planes. This allows it to provide the specialist with detailed information about the dentition, thereby showing its pathologies. This allows the dental specialist to simulate the treatment, before it actually takes place. The examination makes it possible to visualise the patient's entire dentition as well as the structure of a single tooth. The patient does not require any preparation for the examination, and the process is painless and non-invasive [28].

Tomography of the jaw with dental implants - is it possible?

A diagnostic examination, in the form of a CT scan, is in no way contraindicated in patients with an implant if it is not made of: : iron, cobalt, nickel and certain other alloys. It is a completely safe examination and can be carried out for further treatment in the field of implantology, orthodontics, restorative dentistry and endodontic treatments [29].

Tooth tomography and metal implants

Ionising radiation, which finds its use in diagnostic imaging, unfortunately makes it impossible to carry out tomographic examinations in a certain group of patients, following implant surgery. Implants made of the metals mentioned in the subsection above, i.e. consisting of : iron, cobalt, nickel and certain other alloys, are contraindicated. In the case of computed tomography, it is also irrelevant whether the implant contains ferromagnetic materials in its composition, but this is of colossal importance in the imaging diagnosis carried out in the form of magnetic resonance imaging. In this procedure, implants consisting of, among other things, ferromagnets are attracted to the magnesium used in the examination. This situation can lead to the displacement of the implant, with the consequent risk to the patient's health. Patients with implants containing ferromagnets are strictly excluded from MRI examinations. CT scanning is completely safe for implants made of metal, but this does not mean that they do not affect the result of the examination. Their presence is shown as artefacts in the examination and, as a consequence, they interfere with the diagnostic result [29].

Conclusions

Cone beam computed tomography (CBCT) is currently one of the standard tests for successful surgery is diagnostic imaging. It finds its application not only in the field of implant dentistry, but is also used by many other specialists.

Its impact on the state of current dental treatment is invaluable. We can currently say that CT has become the gold standard for diagnosis and treatment planning in the field of dentistry.

Author’s contribution

Conceptualization, Zuzanna Popińska and Filip Pactwa; methodology, Wiktoria Jakubowska and Piotr Pisera; software, Daniel Ślusarczyk and Aleksandra Kiełkowicz; check, Zuzanna Popińska and Bartłomiej Żmuda; formal analysis, Zuzanna Popińska and Daniel Ślusarczyk; investigation, Filip Pactwa and Michał Żuberek; resources, Michał Żuberek and Wiktoria Jakubowska; data curation, Piotr Pisera and Bartłomiej Żmuda; writing - rough preparation, Zuzanna Popińska; writing - review and editing, Filip Pactwa; visualization, Piotr Pisera and Aleksandra Kiełkowicz; supervision, Michał Żuberek, Bartłomiej Żmuda and Wiktoria Jakubowska; project administration, Zuzanna Popińska.

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References:

1. Venkatesh E, Elluru SV. Cone beam computed tomography: basics and applications in dentistry. J Istanb Univ Fac Dent. 2017 Dec 2;51(3 Suppl 1):S102-S121. doi: 10.17096/jiufd.00289. PMID: 29354314; PMCID: PMC5750833.

2. Van Assche N, Vercruyssen M, Coucke W, Teughels W, Jacobs R, Quirynen M. Accuracy of computer-aided implant placement. Clin Oral Implants Res. 2012 Oct;23 Suppl 6:112-23. doi: 10.1111/j.1600-0501.2012.02552.x. PMID: 23062136.

3. Guillaume B. Dental implants: A review. Morphologie. 2016 Dec;100(331):189-198. doi: 10.1016/j.morpho.2016.02.002. Epub 2016 Mar 16. PMID: 26995275.

4. Cherian JM, Samuel S, Sabu AM, Thomas AM, Injety RJ. Dental implants in growing patients: A quality assessment of systematic reviews. J Oral Biol Craniofac Res. 2023 Sep-Oct;13(5):610-615. doi: 10.1016/j.jobcr.2023.07.004. Epub 2023 Aug 2. PMID: 37565026; PMCID: PMC10410509.

