Review Article

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Three-Dimensional Craniofacial Imaging in Orthodontics: A Review

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ABSTRACT

Background: One of the most important achievements of orthodontic therapy is the development of orthodontic records. Record keeping is necessary not only for diagnosis and treatment planning, but also for case follow-up, communication with colleagues, and treatment evaluation. Two-dimensional (2D) imaging technology, like cephalometric and OPG and photos, as well as plaster models, have recently become commonplace. Though, after the advent of three-dimensional (3D) technologies (computed tomography, stereophotogrammetry and laser scanners) into dentistry, 3D imaging systems have become increasingly popular, particularly in cases involving craniofacial deformities. Indeed, 3D imaging offered further accuracy and objective diagnostic details about the craniofacial soft and hard tissue, as well as making 3D analyses simpler, quicker, and more effective. The aim of this review is to give an overview of 3D imaging techniques, as well as their benefits, drawbacks, and the indications for 3D imaging.

Keywords: Orthodontics imaging, 3-D imaging, Computed tomography, Stereophotogrammetry Laser scanner.

INTRODUCTION

One of the most important achievements of orthodontic therapy is the development of orthodontic records. Record keeping is important not only for diagnosis and treatment planning, but also for case follow-up, communication with colleagues, and treatment evaluation. Two-dimensional (2D) imaging technology, such as cephalometric and OPG and photos, as well as plaster models, have recently become commonplace. However, 2D imaging systems have some drawbacks, such as substantial radiographic projection error, radiation exposure, distortion, enlargement, shortcomings in landmark detection, incorrect replication of extensions, significant variance in the location of orientation points, such as the sella turcica, and severe limitations in determining soft tissue balance (1). Some cephalometric structures and landmarks such as the mandibular symphysis, pterygoid fossa, articulare, and "key ridges" that do not exist in the patient when the clinician uses 2D imaging to display three-dimensional (3D) anatomical craniofacial structures. The loss of parasagittal details and if present, asymmetry of the patient result from averaging bilateral structures (such as the left and right inferior borders of the mandible) to establish a single anatomic framework (mandibular plane). In conclusion, 2D imaging systems cannot solve the circumstance that reducing a 3D object to a 2D view results in data loss (2).

It became possible to test structures in actual three anatomical dimensions after the advent of 3D imaging systems. In addition, the hard and soft tissues of the craniofacial area can be seen in 3 dimensions. There are a number of other benefits to these modern systems. First, since the majority of these systems are non-invasive, repeating images is not an ethical issue. Second, all photographs can be saved in digital form, making archiving even more realistic and reducing the amount of storage space

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needed. The development of software programs allows for the precise and reliable analysis of 3D data. Furthermore, software programs are extremely user-friendly thanks to features such as zooming and rotation (3, 4).

Patients having craniofacial syndromes and abnormalities, like cleft lip and palate (CLP), benefit greatly from 3D imaging systems (Table 1). This group of patient is often treated for a long time, beginning in childhood and continuing until adolescence, needs several surgeries, and needs care of clinicians from various fields, or interdisciplinary approaches.

Table 1: Comparison of cost, radiation dose and indication of 3D imaging systems

Imaging technique	Cost	Radiation dose	Indications
CBCT	High	Dentoalveolar 11-674 µSv Maxillofacial 30-1073 µSv	Craniofacial deformities (other indications with caution)
Laser scanner	High	Non-invasive	May be recommended in every patient
Stereophotogrammetry	High	Non-invasive	May be recommended in every patient
MRI	High	Non-invasive	Airway assessment
Intraoral scanner	High	Non-invasive	May be recommended in every patient

The dentition, hard tissue jaw position, facial bone position, and covering soft tissue must all be considered in treatment plans. Despite the fact that the Eurocleft and Americacleft studies recommended reporting at specific times, the recommendations are all focused on 2D documents, with the exception of 3D dental casts. However, a growing number of studies have been published on the introduction of 3D imaging systems in craniofacial patient care teams, their advantages over 2D imaging, and their indications. However, as compared to 2D imaging systems, the price and radiation dose of few of these 3D imaging systems are more, and should be considered by experts prior recommending them (Table 2). As a result, the aim of this review is to give an overview of the 3D imaging system in everyday orthodontic practice and to highlight indication, particularly in patients with craniofacial abnormalities.

