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Conventional, Digital 2D and 3D CBCT Cephalogram: Assessment of the Reliability of Cephalometric Analysis and Measurements

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Summary

The cephalogram is a radiological image used in orthodontics. Cephalometric analysis includes the interconnection of reference points which allows analyses and measurements of various planes and angles, which serve as an aid in finding the correct treatment of teeth. The standard cephalogram is recorded in two projections – LL and PA. The combination of LL and PA recordings once made up a 3D display up to the appearance of the CBCT device. Since the introduction of cephalometric analyses, numerous authors have pointed out the need for the development of new methods of analysis and measurement to correct the shortcomings of reference points, lines, and angles. The aim of this paper is to present a reliability assessment of cephalometric analysis and measurement on three types of cephalograms: conventional, digital 2D, and 3D CBCT cephalograms. Furthermore, the article presents the methodology and results of several scientific studies. The results of the reviewed studies show that all tested methods are reliable and practical for scientific research, with clinically acceptable differences between manually and digitally analyzed cephalograms. 3D CBCT shows a slightly higher degree of reliability in terms of taking measurements, but it is thought that new ways of producing more accurate measurements as well as better ways of displaying certain reference points should be devised. Finally, 2D cephalometric measurements should not be abandoned because the transition to 3D technology requires more additional research.

Keywords: 2D digital cephalogram; 3D CBCT cephalogram; cephalometric radiography; cephalometric measurements; conventional cephalogram

Introduction

The cephalogram is a standard radiological image in dental radiography and orthodontics (a specialist branch of dentistry that deals with the production of dental braces and teeth straightening) in which it is used to assess the relationship of the teeth to the jaw and the jaw to the rest of the facial skeleton [1]. The first mention of cephalometric analysis was presented by Hofrath in Germany and Broadbent in America in the 1930s [2]. The produced image displays reference points and represents measurements of a variety of angles that serve as an aid in finding proper dental treatment. Reference points refer to soft tissue and hard tissue structures. Lines are obtained by connecting these reference points, the interrelation of which produces the linear and angular variables for calculating the accuracy of measurements. Precise localization of reference points on the PA cephalogram is necessary when assessing lateral problems such as facial asymmetry [3–7].

The cephalogram is very similar to the standard craniogram but the difference is in the size of the imaging field as well as the stabilization and positioning of the patient. Cephalograms can be displayed in two 2D projections – LL and PA. The LL cephalogram is used to evaluate craniofacial structures, dentofacial relationships, malocclusion, and age changes that are key determinants of orthodontic therapy. The PA cephalogram is recorded only when it is necessary to display a specific case of asymmetry or for the purpose of orthognathic operations. The combined interpretation of LL and PA recordings once made up a 3D cephalogram until the appearance of the

CT scan and, later, the device for computerized tomography with a conical beam – CBCT (Cone Beam Computed Tomography). The CBCT scan displays a three-dimensional representation of all anatomical structures. Linear, angular, and proportional measurements are standard cephalometric measurements to which an additional measured dimension is added in a 3D view. A two-dimensional plane, connected by two reference points, receives an additional reference point in a three-dimensional view and is thus marked by three reference points [2].

Methodology

Patient positioning

A cephalogram is a classic X-ray device that has a cephalostat or head stabilizer [5]. A special accessory on the device is used to obtain a cephalometric image, either on a device that uses film or a digital detector [8].

Conventional and digital 2D cephalograms vary depending on the type of receptor and the position of the X-ray tube during imaging (Figures 1 and 2). The device uses a special aluminum filter for better visualization of the soft facial tissue, excluding the bones of the skull and teeth. Furthermore, the focus-film distance should be more than one meter and ideally in the range of 1.5–1.8 meters in order to reduce the effect of increasing structures (Figure 3). In orthodontics, for quality treatment, it is necessary to obtain scans on which the dimensions of anatomical structures are realistic [1,5]. The patient needs to stand up in the correct vertical position, relative to the substrate, and insert special attachments into the outer auditory corridor on both sides of the head with the help of the cephalostate. The device has a built-in head stabilizing and positioning apparatus, funnel-shaped appendages with lead balls that are placed in the ear openings, and a holder with a long lead marking, which leans on the root of the nose. All three of the above lead markings serve as starting points for analysis and reconstruction for the orthodontist or surgeon. Thus, the position of the head is fixed, and the Frankfurt skull line is placed in a horizontal position (Figures 4 and 5). Furthermore, the patient should clench their back teeth, swallow any saliva, and close their mouth [5, 6].

