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Review article

CBCT EVALUATION METHODS IN ORTHODONTICS – REVIEW AND CLINICAL CORRELATION

Nikolay Yanev[1], Greta Yordanova[2], Emanuel Emiliyanov[2]
1) Medico - Dental clinic "Yanev Medico Dent" Sofia, Bulgaria.
2) Department of Orthodontics, Faculty of Dental Medicine, Medical University - Sofia, Bulgaria.

ABSTRACT

In recent years, digital technologies have entered every field of dentistry, allowing the practice to adapt to new and alternative diagnostic and treatment approaches. Every day in the clinical practice, cone beam computed tomography (CBCT) examinations are used. This modality is applicable in every phase of orthodontic or surgical dental or maxillofacial work, from diagnosis, treatment planning, design and fabrication of orthodontic appliances, patient records, growth prognosis, prediction of treatment outcomes etc. In orthodontics particularly, a large spectrum of CBCT studies find their role, in particular - CBCT of the whole skull, which allows a number of analyses and evaluations that cannot be performed on smaller volume images and CBCT of separately one or two jaws. Nowadays, the accessibility to the CBCT examinations is facilitated - almost every X-ray laboratory has a CBCT machine, and there are dozens of software for processing and editing readily available, even with free license. The CBCT and its extremely wide range of applications make it paramount in the orthodontics workflow.

Keywords: CBCT in orthodontics, CBCT review, digital orthodontics, digital treatment planning, 3D cephalometry,

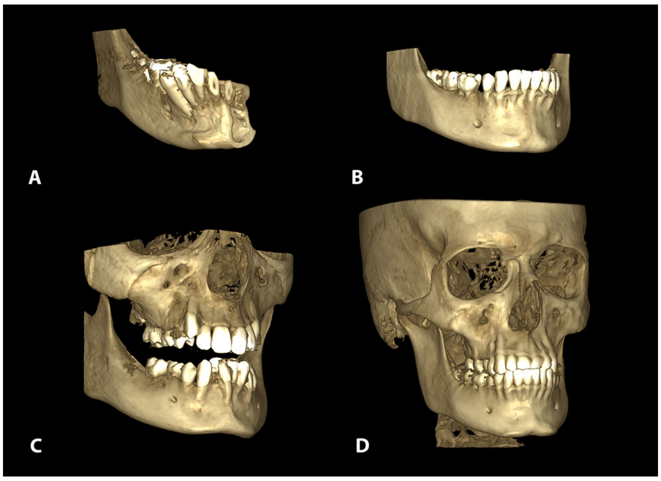
INTRODUCTION

In recent years, digital technologies have entered every field of dentistry, allowing the practice to adapt to new and alternative diagnostic and treatment approaches. The development of artificial intelligence incorporated into various software has seen great advancement [1]. Innovative developments are increasing the speed and accuracy of diagnostics, the number of possible approaches, and reducing human labour, which in turn is saving clinical time and lowering the cost and time of treatment [2].

Innovation is a creative solution applied to practice, and it is seen in every phase of orthodontic work - from diagnostics, treatment planning, design and manufacturing of orthodontic appliances, patient records, craniofacial growth prediction, prediction of treatment outcomes, etc. [3]. This changes the orthodontic thought process and growth. Intraoral scanners, digital models and measurements, CBCT studies to prepare comprehensive treatment plans, 3D printed models and appliances are used in practices on a daily basis.

The introduction and usage of CBCT scans have been a tremendous help for the diagnostics and planning of orthodontic interdisciplinary cases [4]. The acronym CBCT is derived from Cone Beam Computed Tomography. It is a three-dimensional examination that uses a cone beam x-ray (hence the name cone-beam) whose source makes a single rotation of 360 degrees around the patient's head, and during this time, multiple two-dimensional images are created and reconstructed into a single three-dimensional image. The information is usually stored in DICOM format (Digital Imaging and Communications in Medicine), which is an international standard for storing, processing, and transferring medical information. Different software are used for reading and visualizing these images in which this data format is supported and allows their editing and manipulation. The X-ray imaging units can capture different field of view (FOV) sizes. The FOV can cover a jaw segment (small field); an entire jaw or two jaws (medium field); and an entire skull (large or full field), as shown in Figure 1. The larger the FOV, the more structures and information it contains [5]. For the purposes of orthodontics, anatomical markers need to be clearly visible. This imposes the use of medium field (one or two jaws) and, more commonly, large/full field (entire skull) scans. Modern X-ray devices significantly lower the radiation dose, allowing the use of larger FOVs for the necessary studies without large radiation dose loads.