5. Saini M, Singh Y, Arora P, Arora V, Jain K. Implant biomaterials: A comprehensive review. World J Clin Cases. 2015 Jan 16;3(1):52-7. doi: 10.12998/wjcc.v3.i1.52. PMID: 25610850; PMCID: PMC4295219.

6. Sykaras N, Iacopino AM, Marker VA, Triplett RG, Woody RD. Implant materials, designs, and surface topographies: their effect on osseointegration. A literature review. Int J Oral Maxillofac Implants. 2000 Sep-Oct;15(5):675-90. PMID: 11055135.

7. Schulze R, Heil U, Gross D, Bruellmann DD, Dranischnikow E, Schwanecke U, Schoemer E. Artefacts in CBCT: a review. Dentomaxillofac Radiol. 2011 Jul;40(5):265-73. doi: 10.1259/dmfr/30642039. PMID: 21697151; PMCID: PMC3520262.

8. Endo M, Tsunoo T, Nakamori N, Yoshida K. Effect of scattered radiation on image noise in cone beam CT. Med Phys. 2001 Apr;28(4):469-74. doi: 10.1118/1.1357457. PMID: 11339743.

9. Farman AG. Guest editorial--Self-referral: an ethical concern with respect to multidimensional imaging in dentistry? J Appl Oral Sci. 2009 Sep-Oct;17(5):i. doi: 10.1590/s1678-77572009000500001. PMID: 19936508; PMCID: PMC4327655.

10. Jens Wiegert, Matthias Bertram, Dirk Schaefer, Norbert Conrads, Niels Noordhoek, Kees de Jong, Til Aach, Georg Rose, "Soft-tissue contrast resolution within the head of human cadaver by means of flat-detector-based cone-beam CT," Proc. SPIE 5368, Medical Imaging 2004: Physics of Medical Imaging, (6 May 2004); https://doi.org/10.1117/12.535191

11. Tetradis S, White SC. A decade of cone beam computed tomography. J Calif Dent Assoc. 2010 Jan;38(1):24-6. PMID: 20178223.

12. Tyndall DA, Brooks SL. Selection criteria for dental implant site imaging: a position paper of the American Academy of Oral and Maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000 May;89(5):630-7. doi: 10.1067/moe.2000.106336. PMID: 10807723.

13. Benavides E, Rios HF, Ganz SD, An CH, Resnik R, Reardon GT, Feldman SJ, Mah JK, Hatcher D, Kim MJ, Sohn DS, Palti A, Perel ML, Judy KW, Misch CE, Wang HL. Use of cone beam computed tomography in implant dentistry: the International Congress of Oral Implantologists consensus report. Implant Dent. 2012 Apr;21(2):78-86. doi: 10.1097/ID.0b013e31824885b5. PMID: 22382748.

14. Horner K, Islam M, Flygare L, Tsiklakis K, Whaites E. Basic principles for use of dental cone beam computed tomography: consensus guidelines of the European Academy of Dental and Maxillofacial Radiology. Dentomaxillofac Radiol. 2009 May;38(4):187-95. doi: 10.1259/dmfr/74941012. PMID: 19372107.

15. Miracle AC, Mukherji SK. Conebeam CT of the head and neck, part 2: clinical applications. AJNR Am J Neuroradiol. 2009 Aug;30(7):1285-92. doi: 10.3174/ajnr.A1654. Epub 2009 May 20. PMID: 19461061; PMCID: PMC7051564.

16. Van Assche N, van Steenberghe D, Quirynen M, Jacobs R. Accuracy assessment of computer-assisted flapless implant placement in partial edentulism. J Clin Periodontol. 2010 Apr;37(4):398-403. doi: 10.1111/j.1600-051X.2010.01535.x. PMID: 20447264.

17. Jacobs R, Quirynen M. Dental cone beam computed tomography: justification for use in planning oral implant placement. Periodontol 2000. 2014 Oct;66(1):203-13. doi: 10.1111/prd.12051. PMID: 25123769.