Table 2: Comparison of 2D and 3D imaging system

Imaging technique	Effective dose (µSv)	Cost
Periapical radiograph	<1.5*	X
Panoramic radiograph	2.7-24.3	2X
Cephalometric radiograph	<6	2X
Dentoalveolar CBCT	11-674 (61)	
Maxillofacial CBCT	30-1073	10-20X
MSCT maxillo-mandibular	280-1410	10-20X

Many terms should be familiarized in order to comprehend 3D imaging systems. In 2D pictures, there are two axes (a horizontal and vertical). The Cartesian coordinate system, which consists of the x-axis (or transverse dimension), y-axis (or vertical dimension), and z-axis (the anteroposterior dimension “depth axis”), is used in 3D images. The process of creating 3D models consists of many stages. The first is called "modeling." This move involves using mathematics to explain an object's physical properties. After it, the modeled object referred as a "wireframe" (or "polygonal mesh").

A layer of pixels is used to add a surface to the object during the modeling process. This is referred to as "image" or "texture mapping." Some shading and lighting are added in the second phase to give the 3D object more realism. The last step is named "rendering." The machine changes the anatomical data obtained from the patient into a lifelike 3D object that displayed on the computer screen (5).

3D imaging approaches can be summarized as follows:

- Conventional computed and cone-beam computerized tomography (CT/CBCT)
- Laser scanning (3D laser scanning)
- Vision-based scanning techniques
- 3-D orthognathic surgery planning
- Intraoral scanning
- Magnetic resonance imaging (MRI) and surface scanning

- Video camera (four-dimensional (4D) imaging and video stereophotogrammetry).

CT:

It is known as computerized axial tomography, is a 3D imaging systems that uses cross-sectional images of the body to create a three-dimensional image. This scan provides 3D details for both soft and hard tissues. The two types of tomography are fan beam and CBCT. Fan beam tomography is a form of traditional tomography that has a high radiation dose. Furthermore, it is costly and not accessible in any health-care facility. As a result of the heavy radiation exposure, it's not appropriate for routine orthodontic use. However, it is commonly used in dentistry because it provides useful information about the maxillary sinus, airway volumes, orofacial pathologies, structural variations, the temporomandibular joint (TMJ), orofacial trauma and fractures and craniofacial syndromes.

Craniofacial CBCT was first implemented about 20 years ago, and it was created to address few of the drawbacks of traditional CT scanning (6). When compared to CT imaging, the price of CBCT imaging is very low, and more prominently, 3D imagining with much lower radiation dose is possible. The lower radiation exposure, however, is still significantly higher than that of traditional 2D imaging devices (Table 2).

Rearrangement of 2D images in sagittal, oblique, coronal, and several inclined planes is possible with CBCT. All raw data is collected in a single turn with CBCT devices. As a result, the patient's hospital stay is cut short, and the device improves patient satisfaction. The ability to view and organize 3D data in personal computers is CBCT's most significant benefit. There are a number of detailed orthodontic measurement software programs available.

In orthodontic patients, CBCT may be used for a variety of purposes. As per Kapila and Nervina (7) CBCT should be preferred:

- If there is a need in diagnosis, like identifying the position of impacted (8, 9, 10) and supernumerary teeth (10-12).
- If there is a need to measure the severity of the defect, such as in CLP patients (13, 14).
- If it helps in differentiation between malocclusions like craniofacial abnormalities and syndromes (15).
- If there is a need to determine whether a difference is unilateral or bilateral, such as facial asymmetry, particularly in patients who have had orthognathic surgery (16).
- If it aids in determining the cause of the malocclusion, such as TMJ disorders (17).
- If it aids in the evaluation of treatment results including rapid maxillary expansion (18-20) and root angulations (21).
- If the quantity and quality of bone, as well as the anatomical structures, are mandatory for the placement of orthodontic devices like mini-screws.
- If alveolar boundary must be determined (22).
- If 3D airway morphology is required for the treatment of obstructive sleep apnea (23).