Fig. 1. A) Mandibular segment (small field). B) One jaw-mandible (medium field). C) Two jaws (medium field). D) Whole skull (large/full field)



Whole skull CBCT allows a number of analyses and evaluations that cannot be performed on smaller volumetric images - upper airway volume assessment, superimposition of CBCT images, diagnosis of asymmetries, orthognathic surgery planning. With medium FOV CBCT, it is possible to assess the position of impacted teeth, supernumerary teeth, dental morphology, root resorption, bone changes and disorders (cysts, odontomas), and temporomandibular joint disorders and conditions, as well as measure the dento-alveolar and skeletal changes after maxillary expansion. The ability to plan the position and placement of orthodontic mini-screws is excellent.

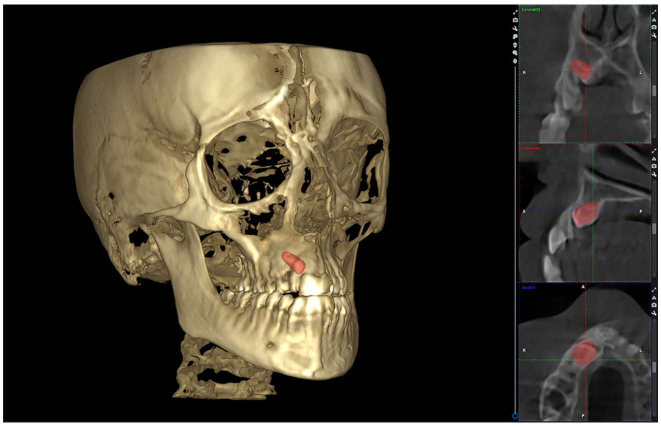
We discuss the most commonly used methods for visualization and analysis of CBCT images used in orthodontic and orthodontic-surgical practice. The following presented CBCT sections and analysis methods are from the own CBCT database and patient records, treated by the authors.

REVIEW RESULTS

Assessing the position of impacted teeth

The most common application of three-dimensional examination in orthodontics is to establish the position of impacted canines. Maxillary canines are the second most frequently impacted teeth after the third molars (0.8- 3%). In addition to these, it can be used to establish the impaction and position of each tooth. CBCT allows assessment of the tooth's position in the bone with a single examination, providing information on its position in the three planes (fig. 2) and its relationship to the other bony structures [6]. The use of two-dimensional images requires at least two radiological examinations to be performed in order to detect the approximate position of the tooth. This results in an increase in the number of radiographs, radiation dose, and clinical examination time. Whereas with CBCT, it can be determined very accurately whether the tooth is horizontally or vertically positioned, what is its proximity to adjacent structures - roots or crowns of adjacent teeth, position relative to the maxillary sinus wall, floor of the nasal cavity; canalis mandibularis; compact bone; stage of root development of the tooth; presence or absence of root resorption of adjacent teeth [6]. All the proven evaluation methods used in 2D images can be applied to slices in different planes extracted from CBCT [7].

Fig. 2. Visualization of CBCT with impacted 13 in coronal, sagittal and axial sections.



In the planning stage, the scan serves the maxillofacial surgeons in determining the surgical access for the impacted teeth exposure, which is in consideration with the traction path, and it serves the orthodontists in selecting the biomechanics for the tooth traction to the dental arch.

Thanks to the CBCT, collaboration between orthodontists and surgeons is facilitated, which in turn leads to changes and improvements in the previous treatment planning that was based only on two-dimensional radiographs. The rate of successful treatment completion has also improved.

Supernumerary teeth

Orthopantomography (OPT) provides the initial diagnostics and approximate location of the supernumerary tooth. Due to its two-dimensional nature, it does not allow accurate localization of the structure, nor does it provide sufficient information on the morphology of the supernumerary tooth. CBCT allows precision in localizing the supernumerary tooth, defining its morphology, stage of development, location in relation to adjacent structures, allows differential diagnosis between true hyperdontia and geminated teeth and between mesiodens and talon cusp [8]. It is widely used in the diagnosis of mesiodens, the most common form of hyperdontia, cases of inversion or their combination with other morphogenic forms are detailed. The three-dimensional examination establishes dental morphology in detail, especially in dens evaginatus et dens invaginatus.

Root resorption

Another advantage of CBCT is that it allows to determine which root (in multi-rooted teeth) has resorption, on which surface and how advanced it is – whether only the root cementum is affected or whether it extends to the dentin [9]. A complete assessment of this problem provides the orthodontist with the basis for deciding whether to extract the tooth or allow sufficient time for recovery and follow-up.

