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3D DIAGNOSTICS IN OROFACIAL REGION

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Summary

Scientific and clinical advances in all fields of medicine are, to a great extent, based on development and practical usage of advanced technological systems. During the past 30 years, three dimensional (3D) diagnostics has been used in virtually all branches of medical practice. However, the inherently high levels of x-ray radiation have limited the application of computerized tomography (CT) in orofacial region only to emergency cases such as tumor diagnostics. The ALARA (*As Low As Reasonably Achiveable*) principle – the fundamental principle of radiological diagnostics – prevented practical application of 3D CT diagnostics in daily clinical practice in dental medicine.

Because of these limitations, a concerted effort was undertaken towards development of diagnostic methodologies that would retain the advantages of CT diagnostics while reducing the concomitant doses of radiation, and thus enhance their diagnostic value and ethical acceptability.

The application of conic-beam-based CT instruments (CBCT – Cone Beam Computer Tomography), enabled wider application of 3D diagnostics in dental medicine and, primarily, orofacial surgery. Awareness of the 3rd dimension and the spatial relationships of anatomical structures greatly facilitates the planning of surgical procedures and reduces their inherent risks. Furthermore, it allows a more thorough understanding of the proposed therapeutic procedures by the patient, enables asessment of the quality and quantity of bony structures, and reduces the chances of peri/post operative complications. CBCT methodology features lower relative radiation doses, a high resolution of quantitative and qualitative details, and simple, economical manipulation of images. CBCT is based on two-dimensional conic beam and a wide array of sensors with the imaging angle greater than 400 degrees. Radiation exposure is significantly reduced by the usage of pulse exposure and data analysis algorithms based on a wide digital panel that simultaneously receives data from all imaging angles and calculates the exact values of the imaged structures.

Due to its significant advantages compared to two-dimensional radiological diagnostic methods, the application od 3D diagnostics is expanding to virtually all branches of dental medicine. Also, based on its high acurracy and precision, the CBCT technology holds great potential for future applictions in scientific research.

Key words: Cone-Beam CT; 3D diagnostics; dental radiology.

INTRODUCTION

X-ray imaging is an indispensable tool of dental diagnostics. It is widely applied in diagnostics of odontogenic and nonodontogenic pathoses, various phases of endodontic therapy, pre-surgical and trauma diagnostics, periodontal evaluation, morphologic and anthropologic analyses of orthodontic patients' features, planning of implant procedures, and general patient follow up. X-ray imaging may be classified into pre-operative, intra-operative, and post-operative, based on indicated diagnostic requirements and treatment status. X-ray images may be generated using the conventional analog, semi-digital, or digital procedure. In the analog procedure, the x-radiation is recorded on a photo-sensitive film. In semi-digital procedure, the radiation is recorded on phosphorus plates. In digital procedures, digital sensors transform the electromagnetic energy of x-rays into electric impulses. Electric impulses carry different photosensoric values which are transformed into pixels by the digitalization board, and assembled into horizontal raster lines. Raster lines combine to form a matrix map, wherein every pixel – i.e. the basic unit of an image – has its unique dimension and intensity that defines the surface area and grayscale degree depicting tissue structures.

The following two-dimensional (2D) images are most commonly used in dental medicine: panoramic images of teeth and jaw (orthopan), intraoral retro alveolar images of individual teeth or areas of the jaw, as well as occlusal, bite-wing and cephalometric images of various projections (latero-lateral (L-L), posterior-anterior (P-A), submento-ventral (Sm-V)). The 2D imaging procedures summarize 3D data on a 2D image. Any disturbance of the patient or instruments during the imaging procedure (e.g. patient fidgeting, movement of the film tube or sensors) results in geometric or exposition errors that will further cause generation of incomplete and / or inaccurate images [1].

X-ray image analysis is an important step in diagnostics and medical procedure planning that yields itself well to the needs of the treatment provider's need to deduce the 3rd dimension from 2D images. However, 2D images sometimes lack the information for a reliable assessment of the 3rd dimension. In those cases, a three-dimensional (3D) tomographic analysis of areas of interest is indicated [2]. Although 3D computerized tomography (CT) has been used in various branches of medicine, its application in orofacial medicine has mostly been limited to cases of maxillofacial traumas and diagnostics of head and neck due to high levels of radiation exposure during CT scanning [3].

Three types of CT scanners are currently in operation: traditional scanner, helicoid or volumetric scanner, and the Cone-Beam Computed Tomography (CBCT) scanner. Based on exposure shape, scanners are further divided into fan-beam and cone-beam scanners. Fan-beam scanners create 3D images by stringing together a great number of axial images acquired through circular motion of the radiation source and the detector around the object of interest. Currently used detectors simultaneously scan up to 64 layers, and thus keep the total radiation exposure time to a minimum [4].

Computed tomography (CT) enables detailed, high-definition 3D analysis of structures in correct and precisely defined frames of reference, without the need to summarize data. Thus, CT imaging is the most precise method for defining anatomical structures, pathological processes, deformations, traumas, maxillar and mandibular anomalies, as well as determining the dimensions of anatomic structures with high precision [5].