CBCT is often used to diagnose and schedule care for impacted teeth. According to Lai et al. (10), CBCT develops exact localization of the impacted canines, assessment of the proximity to teeth and other structures, determining the existence of any pathology, and root resorption associated with impacted teeth and adjacent teeth. CBCT also assists in the management of impacted teeth, as well as determining surgical access and extrusion of impacted teeth into the oral cavity. Furthermore, it has been shown that CBCT scans provide a more precise picture of root resorption associated with impacted teeth than 2D radiographs. The most important points in treating supernumerary teeth cases are determining the location of the extra teeth, particularly if they are impacted, and explaining the morphology of the extra teeth. The shape and location of the supernumerary tooth, any anomalies around the tooth, and root resorption of adjacent permanent teeth are all visualized using CBCT (10-12).

Even though most studies haven't found a connection between orthodontic treatment and TMJ, it's still a good idea to get a TMJ examination before starting orthodontic treatment. CBCT offers more exact anatomic imaging than 2D radiographs and is more effective than CT and MRI in identifying osseous changes (17). When inserting temporary anchorage devices (TADs), CBCT images will aid in the assessment of nearby tissues and anatomical structures such as nerves, tooth roots, and sinuses reducing the risk of complications (7). CBCT is used for more than just treatment planning and diagnosis; it's also used to assess treatment outcomes. CBCT has been used in a number of studies to measure the skeletal and dental effects of maxillary expansion (18, 19) and to compare the dentoalveolar, periodontal, and skeletal effects of tooth-borne and tooth-bone-borne expansion strategies (20), as well as to determine how expansion forces affect various areas of the maxilla (18).

To aid post-treatment stability, CBCT may be assessed root parallelism and angulations after orthodontic treatment (22). Rapid maxillary expansion (RME) and surgery as treatment options for a narrow airway have been investigated using CBCT imaging (7). In conclusion, CBCT imaging is recommended for determining airway volume (23). According to Kujipers et al., CBCT was also preferred in airway assessment researches to test the nose and sinuses, as well as the volumes of airway spaces at various levels; however, none of these research had high-quality ratings, so a real indication could not be specified (24).

Impacted or supernumerary teeth are common in patients with craniofacial syndromes; CBCT imaging have been observed to be helpful in planning orthodontic treatment for patients with supernumerary and impacted teeth (15).

Patients with craniofacial malformations, such as those with CLP, facial asymmetries orthognathic surgery, and syndromes may benefit from 3D imaging for pre-treatment assessment. De Moraes et al. (25) stated that CBCT allows for a more accurate assessment of craniofacial morphology than 2D images. According to Nur et al. (16), CBCT is a good way to diagnose facial asymmetry since it allows you to associate the left and right facial hard tissues while not limiting soft tissue extents. Current studies have shown that CBCT is useful in assessing the volume of the alveolar defect, its location, proximity, the paths of the teeth near the cleft site and the eruption status in patients with CLP (13, 14). As a result, CBCT increases the facility to determine the exact volume of the post-expansion defect, allowing for better preparation and evaluation of bone grafting outcomes. Overall, the SEDENTEXCT Consortium indicated that CLP is one of the most common appropriate indications for CBCT in dentistry, and that other indications should be approached with caution (26).

Laser Scanning (3D Laser Scanning):

A non-invasive method for recording facial anatomy and soft tissue is laser scanning (Table 1). The method's strength has been demonstrated in several researches (27, 28). As per Kau and Richmond (29), laser scanning systems are less costly and easier to use, in addition to creating accurate 3D facial models.

Indications for Laser scanning-

- Analysis of facial morphology in 3D (27, 28).
- Facial symmetry evaluation (30, 31).
- Cross-sectional growth assessment (32).
- Treatment outcome valuation (33).
- Treatment outcome assessment for surgical cases (34).
- CLP patient evaluation (31).
- Changes in soft tissue (35).
- Dental cast scanning (36).

Laser scanning used to quantify facial symmetry in adolescents (30) and cleft lip and palate patients, as well as soft tissue modifications during treatment (31). Furthermore, according to Kujipers et al. (24) a laser scanner and stereophotogrammetry are accurate soft tissue imaging devices with a maximum extent error of 1 mm.

The most significant drawback of this technique is that it need time to capture. As a result, it is difficult in pediatric situations (37). Laser scanning, on the other hand, could be an appropriate approach for pre-school children if they are well educated, according to a report (31). Other flaws in the process have been identified, including the failure to record soft tissue surface texture and safety concerns associated with exposing the eyes to the laser beam (5).