Bone loss assessment

Periodontal assessment is commonly facilitated by an OPG or a set of periapical radiographs. The limitation of these two-dimensional images is that, because of the superimposition of structures, the existence of the lamina dura cannot be assessed, whether there is furcation involvement in multirooted teeth cannot be accurately evaluated, the volume of bone loss in the vestibulo-oral direction also cannot be determined, nor the configuration of bone defects - how many walls they have and how many root surfaces they cover [6]. Three-dimensional imaging allows for a more precise visualization of these findings, which aids in planning the biomechanics (because of the altered centre of resistance), the movements (when there is dehiscence, fenestration, and bone pockets) to avoid moving the root out of the bone and enhancing the negative effects (increased mobility and additional bone loss). In generalized and severe bone loss, it is assessed whether orthodontic tooth movement is appropriate.

In addition to periodontal disease, bone loss may also occur due to trauma during intercuspidation. In orthodontics traumatic occlusions are – edge-to-edge bite, deep bite, cross bite in distal segments - of single teeth, multiple teeth, cross bite in anterior segments [10]. From an endodontic perspective, CBCT contributes to the establishment of multiple and accessory canals distinction between pathology and normal root anatomy [6].

Temporomandibular joint disorders

The most commonly used examination in the diagnosis of temporomandibular joint disorders is conventional tomography. It is a sensitive and time-consuming method, unlike CBCT, which has been shown to give better results, accuracy, better resolution, and lower radiation dose. It can help detect degenerative bone changes in the joint, osteoarthritis, trauma, and abnormalities in joint development and function. CBCT is the tool of choice when the bone morphology of the joint needs to be determined because of its high spatial accuracy in measuring facial structures. Its diagnostic capabilities are superior to conventional panoramic radiography and TMJ radiography for the diagnosis of temporomandibular joint bone changes [11].

Indirect bonding of fixed appliances in orthodontics

A number of orthodontic software now incorporate CBCT images when planning the position of brackets and creating 3D-printed indirect bonding trays. The use of CBCT eliminates the existing inaccuracy when using a virtual root and allows for precise control and correct positioning of the brackets in the three planes, especially along the longitudinal axis of the teeth. Compared with direct bonding, clinical time is reduced, and positioning accuracy is increased [12]. With modern software and CBCT, the laboratory stage time of indirect bonding and tray fabrication is reduced. Plaster models, tooth sectioning, bonding brackets to the models, and subsequently fabricating the tray have been replaced by digital planning in software and 3D printing of the tray.

On the same principle the incorporation of CBCT is possible when planning the treatment steps with aligners, which allows visualization of the root movements in the individual steps, which was not possible until recently [13].

Asymmetry

The diagnosis and treatment of facial asymmetries in orthodontics are challenging. Thanks to the CBCT and the options offered by the software to analyze them, it is possible to make various measurements and analyses in order to establish the origin of the asymmetry - whether it is dento-alveolar or skeletal; from which structures it originates - maxilla, mandible (base and ramus); the direction of the asymmetry - is it vertical, sagittal or transversal discrepancy of bony components; what is its magnitude. When asymmetries are identified, a full examination is needed - whole skull CBCT. Measurements on the three-dimensional image are much more accurate and comprehensive compared to the measurements made on two-dimensional cephalography [14]. With CBCT, there is no overlapping of structures unlike with two-dimensional images. Each point can be detected in all three directions and placed very precisely. It allows for the assessment of the problem in a sagittal direction. These possibilities of CBCT led to the development of 3D cephalometric analyses, as visualized in Figure 3. Such analysis is the Total Face Approach (TFA), which offers a 3D skeletal classification and presents value ranges supporting the created nosological classification [15]. The analysis values †of the studied patients are shown in Figure 4. The classification has been established in recent years, but it is gaining popularity and aims to facilitate orthodontists and maxillofacial surgeons in the diagnostic phase and identification of asymmetries, as well as for treatment planning and the volume of orthognathic surgery. In aid of orthodontic diagnostics, the software can create 2D images - frontal and lateral cephalography from the 3D examination of the whole skull (fig. 5).

Fig. 3. 3D cephalometric analysis with reference points and planes.