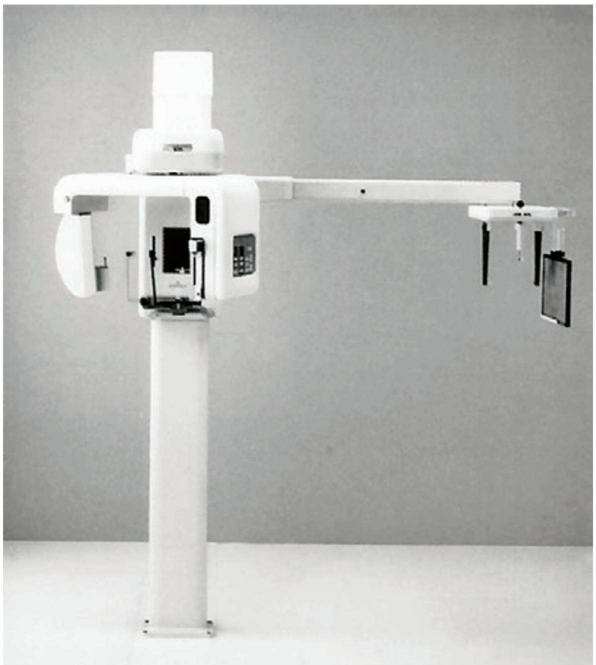

Figure 1. Example of a combined orthopantomogram imaging device and a cephalogram for film-based or phosphor-plate imaging
Source: https://pocketdentistry.com/14-cephalometric-radiography/

Figure 2. Example of a combined orthopantomogram imaging device and a cephalogram for recording with a digital detector
Source: https://henryscheinequipmentcatalog.com/imaging/extraoral-imaging/air-techniques-provectar-s-pan-cephalometric-x-ray-system

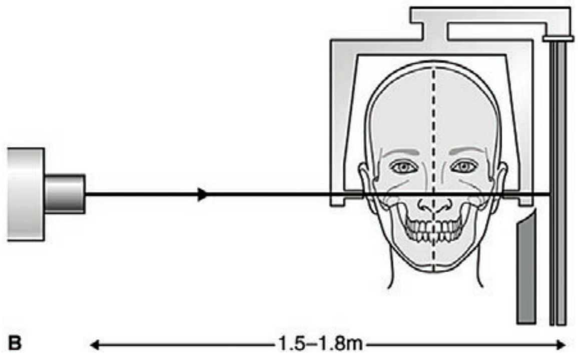

Figure 3. Position of the X-ray tube and receptors (film) at a 1.5-1.8 m distance
Source: https://pocketdentistry.com/14-cephalometric-radiography/

Positioning the patient in the 3D CBCT device does not involve the stabilization of the head with the aid of a cephalostat, but rather by using a laser display to pay attention to the verticality of the Frankfurt and sagittal planes of the head, relative to the base. After a complete, 360-degree rotation of the X-ray tube around the patient's head, an image is produced in all three planes, using a large range of the imaging field. The process involves

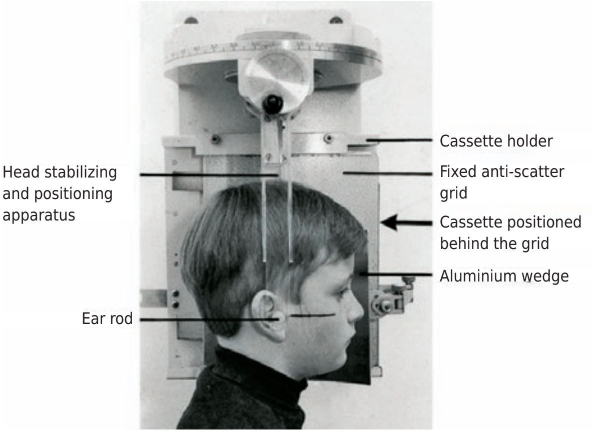

Figure 4. Setting the patient in the correct position for a 2D cephalogram – before
Source: https://pocketdentistry.com/14-cephalometric-radiography/

Figure 5. Setting the patient in the correct position for a 2D cephalogram nowadays
Source: https://henryscheinequipmentcatalog.com/imaging/extraoral-imaging/air-techniques-provectar-s-p

getting multiple images at different angles, which are then reconstructed into a single 3D image [9].