Vision-Based Scanning Techniques:

Non-invasive and user-friendly vision-based scanning techniques include structured illumination, stereophotogrammetry, Moiré topography and 3D facial morphometry. Among vision-based scanning methods, stereophotogrammetry is the most commonly used in orthodontic practice.

Stereophotogrammetry:

Stereophotogrammetry is a method of creating 3D models by photographing things with a pair of configured cameras and integrating images taken from two dissimilar directions. Stereophotogrammetry has a number of benefits, according to various studies:

- It is a non-contact, non-invasive procedure that does not expose to radiation.
- It succeeds at capturing improvements in facial morphology and soft tissue (38-40).
- It has a quick learning process and is simple to use (in child patients particularly infants).
- It can be used in conjunction with CBCT images.
- On a screen, 3D images can be observed and used as a communication tool between clinicians.
- Stereophotogrammetry is very useful for orthognathic surgery (24, 42, 43) and patients with craniofacial abnormalities (CLP) since 3D images can be rotated and observed from either direction (5, 41).

Stereophotogrammetry was also used in a thesis to scan dental casts to assess intraoral variations after nasoalveolar therapy. It was determined that 3D data allowed rotating and zooming into the image, allowing models to be observed from any angle and thus performing more precise measurements on the object (42). It is very good at recording facial morphology (38-40); however, tissue reflections, eyebrows, hair, and angled surfaces like the ears and eyes can affect the image process (44). Stereophotogrammetry helps orthodontists to examine the face from all angles with single capture, making it valuable for patients that have had orthognathic surgery or who have craniofacial deformities (5, 41). After orthognathic surgery, stereophotogrammetry has also been preferred for superimpositions (5).

In patients with CLP, stereophotogrammetry is the most commonly used 3D technique for soft tissue assessment. It can be used safely in pediatric patients because it is a non-invasive procedure that does not expose patients to radiation. Another rationale for using stereophotogrammetry on small children is the device's short capture time and ease of use. As a result, it is advantageous during the infancy phase, when infants undergo pre-surgical orthopedic care, to track follow-ups as well as treatment outcomes. The digital recording of soft tissue data at the time of the initial surgery allows for the monitoring of soft tissue growth differentiations caused by surgical approaches. This allows procedures and approaches to be improved and adapted in order to resolve specific surgical side effects. Several studies on babies were recently conducted using stereophotogrammetry to develop superimpositions in order to distinguish physiological from approached-based development (42-43).

MRI and Surface Scanning:

These are non-invasive imaging methods include MRI and surface scanning. MRI used in craniofacial imaging for several years and provides reliable and comprehensive information on abnormalities and disorders of craniofacial soft and hard tissues, especially the TMJ (45). Upper airway mapping and 3D imaging of TMJ morphology are the most common uses of MRI. According to Kujipers et al. (24) researches on velopharyngeal function using MRI were of excellent quality, and thus may be indicated for calculating airway room, function and motion particularly in patients with cleft to define velopharyngeal incompetence in patients with cleft. Due to its limited use in dentistry, the device's cost, and orthodontists' lack of experience in operation, MRI have some limitations (46). Recent studies, however, have shown that MRI is effective in a variety of orthodontic fields, and have compared MRI to traditional 3D imaging techniques (CBCT and CT) (Table 1). Detterbeck et al. (47) linked mesio-distal tooth width using 3D imaging techniques with and without ionizing radiation, concluding that MRI provides comparable dimensions to CBCT and that tooth germs are well visualized on MRI than erupted teeth. It was tested if MRI is equivalent to cephalometric radiographs in cephalometric research, and it was found that orthodontic treatment preparation without exposure to radiation is possible using the MRI (48). Finally, with advantages such as a high contrast ratio and the lack of ionizing radiation, MRI has a lot of potential for use in clinical practice in orthodontics.