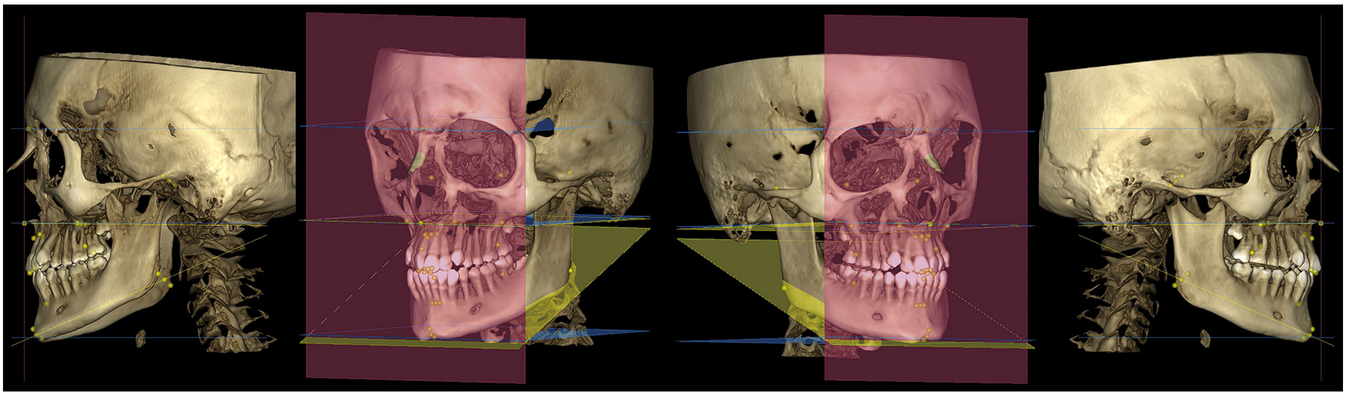
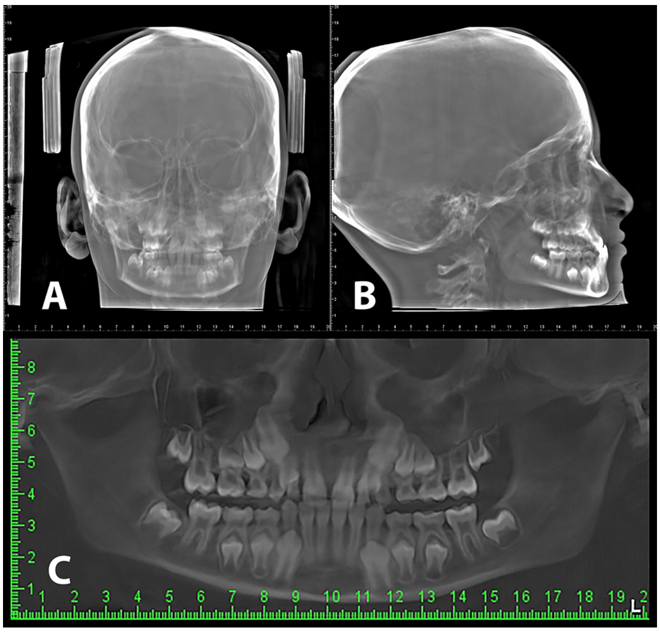


Fig. 4. Results of 3D cephalometric analysis to establish the origin of asymmetry.

	Left	Right	Diff	
Module A: Vertical dimensions				
(S) Superior vertical dimension	51.8			Borderline
(I) Inferior vertical dimension	62.9			Medium
(T) Total vertical dimension	114.7			Borderline
Module B: Sagittal dimensions				
(MX) Maxillary position	5.2			Mixed
(MB) Mandibular position	4.8			Balanced
(IR) Intermaxillary ratio	0.4			Balanced
Module C: Skeletal symmetry				
(Vert) Verticality	79.5	85.9	-6.4	Asymmetric
(MbH) Mandibular height	53.7	55.0	-1.2	Symmetric
(MxH) Maxillary height	12.2	15.7	-3.6	Asymmetric
Module D: Teeth				
(IUA) Incisal upper axis	74.6			Normal
(ILA) Incisal lower axis	94.0			Normal
Module E: Growth pattern				
(MGD) Mandibular growth direction	156.6			Postrotation

Fig. 5. A) Frontal cephalography obtained from whole skull CBCT. B) Lateral cephalography obtained from whole skull CBCT. C) Orthopantomography