Conventional CT scanners are large and expensive machines that emit high doses of radiation and are designed for whole-body imaging. They compensate for movement artifacts generated through physiological activity of organs or patient-induced movements during prolonged scanning sessions. Following the basic radiology diagnostic principle of as low as reasonably achievable (ALARA) exposure of patients, the high radiation emitting CTs are used in dental diagnostics only in special cases, and are not considered an appropriate diagnostic tool for regular dental practice. The need for development of clinically more applicable CT modalities with lower radiation exposure doses spurred technological breakthroughs in 3D maxillofacial diagnostics. These efforts resulted with the development of the first CBCT machine in 1982 at the Mayo Clinic Biodynamics Research Laboratory [6]. Its primary application was angiography. In 2001, The Food and Drug Administration (FDA) approved the NewTom QR DVT 9000; Quantitative Radiology, Verona, Italy (1) as the first CBCT machine with specific dental maxillar applications.

PRINCIPLES OF CBCT

Principles of CBCT are based on the rotating x-ray tube and a digital sensor. The x-ray tube and the sensor are located on the opposite sides of the rotating arm, such that the imaged patient is located in supine or seated position, in between. CBCT devices in which the patient is seated during the imaging procedure are more commonly used in clinical practice since they require less space, are more readily accepted by the patients and provide a relatively good way of head fixation. A safe and stable procedure for patient's head fixation is of utmost importance since it reduces or eliminates movement artifacts in acquired images. The seating position is also preferential for disabled and movement impaired patients (*Figure 1*).

Figure 1. Cone-Beam CT device

The x-rays diffuse in pyramidal or conical pattern, while the digital sensor is shaped as a rectangular board. During image acquisition, the digital sensor registers a large number of images that are then assembled into a 3D image. Image overlaps – i.e. duplicate images acquired from different perspectives and positions – are used to control and modify the accuracy of the final 3D image. In order to acquire overlapping images of the region of interest (ROI) (1), the rotation of the x-ray tube around the imaged object must exceed full circle (i.e. more than 360 degrees). Such image acquisition geometry requires the entire field of view (FOV) area to be registered from different orientations, which in turn results in acquisition of large data sets and pixels for every point within the FOV.

At this stage of the imaging process, the data are assembled 2-dimensionally for every particular imaged layer. The data are acquired at different angles and since the radiation source and the sensors are oriented in multiple dimensions. Filtration algorithms are used to reduce the signal to noise ratio of thus registered, inherently noisy images. Without sufficient filtering, the acquired final images contain error artifacts. Error artifacts are more common when using larger FOVs and lower scanning resolutions [1]. Base images are comprised of single layer images, which are then computationally assembled into 3D images by data reconstruction in three orthogonal projections (axial, sagittal, coronal). The commonly used digital sensors fall into two categories: the image intensifier tubes (IIT) with relatively high noise ratios, and the flat panel imagers (FPI) whose amorphic silicone semi-conductor amplifier is covered by cesium-iodide [7].

When comparing the geometry of CBCT to that of fan or spiral CT scanners, CBCT geometry allows greater usage economy of the x-ray beam, faster volumetric image synthesis, and reduction of the overall scanner cost. The CBCT geometry enables performance of single scans with varying FOV sizes by means of conic x-ray beam. CBCT scans take the same amount of time as single scans of individual layers using the fan beam, while CBCT acquired image data encompass the entire FOV, unlike single layer data acquired by the fan beam. Finally, the price of the CBCT scanners is lower than MSCT scanners, and is thus more acceptable for a greater number of institutions.

Several basic technologic factors enabled the development and broad application of CBCT scanners. The primary factor was development of computational hardware that enabled processing and analyses of large and complex data sets. The price of CBCT hardware has been significantly reduced in the recent years, while 3D image analysis capabilities increased concurrently. The technology of manufacturing high resolution flat digital sensors was also significantly advanced. Due to the less technologically demanding manufacturing process, the price of the CBCT x-ray tubes is lower than that of the MSCT radiation source. Finally, due to specialization of CBCT application to imaging of head and neck, removed the need for specific secondary rotation inherent to imaging of inner organs such as heart and lungs [3].

The data format used for viewing, storage, transfer and output of CBCT images is called the Digital Imaging and Communications in Medicine (DICOM) (National Electrical Manufacturers Association, Rosslyn, Va.) format [8,9].

FIELD OF VIEW (FOV)

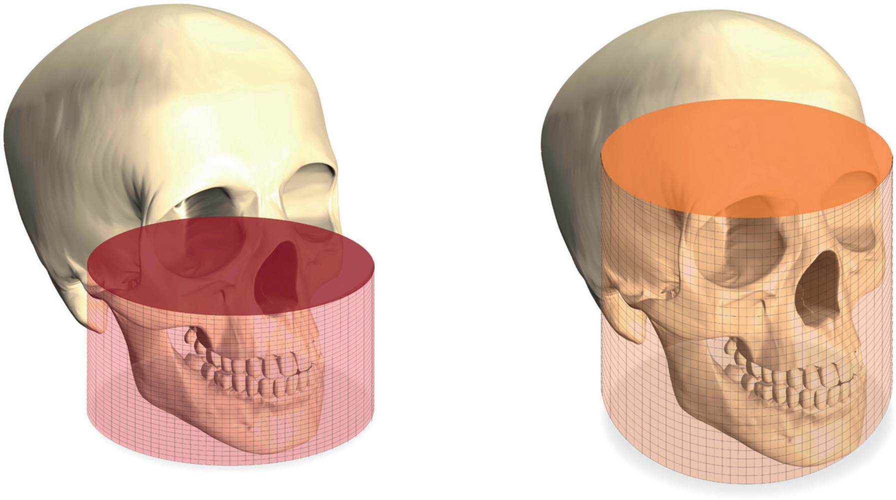
The area encompassed by a single image is referred to as the field of view (FOV). The size of FOV depends on several factors: detector size and shape, projection geometry, and x-ray beam collimation. FOVs are most commonly cylindrically or conically shaped, while their sizes vary depending on specific diagnostic indications.