Video Camera (4D Imaging and Video Stereophotogrammetry):

The methods described above are used to assess facial morphology in two or three dimensions. Though, the human face, especially the areas of the nose, lip, and mouth, is a dynamic structure. 4D video recording is the most recent technique, which can capture complex activities of the human face and examine the dynamics of facial expressions (49). Numerous research used 4D imaging to show asymmetry when making facial expressions in patients with CLP and orthognathic surgery, and discrepancies in facial motion among individuals with and without CLP were analyzed (49). New attempts have been made to build virtual patients using these new technologies by superimposing facial skeletons, soft tissue, and/or dentition (50). In the literature, more research is required to build a real-time 4D virtual patient in motion.

3D Planning in Orthognathic Surgery:

The key components of orthognathic surgery preparation are dentition, facial soft tissues and facial skeleton. "Image fusion" is the only way to capture these three essential tissue types (51). Surgeons and orthodontists will examine the patient's craniofacial soft tissue and skeleton together using 3D facial image capture and CBCT images to create a "virtual 3D patient." These interactive 3D models can be rotated to any view for a more thorough diagnosis and treatment plan. All of the information gathered can be saved in database files that can be conveniently handled online. It also facilitates communication and interdisciplinary patient planning between orthodontists and surgeons. To achieve the best cosmetic and occlusal outcomes, orthognathic surgery needs meticulous treatment planning. The software programs will perform 3D surgical planning on this virtual patient. Surgical splints can also be made using CAD/CAM technology (52). The virtual preparation can be moved to the operating room using these surgical guides (51). 3D surgical models can be used to predict postoperative outcomes in both soft and hard tissues. Postoperative predictions are accurate in some areas, according to Centenero et al. (52), but additional work is required to represent the postoperative variations in facial soft tissue. This technology is available to the followings:

- Virtually osteotomies (51, 52).
- Repositioning of bone structures that have been osteotomized.
- Intercuspation regulation.
- Monitor interfering bony structures and area at the base of the skull that have been osteotomized (52).
- Osteogenesis by simulated distraction (53).
- Surgical outcome prediction (51, 52).
- Make a number of simulations of various osteotomies and skeletal activities (5).
- Data management.
- Surgical splints manufacturation.
- Orthodontists and surgeon's communication.

The 3D image fusion process, on the other hand, is an costly method that necessitates both equipment and time (about 1 hour to create a virtual patient) (51).

Intraoral Scanning:

An intraoral scanner is a piece of technology that includes an intraoral camera, a monitor, and software. It makes a digital 3D model of scanned articles including teeth, impressions, and dental casts. The drawbacks of traditional impression methods, such as dimensional changes in impression materials, dental stone errors and storage issues have been resolved with the advent of intraoral scanning technology. Furthermore, using an intraoral camera makes taking impressions from patients with gag reflexes much easier. Digital models allow 3D diagnostic details, communication between laboratories and orthodontists, virtual set-ups and treatment planning, and fabrication of custom-made removable or fixed appliances. Orthodontists may use the digital model to schedule treatment, monitor bracket placement, and overlay before and after images.

Intraoral scanning can have the following benefits:

- Study casts archiving.
- Evaluate intra-arch and inter-arch relations.
- Treatment planning.
- Treatment and set-ups virtually.
- Arch wires prefabrication in 3D.
- 3D aligner construction.
- CAD/CAM retainer.
- Lingual brackets fabrication.
- Bonding of indirect brackets.

Inter-arch measurements such as overbite, overjet, molar relationship, and canine relationship, according to a systematic analysis, must be verified on virtually occluded digital models (54). Furthermore, in normal practice, the time required for complete arch scanning can be considered a drawback of this technique.

CONCLUSION

The use of 3D imaging methods in orthodontic practice is extremely beneficial. These strategies improve care choices by allowing for more accurate diagnostic details on individual cases, like patients with craniofacial defects. CBCT has a wide range of applications, especially for evaluating the craniofacial skeleton and associated pathologies; however, due to the high radiation exposure, the indications should be carefully considered. One of the most supportable causes for CBCT is in patients with cleft palate. While noninvasive systems including stereophotogrammetry, intraoral scanning, laser scanning and MRI are appropriate for all patients, the high cost must be considered. Stereophotogrammetry is recommended for patients with craniofacial deformities like CLP, and it is particularly suggested for child patients (infancy period) who are difficult to photograph due to movement. Some of laser scanning's flaws, such as its inability to capture soft tissue surface texture, make it better suited to scanning dental casts. Digital dental casts are simple to use methods for assessing the dentition. The reliability of MRI was high, and it could be used to assess airway space and velopharyngeal functions. Overall, as all 3D imaging techniques become more common, chair time for complete orthodontic records, record loss, and storage issues will decrease, and interdisciplinary communication will improve. Whereas evidence-based guidelines for 3D imaging were once expected to incorporate it into the traditional orthodontic record-keeping process, the future of 3D imaging now provides clinicians with a dynamic 4D virtual patient in motion that allows them to identify functional recovery after treatment.