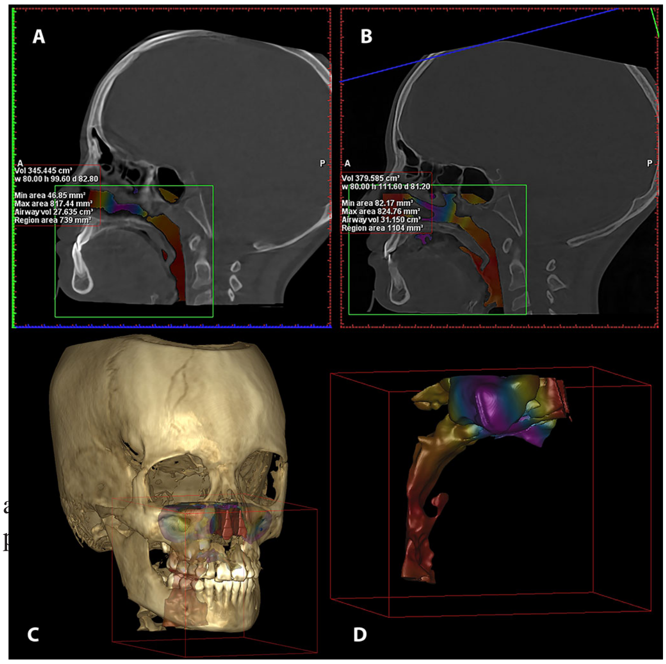
Airway volume measurements

Prior to the advent of CBCT, upper airway analysis was performed on à lateral cephalography. Two-dimensional imaging allowed the measurement of linear and angular parameters. With CBCTs, it is now possible to measure airway volume (volumetric analysis) and to analyze and determine the cross-sectional area of each section (airway tube level) of interest [16]. Most often, the cross-sectional area is measured at the site of greatest constriction. Some software allow segmentation of the airways from the entire CBCT and obtain its volumetric shape (fig. 6C, 6D). This approach is often used when comparing airway volume changes after orthodontic treatment. In this way, the overall increase in volume, as well as the change in cross-sectional area, can be measured (fig. 6A, 6B). To perform a volumetric analysis of the airway, a large-field CBCT must be used, covering the entire skull so that structures such as the nasal cavity, maxillary, and frontal sinuses can be included. Airway volume measurement is an important approach in the diagnosis and management of complex conditions such as obstructive sleep apnea and enlarged pharyngeal tonsils.

Orthognathic surgery

In orthognathic surgery, a full skull CBCT is used with the following applications - planning the surgical manipulation, surgical treatment simulations, fabrication of jaw repositioning splints and evaluation of treatment outcome. The extent of orthognathic surgery is determined comprehensively by the interdisciplinary team of orthodontist and maxillofacial surgeon, guided by the results of 3D cephalometry and the patient's facial profile. The development of digital technology has made the combination of CBCT and facial scanning possible, which has allowed various simulations and visualizations of how the occlusion and facial profile of the patient changes [17]. To use the surgical module, the CBCT image must be prepared in several steps. Typically, they include segmentation of the maxilla and mandible, thus allowing their repositioning. Intraoral scans are then superimposed on the mandible and maxilla (fig. 7). Only after these steps the specific orthognathic planning work with the module can begin,

Fig. 6. A) Volumetric analysis of the upper airways and minimum cross-sectional area before maxillary expansion. B) Volumetric analysis of the upper airways and minimum cross-sectional area after maxillary expansion. C) Visualization of the upper airway volume relative to the cranial bones. D) Segmented volumetric shape of the upper airways.



ated by the help of the software to reposition the jaws and plan the moves during surgery [18]. These digital splint designs are printed from resins that can withstand sterilization and are approved for intraoral use.

Orthodontic mini-implants

Orthodontic mini-screws/mini-implants are placed in different locations - in the hard palate, in the infrazygomatic crest, in the retromolar space, in the buccal compact bone of the lateral segments of the mandible base, or interradicularly. When planning their placement, it is important to evaluate the surrounding structures and roots, what is the proximity to them and what screw length is appropriate. For the interradicular mini-screws, it is necessary to position them in a way that they do not affect the roots of the adjacent teeth. When placing mini-screws in the palate, the CBCT scan allows planning of their length and position - if they are placed in the anterior palate - to be perpendicularly positioned in the bone, to not affect the roots of the upper incisors, to be paramedially positioned so that they do not affect n. incisivus and consistent with the thickness of the gingiva [19]. When placing implants in the posterior palate, the length of the implants and whether they will be monocortically or bicortically placed is planned. The planning of the mini-screws is done with the help of the software for the CBCT analysis and planning, in which there is usually an implant module. Implant libraries with different types and manufacturers' specificities of mini-screws are used, allowing the digital planning to resemble the intraoral situation as closely as possible.

Fig. 7. Combining intraoral models with whole skull CBCT.