Most CBCT scanners can acquire images using FOVs of varying sizes. Small FOVs effectively reduce the radiation dosage because its emission is limited to a smaller region encompassing smaller volume and less sensitive tissues. If the ROI encompasses one or several teeth, a smaller FOV may be used. However, if the ROI encompasses the entire jaw or the entire viscerocranium, a larger FOV should be used. The majority of CBCT scanners have inbuilt functions for resolution reduction and simultaneous increase of the FOV. Such optimization functions allow for lower patient radiation exposure with simultaneous usage of large FOVs. When using large FOVs, good clinical practice suggests all areas of the image should be studied in detail – in addition to the particular ROIs – since CBCT images contain a wealth of useful data that can be used in ancillary diagnostics of neoplasms or atherosclerotic changes such as carotid artery calcification [10].

Sizes of field of view vary from scanner to scanner, and may be divided into following categories (*Figures 2.1-2.4*):

1. small field
2. medium field
3. large field
4. extra large field

Figures 2.1-2.2. Different fields of view (FOV): small (2.1), medium (2.2).



Figures 2.3-2.4. Different fields of view (FOV): large (2.3), extra large (2.4).

RADIATION DOSE

When evaluating the risks of x-ray radiation exposures, the measure of the Effective Dose (E) or radiation – expressed in Sieverts (Sv) – is used. To establish the Effective Dose, the magnitude of radiation absorbed by the tissues is measured. The values of E are calculated based on the relative tissue compositions within the FOV, and their sensitivity to radiation. Factors that are used to describe tissue sensitivity to radiation are used to calculate the total Effective Dose for a particular FOV, which are then compared to natural radiation exposures incurred in daily life. When calculating the Effective Dose for the head and neck, sensitivity factors for bone marrow, thyroid, esophagus, skin, bone surface, salivary glands, brain and „other" tissues are factored in [11]. Thus, unless specific organs – such as the thyroid gland – are irradiated, the E remains relatively lower. Except by avoiding irradiation of highly sensitive organs, the Effective Dose may be lowered by using pulse instead of continuous beam. The Effective Dose is also affected by sensitivity of the digital sensor, quality and characteristics of the x-ray beam, number of rotations around the imaged object, the electric potential (voltage) power (wattage) in the x-ray tube, FOV size, and filter type (1). CBCT radiation doses are significantly lower than those produced by conventional CTs, but are larger than doses produced during 2D imaging procedures used in dental medicine [12]. Due to relatively low radiation doses, CBCT is the method of choice for 3D imaging of the maxillofacial region.

International Commission on Radiological Protection (ICRP) – the international organization for radiation protection – in 2007 published new factor values for specific tissues and organs to be used in calculating the effective radiation doses [11]. The new data include salivary glands as separate entities, while mucous buccal cavity has been classified under „other“ organs whose E factor was increased from 0.05 to 0.12.

Investigations of irradiation for orthopantomographic images suggests of 5.5-22 μSv [13], between 2.2 and 3.4 μSv for cephalograms [14], 1-8 μSv for intraoral periapical images [12] and 8 μSv for occlusion images [12]. The effective dose of radiation differs with different CBCT scanners, depends on the FOV size, and ranges between 13 and 498 μSv. CBCT generated maxillofacial images incur effective radiation doses in the 30-80 μSv range, which is significantly less than the average effective dose of 860 μSv for comparable FOV size images generated by MSCT scanners [15], or the 1320–3324 μSv for mandibular, and 1031–1420 μSv for maxillary images [16-20]. The average effective doses of CBCT images correspond to average effective doses of intraoral images of individual teeth when using classic x-ray film radiography – i.e. 13–100 μSv [21-23,7]. The effective radiation dose incurred by CBCT image of the middle ear area is about 13 μSv – i.e. 60 times lower than the same image generated using MSCT scanner [24,25]. For comparison, ICRP is a measure of space radiation that an individual absorbs during one year (measured in the United States), and amounts to 3000 μSv [1].

APPLICATION OF CBCT IN OROFACIAL MEDICINE

CBCT diagnostics is considered to be the best diagnostic procedure in dental medicine. Based on the current regulations in the United States, every dentist is required to offer their patients the best available diagnostic procedure. If the patient refuses to accept the CBCT scan they are required to sign an informed procedure refusal form. Thus, CBCT diagnostics is considered a Standard of Care radiological procedure that provides all diagnostically relevant information. As such, it represents the lowest acceptable level of regular diagnostic care. Not offering CBCT imaging to the patient prior to their treatment may be considered legal malpractice based on inappropriate and / or incomplete performance of diagnostic procedures (26).

CBCT technology is especially important in diagnostics of hard tissues, and has wide applicability in orofacial medicine. The most important applications of CBCT include planning of surgical procedures – implant therapy in particular – and skeletal augmentation, orthodontic and TMJ diagnostics, and determination of periapical pathology and periodontal changes.

***Indications of CBCT*:**

1. Evaluation of the jaw bones which includes the following:
   - Pathology;
   - Bony and soft tissue lesions;
   - Periodontal assessment;
   - Endodontic assessment;
   - Alveolar ridge resorption;
   - Recognition of fractures and structural maxillofacial deformities;
   - Assessment of the inferior alveolar nerve before extraction of mandibular third molar impactions;
   - Orthodontic evaluation—3D cephalometry;
   - TMJ evaluation; and
   - Implant placement and evaluation
2. Airway assessment
3. Whenever there is need for 3D reconstructions [3]

Maxillofacial and oral surgery

Currently, it is hard to conceive surgical planning without precise diagnostics. However, for a long time, the diagnostics of maxillofacial region was limited to only 2D radiography or to MSCT images offering some insight into the 3rd dimension, but at the cost of exposing the patient to high levels of radiation.