CONFLICTS OF INTEREST

The authors declare they have no potential conflict of interests regarding this article.

REFERENCES

1. Jacobson A. Radiographic Cephalometry: From basics to videoimaging. Chicago: Quintessence; 1995.

2. Palomo JM, Yang C, Hans MG. Clinical Application of Three-Dimensional Craniofacial Imaging in Orthodontics. J Med Sci 2005; 269-78.

3. Lane C, Harrell W Jr. Completing the 3-dimensional picture. Am J Orthod Dentofacial Orthop 2008; 133: 612-20.

4. Germec-Cakan D, Canter HI, Nur B, Arun T. Comparison of Facial Soft Tissue Measurements on 3D Images and Models Obtained with Different Methods. J Craniofac Surg 2010; 21: 1393-9.

5. Hajeer MJ, Millett DT, Ayoub AF, Siebert JP. Applications of 3D imaging in orthodontics: Part I. J Orthod 2004; 31: 62-70.

6. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the conebeam technique: preliminary results. Eur Radiol 1998; 8: 1558-64.

7. Kapila SD, Nervina JM. CBCT in orthodontics: assessment of treatment outcomes and indications for its use. Dentomaxillofac Radiol 2015; 44: 20140282.

8. Botticelli S, Verna C, Cattaneo PM, Heidmann J, Melsen B. Two- versus three-dimensional imaging in subjects with unerupted maxillary canines. Eur J Orthod 2011; 33: 344-9.

9. Katheria BC, Kau CH, Tate R, Chen JW, English J, Bouquot J. Effectiveness of impacted and supernumerary tooth diagnosis from traditional radiography versus cone beam computed tomography. Pediatr Dent 2010; 32: 304-9.

10. Lai CS, Bornstein MM, Mock L, Heuberger BM, Dietrich T, Katsaros C. Impacted maxillary canines and root resorptions of neighbouring teeth: a radiographic analysis using cone-beam computed tomography. Eur J Orthod 2013; 35: 529-38.

11. Toureno L, Park JH, Cederberg RA, Hwang EH, Shin JW. Identification of supernumerary teeth in 2D and 3D: review of literature and a proposal. J Dent Educ 2013; 77: 43-50.

12. Mossaz J, Kloukos D, Pandis N, Suter VG, Katsaros C, Bornstein MM. Morphologic characteristics, location, and associated complications of maxillary and mandibular supernumerary teeth as evaluated using cone beam computed tomography. Eur J Orthod 2014; 36: 708-18.

13. Garib DG, Yatabe MS, Ozawa TO, Filho OG. Alveolar bone morphology in patients with bilateral complete cleft lip and palate in the mixed dentition: cone beam computed tomography evaluation. Cleft Palate Craniofac J 2012; 49: 208-14.

14. Oberoi S, Gill P, Chigurupati R, Hoffman WY, Hatcher DC, Vargervik K. Three-dimensional assessment of the eruption path of the canine in individuals with bone-grafted alveolar clefts using cone beam computed tomography. Cleft Palate Craniofac J 2010; 47: 507-12.

15. Dalessandri D, Laffranchi L, Tonni I, Zotti F, Piancino MG, Paganelli C, et al. Advantages of cone beam computed tomography (CBCT) in the orthodontic treatment planning of cleidocranial dysplasia patients: a case report. Head Face Med 2011; 7: 6.

16. Nur RB, Çakan DG, Arun T. Evaluation of Facial Hard and Soft Tissue Asymmetry using Cone Beam Computed Tomography. Am J Orthod Dentofacial Orthop 2016; 149: 225-37.

17. Ilguy D, Ilguy M, Fisekcioglu E, Dolekoglu S, Ersan N. Articular eminence inclination, height, and condyle morphology on cone beam computed tomography. ScientificWorldJournal 2014; 2014: 761714.