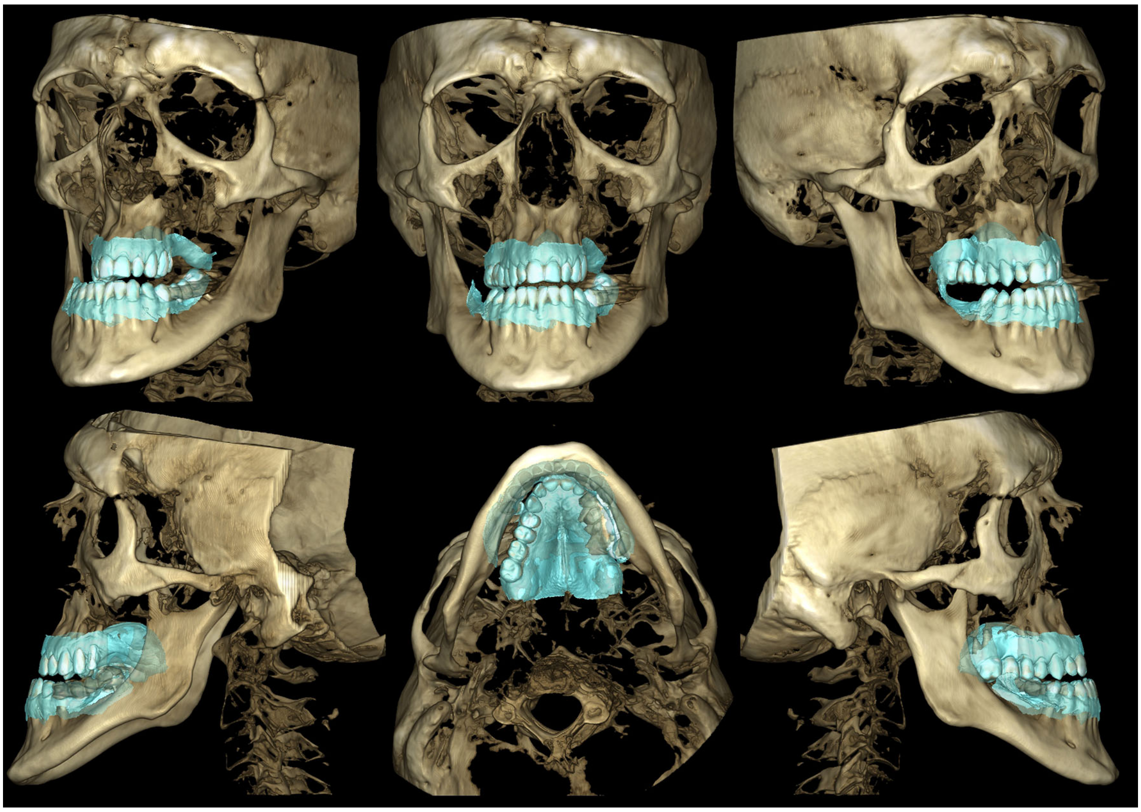
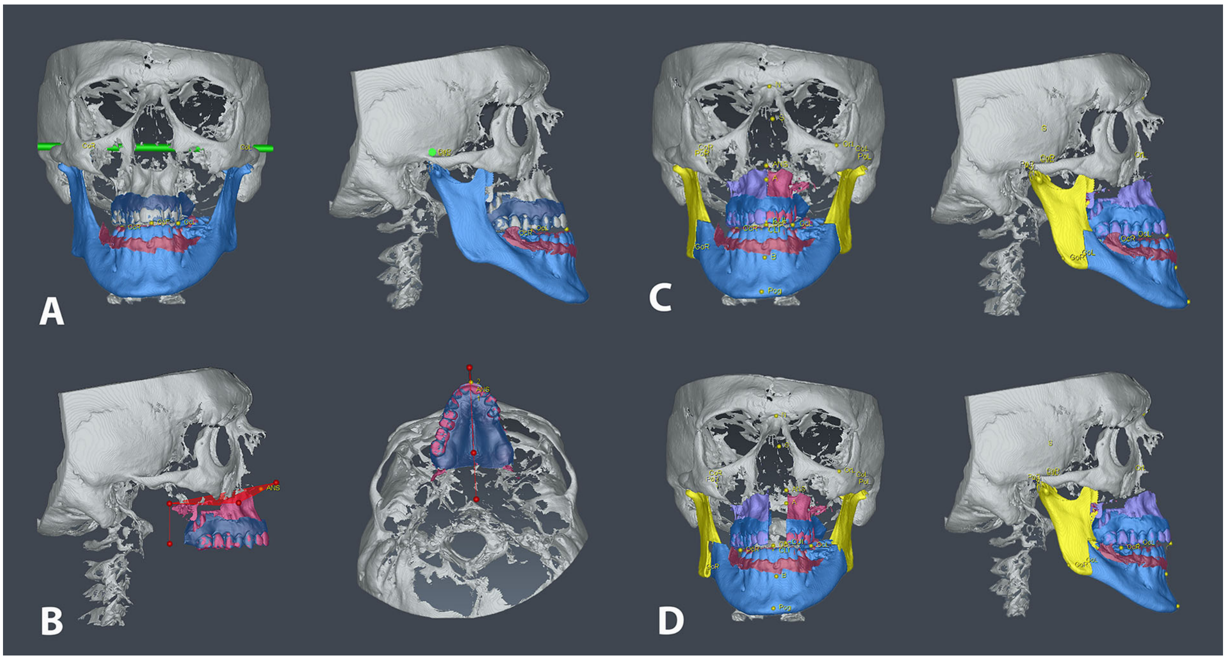


Fig. 8. A) Whole skull CBCT prepared for the surgical module. B) Selecting the type of osteotomies. C) Segmented CBCT after selection of the osteotomies. D) New position of both jaws.