There are multiple indications for application of 3D CBCT diagnostics in oral and maxillofacial surgery. From the early days of CBCT, it has been used in planning of various oral surgery procedures. Thus, the range of CBCT applications in maxillofacial and oral surgery includes teeth extractions, alveotomies, impacted teeth, apicotomies, foreign body diagnostics, TMJ, oroantral fistulas and vestibuloplastics. It is also used in diagnostics of traumas and fractures, clefts, syndromes and malformations, as well as in ortognathic and reconstructive surgery. CBCT technology plays an particularly important role in dental implantology.

As a part of maxillofacial trauma treatment, CBCT is used pre-operatively, intraoperatively, and post-operatively. It is used in surgical navigation, determination of mandibular and maxillary fractures [27], determination of the position of skeletal fragments and metal screws and plates during osteosynthesis, and in post-operative evaluation. Another aspect of CBCT usage is in cases of rupture fractures of orbito-maxillary complex. However, diagnostic value of this particular aspect of CBCT clinical application is relatively low due to lower skeletal calcification in elderly population and lower resolution of the medial orbital wall caused by the air-filled ethmoidal cells [28]. The complex anatomy of the base of the skull requires high image resolution of hard and soft tissues. A common practice of producing the required level of skull base image accuracy is to combine CT and MR imaging techniques. Yet, the use of CBCT in skull base imaging is the preferred method on account of higher precision and accuracy, while exposing patients to lower effective radiation doses [15].

Implantology

Radiologic diagnostics is a requirement in the planning of implant therapy. The use of panoramic images has been an integral part of planning since the beginnings of implantology. Determination of implant positioning is the most important procedure in the planning process, wherein knowledge of maxillar or mandible anatomy is of vital importance. In the treatment planning phase, it is essential to precisely determine a number of structures, including the mandibular canal, the ansa of the mandibular nerve, the mental foramen, as well as the width and height of the alveolar ridge [2]. Panoramic images have often been used in planning of implant therapy in spite of its obvious drawbacks such as providing only 2D views and low image resolution. In order to reduce the presence of artifacts generated during image enlargement, celluloid matrices for various image enlargement factors have been developed. However, celluloid matrices yield insufficient precision for clinical applications since the precision depends on individual characteristics of panoramic image acquisition setup and uneven enlargement factors.

The width and angle of alveolar ridges, anatomy of the inner mandibular surface, position of important anatomical structures – such as mandibular canal and the basis of the maxillary sinus, nor bone density are measurable from 2D images [3]. Three-dimensional cross-sectional imaging techniques are therefore an important aspect of implant diagnostics. Until CBCT technology was introduced, 3D cross-sectional imaging was only possible by using conventional CT scanners that exposed patients to high effective radiation doses. Cross sections imaged by conventional machines did not generate images of sufficient precision, accuracy and clarity to be used in implant planning. On the other hand, CBCT scanning generates precise and accurate images of all the relevant structures including maxillary sinuses, mandibular canals, incisal canal, foramen mentale, ansa n. mentalis, bone morphology, and the ratio of compact and spongiose bone [15].

The use of such 3D images in implant diagnostics may prevent dehiscence, fenestration, mandibular fracture, injury of the mandibular nerve and the related partial or full loss of innervation that may be temporary or persistent. Hemorrhagic perforations of the lingual membrane in the base of the buccal cavity are particularly dangerous [29,30], and can be prevented through appropriate implant orientation with respect to the anatomic features of mandibular body that are visible in a cross-sectional image (*Figure 3*).

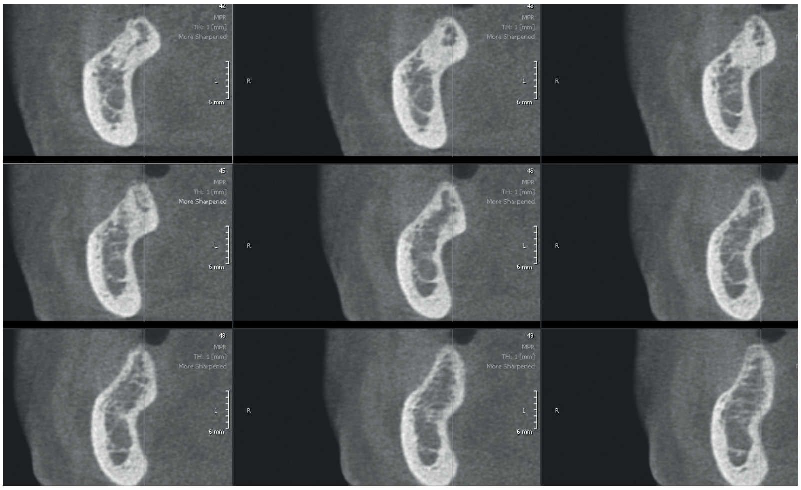


Figure 3. Mandibular lingual surface

These images are used for implant location planning with respect to the dimensions of alveolar ridge, bone density, and surrounding anatomic structures. Such implant treatment in mandibular area between foramen includes planning of 2-6 implants with gingival elevation and ridge remodeling. In many cases it is necessary to place the distal implant closer to the mental neurovascular bundle, in order to extend the prosthesis distal cantilever [31]. One millimeter of skeletal mass between ansa mentalis and the implant is considered sufficient to prevent nerve irritation [32]. Precise determination of nerve position is extremely important, but not possible with panoramic imaging.