Cephalometric Analysis

A cephalometric analysis begins by identifying reference points, the connection of which ultimately produces planes used for certain cephalometric measurements (Figures 6 and 7). Several cephalometric analyses were defined, including those of Steiner (1953), Ricketts (1960), and McNamara (1983). Computerized cephalometry, with a significantly improved workflow due to the automatic calculation of distances and angles, was introduced in the late 1960s (Figure 8) [10]. Since the beginning of the development of cephalometric analyses, numerous authors have been developing new analyses to correct the previous shortcomings of reference points, lines, and angles. The resulting 3D recordings are transferred to special software, which can generate 2D and 3D views. CBCT offers the option to use a filter that can display reference points in different ways for better visualization.

Discussion

Conventional followed by 2D cephalometric radiography, has evolved as a key orthodontic diagnostic tool in setting certain parameters for assessing cephalometric imaging analyses. This is also compounded by a significantly reduced dose of radiation received by the patient [9]. Cephalometric analysis and measurements on 2D images are somewhat limited because of several defects such as inhomogeneous magnification and distortion of lateral structures, imprecise locations of reference points due to overlapping structures, and the fact that reference points may not be displayed in the lateral and frontal recordings. Improper head positioning can lead to a wrong diagnosis [12]. Furthermore, the average analyses and

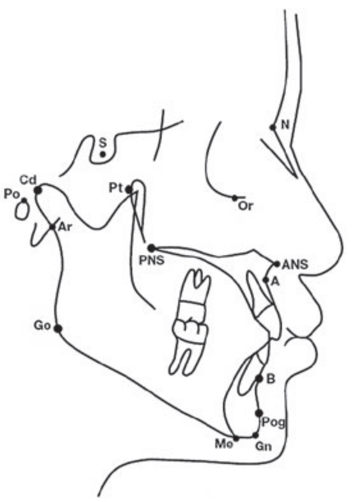

Figure 6. The display of hard tissue reference points. Source: http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0011-85162019000600009

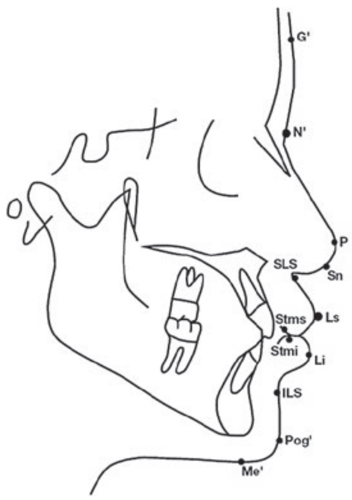

Figure 7. The display of soft tissue reference points. Source: http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0011-85162019000600009

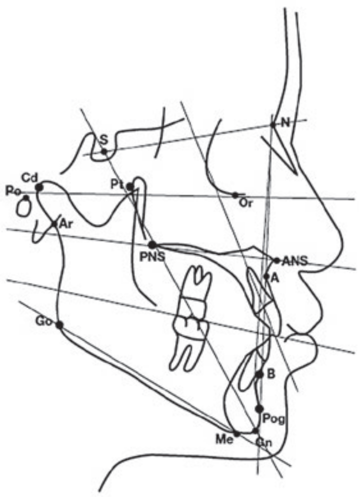

Figure 8. Example of cephalometric measurements. Source: http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0011-85162019000700008

measurements are not fully realistic since the human skull is asymmetric [13].

3D CBCT has become relatively accessible and is increasingly used in modern orthodontic practice. Studies have shown that using 3D CBCT is a more reliable method of cephalometric analysis and measurement [9]. 3D CBCT allows craniofacial measurements with good geometric accuracy for obtaining. The only disadvantage of using 3D CBCT is the large amount of radiation exposure, which is relatively higher compared to conventional imaging. However, the image has a high resolution and is better for observation. This is, without a doubt, one of the limitations that will have to be addressed, so many orthodontists limit its use to high-priority patients who need a detailed diagnosis [9]. When trying to locate an incisor on a 2D cephalogram or when a patient suffers from crowded teeth, these features can be easily located using the 3D method. It is also able to reduce identification errors and projections that lead to errors in 2D cephalometric measurement. One of the attributes of 3D technology is an increase in diagnostic accuracy, especially when identifying orthodontic conditions such as overlapping teeth, hidden nerve channels, implanted teeth, airway analyses, and hidden roots or anomalies in the temporomandibular joint [9].