18. Habeeb M, Boucher N, Chung CH. Effects of rapid palatal expansion on the sagittal and vertical dimensions of the maxilla: a study on cephalograms derived from cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2013; 144: 398-403.

19. Kanomi R, Deguchi T, Kakuno E, Takano-Yamamoto T, Roberts WE. CBCT of skeletal changes following rapid maxillary expansion to increase arch-length with a development-dependent bonded or banded appliance. Angle Orthod 2013; 83: 851-7.

20. Toklu MG, Germec-Cakan D, Tozlu M. Periodontal, dentoalveolar, and skeletal effects of tooth-borne and tooth-bone-borne expansion appliances. Am J Orthod Dentofacial Orthop 2015; 148: 97-109.

21. Bouwens DG, Cevidanes L, Ludlow JB, Phillips C. Comparison of mesiodistal root angulation with posttreatment panoramic radiographs and cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2011; 139: 126-32.

22. Johnson DP. Effects of curve of Wilson correction and pretreatment boundary conditions on quantitative changes in alveolar bone morphology. University of Michigan School of Dentistry, MSc thesis. 2011.

23. Feng X, Li G, Qu Z, Liu L, Näsström K, Shi XQ. Comparative analysis of upper airway volume with lateral cephalograms and cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2015; 147: 197-204.

24. Kuijpers MA, Chiu YT, Nada RM, Carels CE, Fudalej PS. Three-dimensional imaging methods for quantitative analysis of facial soft tissues and skeletal morphology in patients with orofacial clefts: a systematic review. PLoS One 2014; 9: e93442.

25. De Moraes ME, Hollender LG, Chen CS, Moraes LC, Balducci I. Evaluating craniofacial asymmetry with digital cephalometric images and cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2011; 139: 523-31.

26. European Comission. Radiation protection no 172. Cone beam CT for dental and maxillofacial radiology (evidence-based guidelines), 2012. (cited 2017 Nov 17). Available from: URL: http:/www.sedentexct.eu/files/radiation_protection_172.pdf.

27. Kau CH, Richmond S, Zhurov AI, Knox J, Chestnutt I, Hartles F et al. Reliability of

measuring facial morphology with a 3-dimensional laser scanning system. Am J Orthod Dentofacial Orthop 2005; 128: 424-30.

28. Kovacs L, Zimmermann A, Brockmann G, Baurecht H, Schwenzer-Zimmerer K, Papadopulos NA, et al. Accuracy and precision of the three-dimensional assessment of the facial surface using a 3-D laser scanner. IEEE Trans Med Imaging 2006; 25: 742-54.

29. Kau CH, Richmond S. Three-dimensional imaging for orthodontics and maxillofacial surgery. Iowa: Willey-Blackwell; 2010.

30. Djordjevic J, Pirttiniemi P, Harila V, Heikkinen T, Toma AM, Zhurov AI, et al. Three-dimensional longitudinal assessment of facial symmetry in adolescents. Eur J Orthod 2011; 35: 143-51.

31. Djordjevic J, Lewis BM, Donaghy CE, Zhurov AI, Knox J, Hunter L, et al. Facial shape and asymmetry in 5-year-old children with repaired unilateral cleft lip and/or palate: an exploratory study using laser scanning. Eur J Orthod 2012; 36: 497-505.

32. Nute SJ, Moss JP. Three-dimensional facial growth studied by optical surface scanning. J Orthod 2000; 27: 31-8.

33. Moss JP, Ismail SF, Hennessy RJ. Three-dimensional assessment of treatment outcomes on the face. Orthod Craniofac Res 2003; 6: 126-31.

34. Meehan M, Teschner M, Girod S. Three-dimensional simulation and prediction of craniofacial surgery. Orthod Craniofac Res 2003; 6: 102-7.

35. Jeon H, Lee SJ, Kim TW, Donatelli RE. Three-dimensional analysis of lip and perioral soft tissue changes after debonding of labial brackets. Orthod Craniofac Res 2013; 16: 65-74.

36. Kusnoto B, Evans CA. Reliability of a 3D surface laser scanner for orthodontic applications. Am J Orthod Dentofacial Orthop 2002; 122: 342-8.