Some important structures such as foramen mentale cannot be precisely determined in up to 21% of cases when using panoramic imaging [2]. Conversely, all parts of the nerve, including the foramen, are clearly visible on CBCT images. When compared to CBCT images, the distance measurements in panoramic images are systematically too high. Thus, it is recommended that panoramic imaging should be used for orientation planning and initial insight into a patient's anatomy, while CBCT 3D imaging should be used in pre-implant diagnostics [2], (*Figure 4*).

3D images are a revolutionary novelty in implantology, which enables precise planning and guided implant procedures. This technique resulted in reduction of complications, and in some cases removed the need for bone augmentation [3].

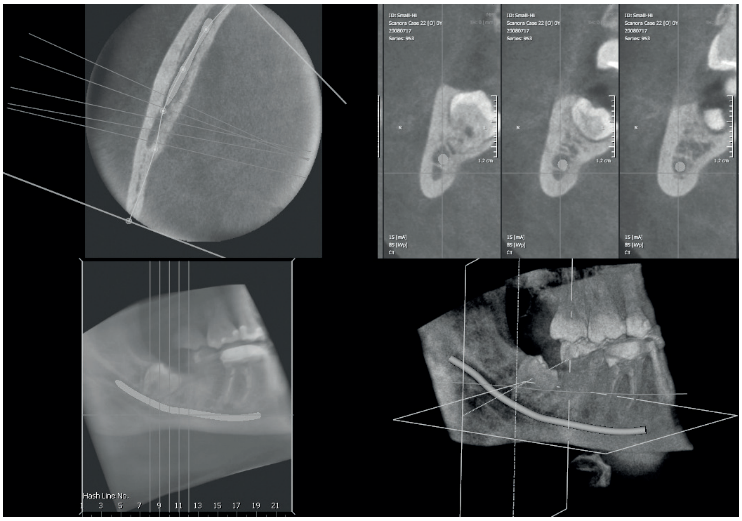


Figure 4. Multi-planar reconstruction in mandibular region

Development of specialized software applications is directed toward development of individual 3D models for patients, with application in implant guidance, diagnostics, treatment planning, simulations and modeling of prosthetic procedures [3]. The choice of appropriate radiological diagnostics, following the principle of administering an ALARA radiation dose, ensures acquisition of maximum diagnostic information, avoidance of potential intra-operative and post-operative complications, and increases the likelihood of a favorable outcome of implant therapy. A combination of diagnostic precision, accuracy, low radiation dose, and value for the price make CBCT diagnostics an essential procedure in implant planning and implant therapy.

Orthodontics

The use of 3D images is indicated in various areas of orthodontics. The application of MSCT technology has, in the past, been generally related to ortognathic surgery. With the introduction of CBCT technology, 3D imaging indication has widened to include application in numerous and various cases such as determination of the width of palatal and vestibular bone cortex, skeletal growth pattern, dental age, airway clarity, visualization of impacted teeth, or 3D analyses [15].

The advantages of CBCT systems are routinely used in volumetric analyses and precise determination of the position of impacted teeth, structural appearance of the TMJ, asymmetry diagnostics, and discrimination of positional vs. morphological asymmetries [33]. The positioning of the impacted teeth and their relation to adjacent structures are important factors in planning of therapeutic procedures. Thus, CBCT application in orthodontics is very common when planning extractions of pallataly impacted or retained teeth of the lower jaw (*Figure 5*).

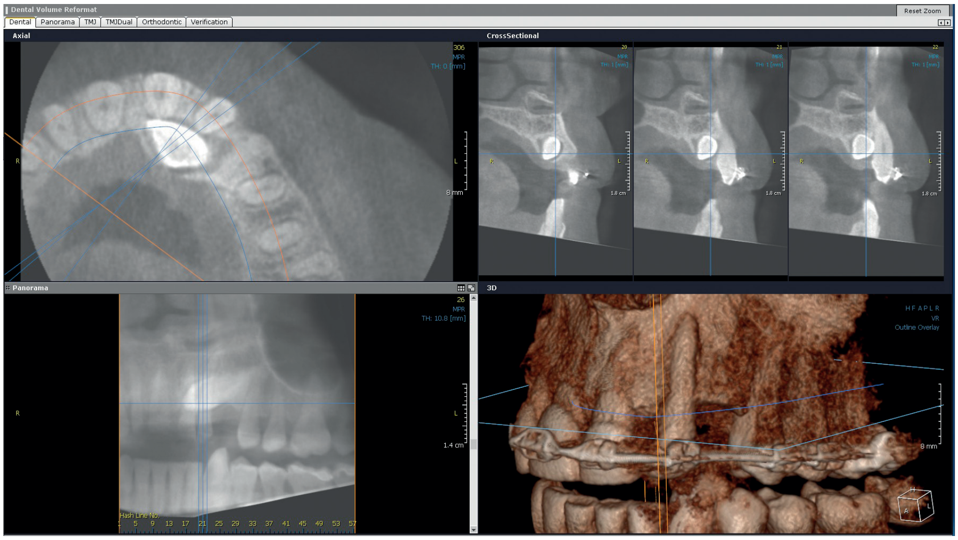


Figure 5. Orthodontic case - Pallataly displaced canine

3D superposition is used increasingly during patients' growth and development. In these cases the technique augments or partially substitutes classical cephalometric analyses and 2D cephalogram superposition [34,35].