Conventional, digital 2D and 3D CBCT cephalogram: assessment of the reliability of cephalometric analysis and measurement

Couceiro and Vilella examined the reliability of lateral cephalometric measurements on a conventional cephalogram as well as 2D and 3D images obtained by CBCT on two patients. When analyzing a conventional cephalogram, the image magnification factor of 7.2% stands out, while the measurements on the CBCT device are in a 1:1 ratio. 3D CBCT images showed less data dispersion, which confirms that CBCT is more reliable when it comes to identifying some reference points that are difficult to detect in 2D images. A failing of this study is that 3D CBCT images were printed and, as such, did not allow for the visualization of intracranial points, which are essential for analysis. So, the importance of developing software for CBCT measurements in orthodontic practice is emphasized. Finally, the comparison of both patients' measurements showed no statistically significant difference [11]. The results of this study are consistent with an article by Nakajima et al., which also concluded that 3D CBCT images are useful for orthodontic diagnosis and treatment planning [12].

Navarro et al. compared the reliability of three different methods of LL cephalometric analysis and measurements based on manual measurements of the conventional cephalogram, computer measurements on digital 2D cephalograms, and 3D CBCT cephalograms, using filters for better image analysis (Figures 9 and 10). All methods were shown to be reliable with clinically acceptable differences between manual and computer measurements. A magnification factor on conventional images is present, which can lead to differences in the increase and distortion of structures, thus placing reference points in different tomographic planes, which interferes with the proper analysis of linear measurements. With angular measurements, this is not a problem. The highest reliability was obtained by CBCT measurements due to the lack of magnification factors, but it was pointed out that reference points on bilateral structures do not show a high level of accuracy. Nevertheless, the addition of contrast and brightness on CBCT scans can improve the analysis of soft tissue structures. Also, bad positioning of the patient's head can be corrected in CBCT software. Finally, CBCT analyses show greater reliability, but, due to the higher amount of radiation, it should only be used if the patient has a specific indication and for future scientific research [13].

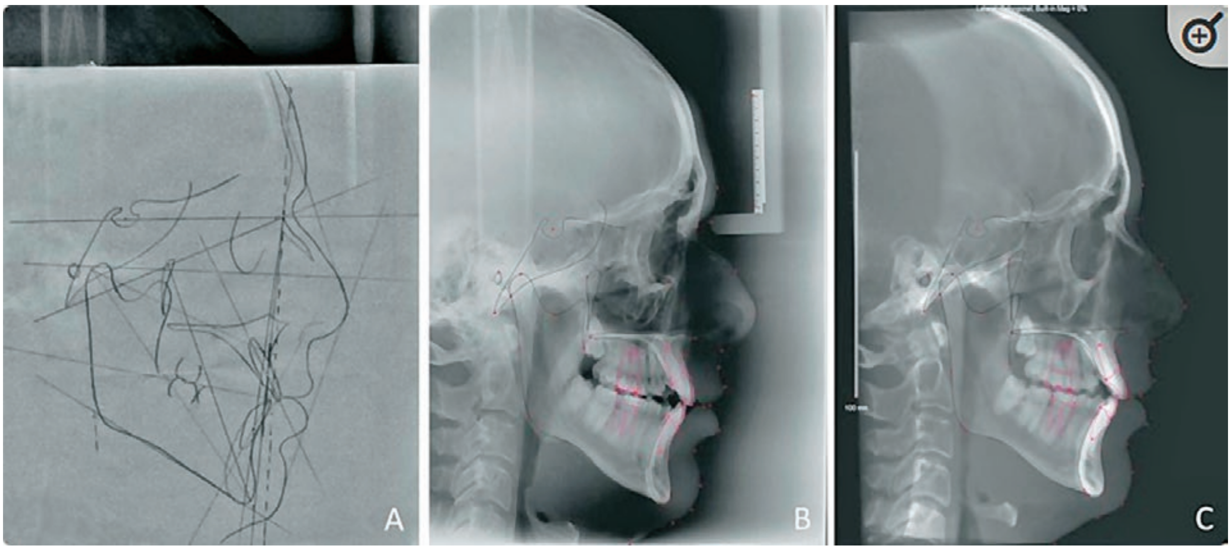

Figure 9. A) Manual cephalometry; B) Digital, 2D, LL cephalogram; C) 3D, CBCT, LL cephalogram
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3881882/