37. Devlin MF, Ray A, Raine P, Bowman A, Ayoub AF. Facial symmetry in unilateral cleft lip and palate following alar base augmentation with bone graft: a three-dimensional assessment. Cleft Palate Craniofac J 2007; 44: 391-5.

38. Plooij JM, Swennen GR, Rangel FA, Maal TJ, Schutyser FA, Bronkhorst EM, et al. Evaluation of reproducibility and reliability of 3D soft tissue analysis using 3D stereo- photogrammetry. Int J Oral Maxillofac Surg 2009; 38: 267-73.

39. Kim YK, Lee NK, Moon SW, Jang MJ, Kim HS, Yun PY. Evaluation of soft tissue changes around the lips after bracket debonding using three-dimensional stereophotogrammetry. Angle Orthod 2015; 85: 833-40.

40. Baysal A, Ozturk MA, Sahan AO, Uysal T. Facial soft-tissue changes after rapid maxillary expansion analyzed with 3-dimensional stereophotogrammetry: A randomized, controlled clinical trial. Angle Orthod 2016; 86: 934-42.

41. Ayoub AF, Siebert P, Moos KF, Wray D, Urquhart C, Niblett TB. A vision based 3D capture system for maxillofacial assessment and surgical planning. Br J Oral Maxillofac Surg 1998; 36: 353-57.

42. Wong JY, Oh AK, Ohta E, Hunt AT, Rogers GF, Mulliken JB, et al. Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images. Cleft Palate Craniofac J 2008; 45: 232-9.

43. Bugaighis I, Tiddeman B, Mattick CR, Hobson R. 3D comparison of average faces in subjects with oral clefts. Eur J Orthod 2012; 36: 365-72.

44. Karatas OH, Toy E. Three-dimensional imaging techniques: A literature review. Eur J Dent 2014; 8: 132-40.

45. Hall RK. The role of CT, MRI and 3D imaging in the diagnosis of temporomandibular joint and other orofacial disorders in children. Aust Orthod J 1994; 13: 86-94.

46. Mah J, Hatcher D. Current status and future needs in craniofacial imaging. Orthod Caniofacial Res 2003; 6: 10-6.

47. Detterbeck A, Hofmeister M, Haddad D, Weber D, Schmid M, Hölzing A, et al. Determination of the mesio-distal tooth width via 3D imaging techniques with and without ionizing radiation:

CBCT, MSCT, and µCT versus MRI. Eur J Orthod 2017; 39: 310-9.

48. Heil A, Gonzalez EL, Hilgenfeld T, Kickingereder P, Bendszus M, Heiland S, et al. Lateral cephalometric analysis for treatment planning in orthodontics based on MRI compared with radiographs: A feasibility study in children and adolescents. PLoS One 2017; 12; e0174524.

49. Hallac RR, Feng J, Kane AA, Seaward JR. Dynamic facial asymmetry in patients with repaired cleft lip using 4D imaging (video stereophotogrammetry). J Craniomaxillofac Surg 2017; 45: 8-12.

50. Joda T, Brägger U, Gallucci G. Systematic literature review of digital three-dimensional superimposition techniques to create virtual dental patients. Int J Oral Maxillofac Implants 2015; 30: 330-7.

51. Plooij JM, Maal TJ, Haers P, Borstlap WA, Kuijpers-Jagtman AM, Bergé SJ. Digital three-dimensional image fusion processes for planning and evaluating orthodontics and orthognathic surgery. A systematic review. Int J Oral Maxillofac Surg 2011; 40: 341-52.

52. Aboul-Hosn Centenero S, Hernández-Alfaro F. 3D planning in orthognathic surgery: CAD/CAM surgical splints and prediction of the soft and hard tissues results–our experience in 16 cases. J Craniomaxillofac Surg 2012; 40: 162-8.

53. Swennen GR, Schutyser FAC. Three-dimensional virtual approach to diagnosis and treatment planning of maxillofacial deformity. In: Bell WH, Guerrero CA, eds: Distraction osteogenesis of the facial skeleton. Hamilton: BC Decker Inc. 2006 (chapter 06).

54. Goracci C, Franchi L, Vichi A, Ferrari M. Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. Eur J Orthod 2016; 38: 422-8.