Modern application of 3D techniques in orthodontics includes development of virtual models and their superposition for determination of growth patterns, tracking of therapy-induced changes, and stability of post-therapeutic results [36]. Virtual 3D models may be used for tracking changes during orthodontic therapy, including determination of the location of the greatest expansion of the dental arch. However, certain problems persist and are generally related to artifacts caused by braces, and reproducibility of the position of centric relation. Furthermore, due to mandibular mobility, it is not possible to use the base of the cranium as a reference for tracking changes in the lower jaw [37]. Mandibular changes should therefore be tracked based on changes in corpus and ramus [37].

In spite of the rapid development of 3D cephalometry, 2D cephalograms are still used for comparison of patient data to reference values [38]. Development of systems for synthesis of cephalogram from 3D data opened the doors for the use of CBCT images as the basic images in orthodontic diagnostics that provide all information required for the planning of orthodontic therapy [36].

An important segment of 3D diagnostic application lies in results planning of ortognathic surgery. Computerized planning of ortognathic surgery includes many planning parameters, including esthetic, functional, morphological, and psychological. Unlike 2D images, 3D CBCT images enable quantitative and qualitative analyses of skeletal changes, adaptations and remodeling during and after surgical treatment [37]. In order to maximize therapeutic outcomes and ensure its stability, the complex repositioning of the jaws should be precisely defined in 3D during the planning stages of the ortognathic surgery. Furthermore, precise 3D planning is necessary to prevent occurrence of post-operative temporomandibular dysfunctions [39]. 3D superposition is clinically used in prediction and planning of skeletal movements and morphological changes in ortodontic-surgical patients, as well as for determination of results of surgical therapy. Complex cases of dentofacial deformities and facial asymmetries could benefit from 3D superposition and CBCT diagnostics [37]. Different programs are used for specific stages of surgical therapy, which, based on registration of voxel intensity, generate the superposition of multiple CBCT images with high precision, and avoid errors that may arise through identification of reference points. Since ortognatic operations do not encompass the base of the skull, the base of the cranium is used as a reference structure in superposition procedures. Although these procedures could be performed by means of conventional CT technology, CBCT is commonly used since it generates superior structural images, lower imaging costs, and lower effective radiation doses.

The use of 3D cephalometric analyses in scientific research has several advantages compared to 2D analyses. First, it eliminates human errors in determination of reference points or anatomical structures. Second, it allows performance of accurate and precise analyses without distortion errors in 2D images. Third, it allows the analysis of bilateral structures and determination of their differences. Fourth, 3D diagnostics allows easier, more precise, simple and accurate comparison of changes in anatomic surfaces. These advantages are based on 3D imaging superior performance over change-tracking methods based on points and lines whose main disadvantage is inability to process large number of parameters and information [37]. 3D based analyses of geometric morphometrics and vectors have been established as methods of choice in dental anthropology and orthodontics [40-42].

Temporomandibular joint (TMJ)

Magnetic resonance, MSCT and CBCT are used in determination of congenital and developmental malformations and morphological changes in the temporomandibular joint (TMJ). 3D imaging of the TMJ prevents inaccurate findings due to specific position of the head and the rotation of the condyle heads that may occur when using 2D summation imaging. Although axially corrected sagittal tomography remains the firsts method of choice for detection of periarticular erosions and osteophytes [43], 3D imaging is also used in follow-up of post-discetomy TMJ remodeling, degenerative changes, and ancyloses [44].

Endodontics

CBCT also has important application in endodontic diagnostics [1]. The stated advantages of CBCT systems are applied in various phases of endodontic therapy and for different diagnostic needs – from assessment of morphology and dimensions of root canals, determination of apical and periapical pathologies, pre-endodontic and pre-surgical planning, intra-operative evaluation, to post-operative control and follow-ups [45-48]. Current research suggests that CBCT images provide significantly better representation of periapical lesions, their relationship to the mandibular canal or sinus maxillaris, with respect to involvement of the sinus membrane [46-48]. CBCT imaging plays an important role in early diagnostics of periapical lesions which increases the likelihood of a positive outcome of endodontic treatment [45]. Planning of endodontic-surgical procedures by means of CBCT imaging allows clear determination of the size of skeletal defects, the position, shape and size of vestibular cortex damage, and the position of skeletal defects behind the top of the root and involvement of adjacent structures. Based on these features, the current research suggests that CBCT imaging procedures may significantly improve presurgical planning [48,49]. Comparative analyses of periapical and CBCT diagnostic imaging has shown that the latter technique yielded a 34% higher lesion detection rate – particularly periapical lesions of the sinuses, enlargement of the sinus mucosa and additional root canals [50].

Since the success of endodontic treatment largely depends on detection of all root canals, the diagnostic performance of CBCT technology was assessed by comparing clinical findings based on CBCT and periapical images. As the prevalence of the second mesobuccal canal (MB2) is high and reaches up to 93% [51,52], but are visible only in about 55% of periapical images [53], CBCT imaging may be a very useful diagnostic tool for detection of MB2 canals. CBCT imaging enables detection of additional canals [54] and is as such a valuable diagnostic tool for pre-operative determination of teeth morphology as well as the number, position and shape of their canals.

Depiction of small structures for endodontic needs – such as determination of outer root resorption – requires minimal resolution of 0.3 mm [55]. The likelihood of detection of the second canal in mesobuccal root of the first upper molar increases with increasing resolution and voxel size: from 60% at 0.4 mm, to 93% at 0.12 mm resolution [56]. Since periodontal ligament is on average 0.2 mm wide, and the first sign of periodontitis is disruption of lamina dura continuity, voxel resolution for early endodontic diagnostic should not exceed 0.2 mm [1].