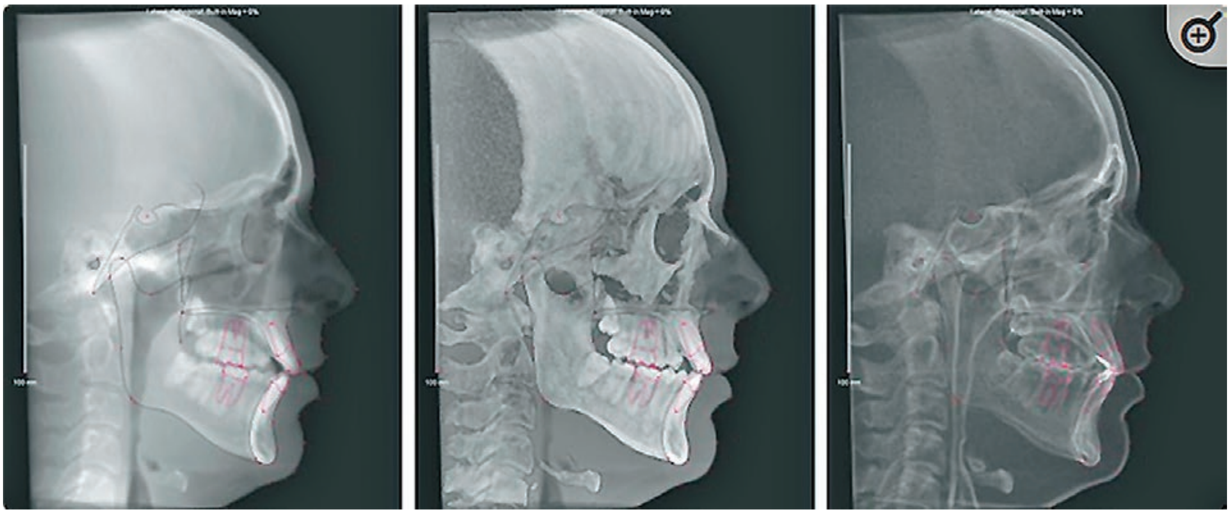

Figure 10. Different types of filters offered by CBCT cephalogram processing software
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3881882/

Digital 2D and 3D CBCT cephalogram: assessment of the reliability of cephalometric analysis and measurement

Li et al. examined the reliability of cephalometric measurements and analysis on digital 2D and 3D images of children and adults, taken from a pre-existing database and obtained using CBCT devices. For the evaluation of the most reliable method of cephalometric analysis, 2D lateral cephalograms with a magnification factor were extracted and thus imitated conventional cephalograms, 2D lateral cephalograms without magnification factors and 3D reconstructed cephalograms. Using the options offered by the software, lateral X-rays (with measured effects of distortion and bending of the classic X-ray) and X-rays with an orthogonal effect without distortion and bending were created. Statistical analysis shows that all methods had good to excellent reliability within the examiner and that 2D images without magnification factors had the highest rate of reliability. With regard to CBCT measurements, Li et al. claim that additional research is needed to set new reference points for 3D analysis. Certain points are not clearly visible on the 3D display, and, in the case of mixed dentition in children, not all teeth are displayed clearly enough; the unerupted permanent teeth overlap with the maxillary and mandibular alveolar bone, which increases the difficulty of tracking children with mixed dentition. Therefore, the authors urge caution against possible differences in the reliability of cephalometric analysis of patients of different ages and types of dentitions. Clinical caution and additional research are necessary when assessing the images of children [14].

Hariharan et al. examined the reliability of cephalometric measurements between examiners on 2D, digital, LL cephalograms compared to 3D CBCT cephalograms showing half-skull and total-skull structures. Half-skull structures are synthesized in the 3D CBCT program using software that removes unwanted structures, thus reducing the thickness of the recording layer. Observers analyzed 23 reference points, nine linear and 14 angular measurements (Figure 11.). 3D CBCT measurements of the total skull proved to be the least reliable. 2D, digital, LL cephalograms had the highest reliability, suggesting that they are more adequate for analyzing and taking measurements and are the gold standard for cephalometric measurements. Furthermore, Hariharan et al. conclude that CBCT is a very efficient modality for the performance