18. Oenning AC, Jacobs R, Pauwels R, Stratis A, Hedesiu M, Salmon B; DIMITRA Research Group, http://www.dimitra.be. Cone-beam CT in paediatric dentistry: DIMITRA project position statement. Pediatr Radiol. 2018 Mar;48(3):308-316. doi: 10.1007/s00247-017-4012-9. Epub 2017 Nov 15. PMID: 29143199.

19. Jacobs R, Salmon B, Codari M, Hassan B, Bornstein MM. Cone beam computed tomography in implant dentistry: recommendations for clinical use. BMC Oral Health. 2018 May 15;18(1):88. doi: 10.1186/s12903-018-0523-5. PMID: 29764458; PMCID: PMC5952365.

20. Schwindling FS, Hilgenfeld T, Weber D, Kosinski MA, Rammelsberg P, Tasaka A. In vitro diagnostic accuracy of low-dose CBCT for evaluation of peri-implant bone lesions. Clin Oral Implants Res. 2019 Dec;30(12):1200-1208. doi: 10.1111/clr.13533. Epub 2019 Sep 20. PMID: 31505065.

21. Aravind BS, Joy ET, Kiran MS, Sherubin JE, Sajesh S, Manchil PR. Attitude and awareness of general dental practitioners toward radiation hazards and safety. J Pharm Bioallied Sci. 2016 Oct;8(Suppl 1):S53-S58. doi: 10.4103/0975-7406.191969. PMID: 27829748; PMCID: PMC5074042.

22. Tschauner S, Marterer R, Nagy E, Singer G, Riccabona M, Sorantin E. Experiences with image quality and radiation dose of cone beam computed tomography (CBCT) and multidetector computed tomography (MDCT) in pediatric extremity trauma. Skeletal Radiol. 2020 Dec;49(12):1939-1949. doi: 10.1007/s00256-020-03506-9. Epub 2020 Jun 14. PMID: 32535775; PMCID: PMC7652807.

23. Widmann G, Bischel A, Stratis A, Kakar A, Bosmans H, Jacobs R, Gassner EM, Puelacher W, Pauwels R. Ultralow dose dentomaxillofacial CT imaging and iterative reconstruction techniques: variability of Hounsfield units and contrast-to-noise ratio. Br J Radiol. 2016;89(1060):20151055. doi: 10.1259/bjr.20151055. Epub 2016 Jan 21. PMID: 26859336; PMCID: PMC4846222.

24. Shen L. Implementation of CT Image Segmentation Based on an Image Segmentation Algorithm. Appl Bionics Biomech. 2022 Oct 12;2022:2047537. doi: 10.1155/2022/2047537. Retraction in: Appl Bionics Biomech. 2023 Aug 16;2023:9840516. PMID: 36276585; PMCID: PMC9581628.

25. Horner K, O'Malley L, Taylor K, Glenny AM. Guidelines for clinical use of CBCT: a review. Dentomaxillofac Radiol. 2015;44(1):20140225. doi: 10.1259/dmfr.20140225. PMID: 25270063; PMCID: PMC4277440.

26. Fan W, Zhang J, Wang N, Li J, Hu L. The Application of Deep Learning on CBCT in Dentistry. Diagnostics (Basel). 2023 Jun 14;13(12):2056. doi: 10.3390/diagnostics13122056. PMID: 37370951; PMCID: PMC10296994.

27. Matijaš, Tatjana & Jurić, Barbara. (2023). The role of CBCT in the field of dental implantology. 47. 16-27. 10.55378/rv.47.1.2.

28. Friedlander-Barenboim S, Hamed W, Zini A, Yarom N, Abramovitz I, Chweidan H, Finkelstein T, Almoznino G. Patterns of Cone-Beam Computed Tomography (CBCT) Utilization by Various Dental Specialties: A 4-Year Retrospective Analysis from a Dental and Maxillofacial Specialty Center. Healthcare (Basel). 2021 Aug 13;9(8):1042. doi: 10.3390/healthcare9081042. PMID: 34442182; PMCID: PMC8392371.

29. Jacobs, R., Salmon, B., Codari, M. *et al.* Cone beam computed tomography in implant dentistry: recommendations for clinical use. *BMC Oral Health* 18, 88 (2018). https://doi.org/10.1186/s12903-018-0523-5.