The comparison of CBCT and intraoral images in cases of periapical pathosis has shown that CBCT imaging significantly improves the diagnostics of periapical processes. While 86 roots were detected on CBCT images, only 53 roots were detected on intraoral images acquired at 10 degree inclination [46]. Compared to intraoral images, CBCT images provided significantly higher diagnostic accuracy as confirmed by a significantly higher rate of intra- and inter-observer agreement compared to that for conventional x-ray images.

In the study on detectability of periapical periodontitis conducted on 1508 teeth with pulp infection, significantly higher detection prevalence was found when using CBCT imaging, compared to panoramic and classical periapical imaging [57]. An index of periapical changes detectable by CBCT (CBCTPAI) [58] has been established with the purpose of more exact diagnostics. The CBCTPAI organizes changes into one of six stages based on the largest dimension of periapical pathosis in buccopalatal, meso-distal, or diagonal direction, and the destruction of cortical bone. CBCT imaging enables detection of periapical changes in 34% to 54.2% more cases than intraoral imaging [50,58]. Periapical changes greater than 2 mm in diameter were detected in 100% of cases by CBCT imaging, compares to only 28% using periapical imaging [59]. Except for CBCT, such high accuracy in detection of periapical pathosis is generated only by conventional CT imagers [60]. Thus, endodontic CBCT diagnostics is the method of choice in all cases of persistent symptoms of periapical region in treated and untreated teeth that do not present with visible periapical changes on intraoral images (*Figure 6*).

CBCT based follow-up of periapical lesion recovery is becoming increasingly common and significant part of endodontic treatment [61]. CBCT imaging is superior to all other radiological procedures for tracking the reduction of periapical skeletal defects. However, tracking of the length and homogeneity of root canals is still more accurate by means of classic radiological periapical imaging. The probable source for this advantage is artifacts caused by metal in gutta-percha and metal filling [62].

Figure 6. Periapical pathosis and vestibular cortex fenestration

Cross-sectional images are commonly used for determination of the size and location of the outer resorption of the root. The outer resorption of the root may be caused by various factors such as impacted teeth, orthodontic treatment, traumas or periapical infection. These can be of very small dimensions, so that for diagnostic purposes, CBCT images need to be of very high resolution [63]. CBCT imaging plays a very important role in differential diagnostics of root resorption: they allow determination of the level of root canal continuity and whether the resorption is of the outer or inner root.

Pre-operative planning for surgical-endodontic treatment in lateral teeth often involves the assessment of the relationship of the roots and the maxillary sinuses in the upper jaw, or the mandibular canal in the mandible. CBCT images provide numerous advantages compared to other radiological procedures during pre-operative planning – especially in pre-molar and molar regions of the maxilla [64]. The comparisons of the distances of patal roots of the vestibular cortex, the relationship of the maxillary sinus and the palatal molar root, and the relationship of the root to palatal skeletal wall – all visible in CBCT images – suggest that CBCT diagnostics may optimize palatal apicotomy through precise localization of palatal root from the palatal side [65].

Root fractures

Numerous studies have shown that 3D diagnostics achieves more precise diagnoses of root fractures compared to conventional x-ray imaging. There are also numerous limitations of 2D radiography which include orientation of the fracture line, the angle of x-ray impact of the fracture fissure, copying of surrounding structures, inability to image the 3rd dimension or a precise determination of periodontal changes around the fracture fissure [66]. The fracture fissure is not visible unless it is parallel to the incoming x-rays, or during early stages when only dentine fracture is present without the movement of the fragments. CBCT images allow the diagnostician to view a part of the tooth in all dimensions, display very thin layers in different plains, and adjust the projection following the fracture fissure. Copying of the surrounding structures is avoided, which enables viewing of periodontal changes. Thus, numerous studies confirm the usefulness of CBCT imaging in diagnostics of root fractures. The results of these studies indicate that accuracy of fracture determination when using CBCT imaging ranges between 86% and 92%, compared to 66-74% when using retroalveolar imaging [67,68]. Other studies suggest an even larger disparity in diagnostic accuracy, with CBCT reaching 90% accuracy compared to 30-40% accuracy of retroalveolar imaging [69]. Radiographic diagnosis of root fractures is based on two signs: radiolucent fracture line in the dentine, and the loss of bone. Exclusion of specific structures – i.e. buccal, lingual bone, intraproximal fissure – from 2D image and their separate analysis, constitutes significant progress in diagnostics of root fractures.

Periodontal space

X-ray imaging is an important diagnostic tool in periodontics. In comparison to 3D images, 2D images provide a sufficient depiction of the continuity of lamina dura, density of alveolar bone, peri-radicular space and periodontal ligament (PDL space) [70]. The first application of CBCT in periodontology was in diagnostics and treatment follow-up of periodontitis [71,72]. 3D diagnostics provides a detailed and accurate insight into dehiscences, fenestrations and root furcations. It also enables quantitative evaluation of the soft tissues, alveolar bone, intra body defects and the healing processes. CBCT generates more valuable diagnostic and qualitative information on the level of periodontal bone in 3D than do conventional radiographic methods – particularly in the area of buccal and lingual bones [3]. CBCT is as reliable as periodontal scanning of interproximal area [3]. Measurement of bone density in small areas around vertical periodontal defects or skeletal augmentations (bone grafts), enables verification of the outcomes of periodontal therapy [72]. Methods of soft-tissue CBCT (ST-CBCT) analyses provide accurate insight into the width of the gingiva and the values of biological width, since they enable determination of the relationship between the edge of the gingiva and the edge of the bone, the edge of the gingiva and the cemento-enamel junction, and the cemento-enamel junction and the edge of the bone [73], (*Figure 7*).