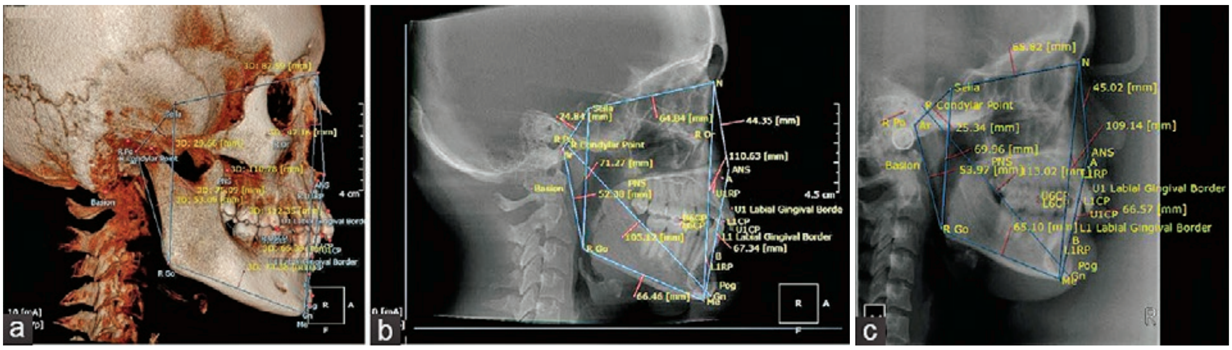

Figure 11. The display of cephalometric measurements and reference points on total- and half-skull structures in 3D images (a, b) and a 2D image (c)
Source: https://www.ijdr.in/article.asp?issn=0970-9290;year=2016;volume=27;issue=4;spage=370;epage=377;aulast=Hariharan

of cephalometric measurements, but for presenting half-skull structures, further studies on its use in practice are necessary [15].

Frazao et al. compared the accuracy of craniometric measurements on 2D, digital, LL cephalograms and 3D CBCT images. They placed 10 plastic beads on 25 models of the skull, positioning them at certain referent points. In the 3D images, 12 points were formed and identified on multiplanar reconstructed images i.e., MPRs (Multiplanar Reconstruction), generated by software (i.e., axial, sagittal, and coronal intersections), using tools to improve the image and maximum zoom, whereas 10 linear measurements were measured using a computer (Figures 12 and 13). The results of the studies were influenced by the quality of the images (the size of the voxel) and the instrument used to perform these measurements (precision of the caliper and software), as well as the size, material, and shape of the reference point markers (plastic balls).

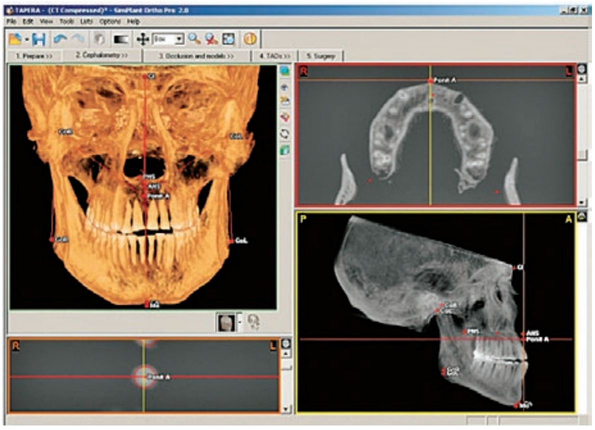

Figure 12. Software overview of the 3D cephalometric model
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8926366/