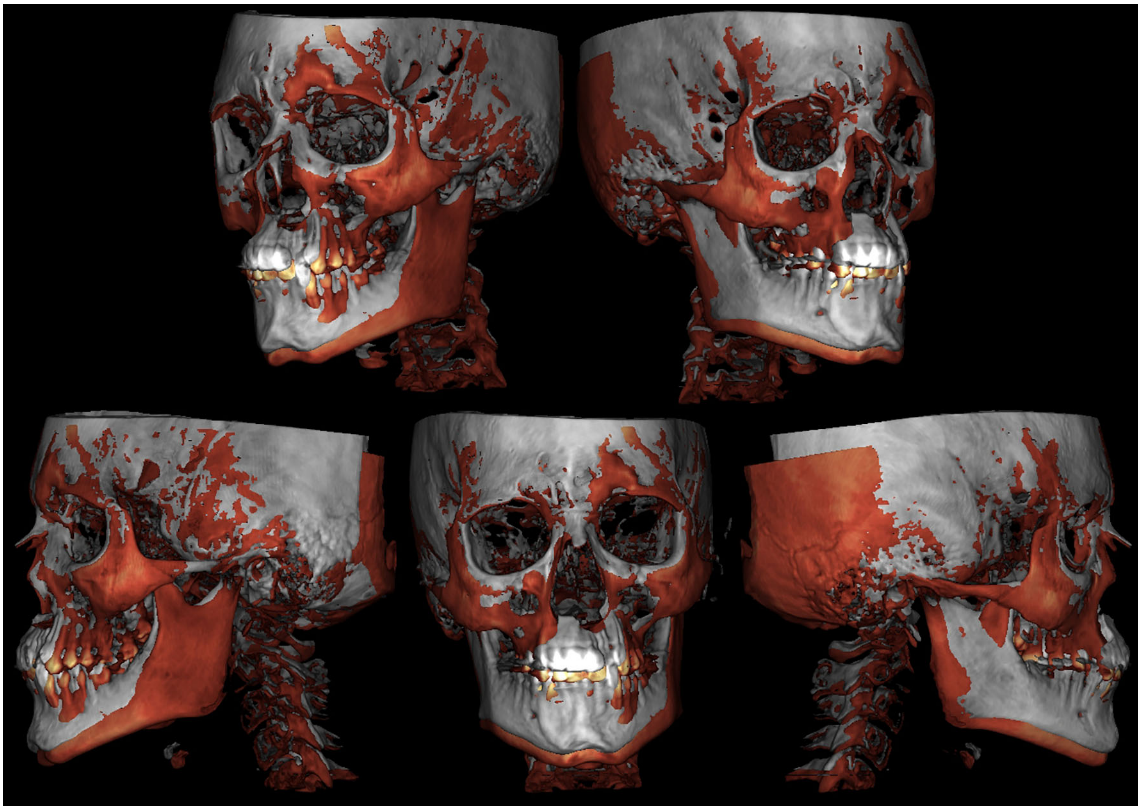


Superimposition

Similar to the superimposition of lateral cephalographs, sequential CBCT examinations can be superimposed, and changes in all areas of the facial skull can be traced. Depending on the software, there are several methods of superimposing images - using anatomical structures; registering 3D surface models of stable structures and voxel-based methods using mathematical algorithms to accurately superimpose images (fig. 9).

The superimposition technique of sequential CBCTs is used to identify changes in craniofacial structures after a given stage of orthodontic treatment or orthognathic surgery, assessing whether these changes are dento-alveolar and/or skeletal and how much they affect the soft tissue profile [20].

Fig. 9. Superimposition of CBCT examination - before (grey colour) and after (red colour) rapid maxillary expansion.



Maxillary expansion

A whole skull CBCT usually includes the first four vertebrae as well, which allows for assessment of bone maturation and age, providing an opportunity to determine when peak growth is. The assessment of bone age is most commonly determined by the Bacchetti method using a lateral teleradiograph. That way, it has not relied on chronological age, which often does not correspond to the degree of bone maturation [21]. Information on bone maturation is important for clinical practice because it is related to the degree of midpalatal suture maturation, which determines the method of maxillary expansion.