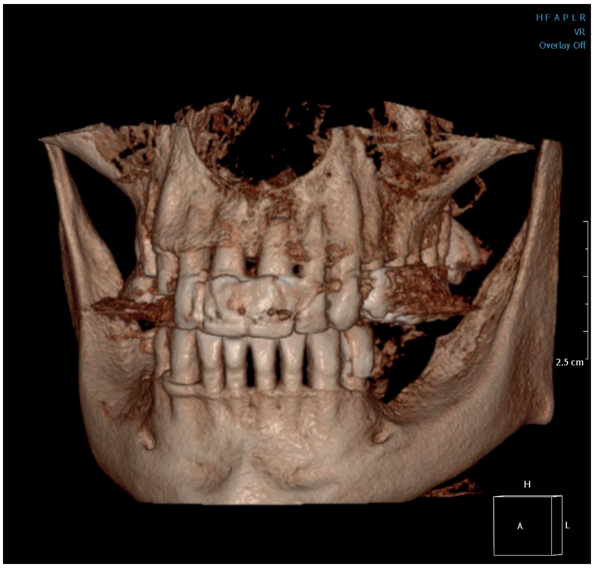


Figure 7. 3D Reconstruction

Paranasal sinuses and temporal bone

The application of CBCT is also highly significant in diagnostics and the anatomy of hard structures, the changes in mucosa of paranasal sinuses, the nasal cavity with the depiction of deviations and chronic inflammations, as well as the anatomy of the outer, middle and inner ears and the temporal bone. The temporal bone has been the subject of CBCT diagnostics from the earliest stages of its development. Low resolution of soft tissues has not been found significantly detrimental to the diagnostic value of CBCT images [15[.

3D radiology is applied in pre-surgical and intra-surgical diagnostics of the paranasal sinuses. Since the use of MSCT is common, a number of comparative studies were performed to determine radiation exposures and the relative diagnostic values of MSCT and CBCT. The results indicate that CBCT imaging yields high quality images of skeletal anatomy, soft tissues and air-filled spaces, while exposing the patients to multiply lower levels of radiation. As such, CBCT is a highly useful method in endoscopic surgery of the sinuses [74]. Twelve line pairs per centimeter (lp/cm) CBCT images produced the effective dose of 0.17 mSv compared to 0.87 mSv produced by 11 line pairs per centimeter images generated by 64-section MDCT scanners [75].

CONCLUSION

Due to its significant advantages compared to two-dimensional radiological diagnostic methods, the application od 3D diagnostics is expanding to virtually all branches of dental and orofacial medicine. Also, based on its high acurracy and precision, the CBCT technology holds great potential for future applictions in scientific research.

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Sažetak

3D dijagnostika u orofacijalnom području

Znanstveni i klinički napredak svih grana medicine u velikoj se mjeri osniva na korištenju i razvoju naprednih tehnoloških sustava. Primjena trodimenzionalne dijagnostike prisutna je u posljednjih 30 godina u gotovo svim granama medicine. Međutim, relativno velika količina zračenja ograničila je primjenu kompjuterizirane tomografije (CT) u dentalnoj medicini na slučajeve krajnje potrebe, primjerice u dijagnostici tumora. Princip ALARA (*as low as reasonably achiveable*), temeljni princip u radiološkoj dijagnostici, nije dozvoljavao primjenu trodimenzionalne CT dijagnostike u svakodnevnoj stomatološkoj praksi.

Zbog navedenog razloga pristupilo se pronalasku dijagnostičkog sredstva koji će objediniti prednosti CT dijagnostike i, u isto vrijeme, pomoću smanjene doze zračenja primjeniti nove i poboljšati postojeće dijagnostičke postupke te ih učiniti etički prihvatljivim.

Primjena CT uređaja na bazi konične zrake (CBCT – Cone Beam Computer Tomography) omogućila je 3D dijagnostiku u dentalnoj medicini i to primarno u orofacijalnoj kirurgiji. Poznavanje treće dimenzije i prostornih odnosa anatomskih struktura u značajnoj mjeri olakšava planiranje kirurških zahvata i čini ih sigurnijim. Pacijent je bolje upoznat s planom terapije, moguća je procjena kvalitete i kvantitete kosti te se smanjuje mogućnost nastanka komplikacija tijekom i nakon operativnog zahvata. CBCT ima smanjenu dozu zračenja, visoku razlučivost detalja, točne kvantitativne i kvalitativne vrijednosti, ekonomičnost i jednostavnost u korištenju snimaka. Princip CBCT bazira se na koničnoj zraci u dvije dimenzije i širokom panelu senzora s kutom snimanja većim od 400 stupnjeva. Zračenje je višestruko smanjeno pomoću algoritama obrade podataka sa širokog digitalnog panela koji istovremeno prima podatke iz svih smjerova i preračunava točne vrijednosti snimanog objekta, te pulsnom ekspozicijom. Zbog značajnih prednosti u odnosu na dosadašnju dvodimenzionalnu radiološku dijagnostiku primjena 3D dijagnostike širi se na gotovo sve grane dentalne medicine. Također, korištenje CBCT tehnologije pruža velike mogućnosti u znanstvenim istraživanjima zbog potpune točnosti i vrlo visoke preciznosti dobivenih podataka.

Ključne riječi: CT na bazi konične zrake; 3D dijagnostika; dentalna radiologija.

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