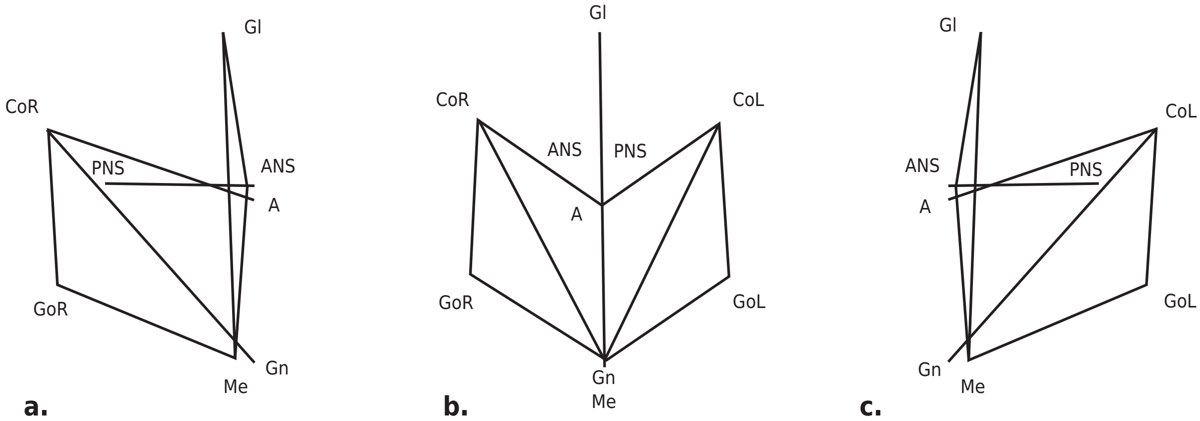

Figure 13. 3D cephalometric analysis
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8926366/

The plastic balls did not disrupt the results of direct measurements on convex surfaces, which would have been the case with steel balls, while offering sufficient contrast for recognition and localization by reducing the effect of the formation of artifacts. 2D LL cephalograms have intrinsic limitations that result in distorted images, which are enlarged in some areas and reduced in others. Mathematic algorithms in 3D form can be used in the future to correct these distortions. A quantitative assessment and diagnosis of 3D CBCT can be derived from previously known 2D standards, without exposing untreated patients to radiation [16].

Conclusion

All three types of tested methods have proven to be reliable and practical for scientific research, with clinically acceptable differences between manually and digitally analyzed cephalograms. The 3D CBCT method shows greater reliability for making measurements. However, since current cephalometric standards are established using conventional LL cephalometric images with built-in magnifications and distortions, 2D cephalograms without magnification are unlikely to directly replace conventional cephalometric analyses. Unlike conventional cephalograms, errors due to the incorrect positioning of the patient during the creation of a 2D image can be corrected in the CBCT dataset by making interactive adjustments within software. Furthermore, new landmarks for 3D cephalometric monitoring are needed to improve the reliability of 3D cephalometric analysis. Finally, radiographic images in orthodontics should be taken strictly based on the ALARA principle. CBCT use should be limited to specific indications such as patients with implanted teeth or those with facial asymmetries and craniofacial anomalies in which CBCT will better quantify the differences between the right and left sides of craniofacial structures. Nowadays, analyses and measurements on digital, 2D, LL cephalograms are the most prevalent, while PA imaging is less prevalent. Finally, conventional 2D cephalometric measurements should not be abandoned because the transition to 3D technology requires more published research. ■

Konvencionalni, digitalni 2D i 3D CBCT cefalogram: procjena pouzdanosti cefalometrijske analize i mjerenja

Sažetak

Cefalogram je radiološka snimka koja se primjenjuje u ortodonciji. Cefalografska analiza uključuje prikaz referentnih točaka čijim se povezivanjem analiziraju i mjere razne ravnine i kutovi koji služe kao pomagala u pronalasku pravilnog liječenja zubi. Standardni cefalogram snima se u dvije projekcije, LL i PA. Kombinacija LL i PA snimke predstavljala je 3D prikaz sve do pojave CBCT uređaja. Od uvođenja analiza, brojni su autori primijetili kako je potrebno razvijati nove metode analize i mjerenja kako bi se ispravili nedostatci referentnih točaka, linija i kutova. Cilj ovog rada jest prikazati procjenu pouzdanosti cefalometrijske analize i mjerenja na trima vrstama cefalograma: konvencionalnom, digitalnom 2D i 3D CBCT cefalogramu. U ovom članaku prikazane su metode rada te rezultati nekoliko znanstvenih istraživanja. Rezultati pregledanih radova pokazuju da su sve testirane metode pouzdane i praktične za znanstvena istraživanja, s klinički prihvatljivim razlikama između ručno i digitalno analiziranih cefalograma. 3D CBCT pokazuje nešto veću pouzdanost za vršenje mjerenja. No, smatra se da bi se trebali osmisliti novi načini preciznijih mjerenja, kao i bolji prikaz određenih referentnih točaka. Konačno, ne treba napustiti 2D cefalometrijska mjerenja jer prijelaz na 3D tehnologiju zahtijeva još dodatnih istraživanja.

Ključne riječi: 2D digitalni cefalogram; 3D CBCT cefalogram; cefalografija; cefalografska mjerenja; konvencionalni cefalogram

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