The use of CBCT allows accurate assessment of the stage of midpalatal suture maturation, which, on its behalf, allows for the correct selection of the type of anchorage (skeletal or dental) and the method of expansion [22].

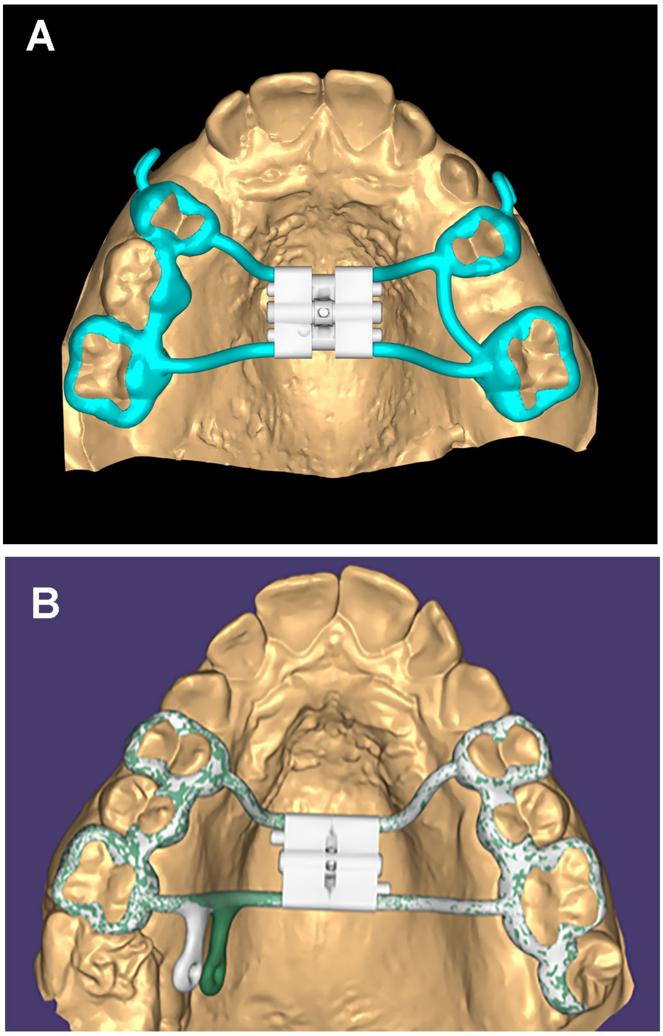
When surgically assisted rapid maxillary/palatal expansion (SARME/SARPE) is required, CBCT aids in planning the osteotomies. In the case of mini-screw assisted rapid maxillary/palatal expansion (MARME/MARPE), planning the placement of palatal mini-screws relies entirely on the information from the CBCT study [19].

The analysis of consecutive CBCT examinations before and after rapid maxillary expansion allows the evaluation of treatment outcomes by both the orthodontist and the maxillofacial surgeon. Dento-alveolar changes can be measured, such as changes in posterior teeth inclination, changes in intermaxillary and intermolar width, changes in dental arch perimeter, and changes in dental arch length [23].

The skeletal changes are mainly associated with alterations of the bony palate width, the width of the maxilla and the interzygomatic width.

CBCT also helps when planning the maxillary expansion appliances (fig. 10). Digital software for creating orthodontic appliances combined with the information from the CBCT study allowed the design of digital appliances that are subsequently printed from metal. Digital planning enables the creation of highly accurate and individualized expanders that can cover the individual needs of each case. Combining intraoral models with CBCT, especially in cases combined with expansion and tooth impaction, assists in planning the appliances, allows the assessment of adjacent structures and placement of the individual elements in such a way that the desired anchorage and biomechanics are achieved in order to produce the necessary movements and reach the final goal [24].

Fig. 10. Digital design of the rapid maxillary expansion appliance.



CONCLUSION

The development of technologies and their integration into contemporary orthodontic practice has led to an increase in diagnostic and treatment options, saving clinical time and human labour. Nowadays, the accessibility of CBCT examinations is facilitated - almost every X-ray laboratory has a CBCT machine, and there are a number of software platforms for processing and editing. The CBCT and its extremely wide range of applications in diagnosis, treatment planning and prediction of treatment outcome has made it paramount in the orthodontics workflow.

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Address for correspondence:
Emanuel Emiliyanov
Department of Orthodontics, Faculty of Dental Medicine, Medical University - Sofia
1, St Georgi Sofiiski Str., 1431 Sofia, Bulgaria.
E-mail: emanuelemilianov@gmail.com,