"Dimensional Perspectives: A Comprehensive Review of 3D Cephalometrics"

Suchita Talmale[1*], Divyaroop Rai[2], Anamika[3], Monika Verma[4], Taruna Saude[5], Madhuri Sharma[6]

[1]Postgraduate, Department of Orthodontics and Dentofacial Orthopaedics, Nims Dental College and Hospital, Jaipur, Rajasthan, India.

[2]Head of the Department, Department of Orthodontics and Dentofacial Orthopaedics, Nims Dental College and Hospital, Jaipur, Rajasthan, India.

[3]Senior Lecturer, Department of Orthodontics and Dentofacial Orthopaedics, Nims Dental College and Hospital, Jaipur, Rajasthan, India.

[4,5,6]Intern, Nims Dental College and Hospital Jaipur, Rajasthan, India.

ABSTRACT

Two-dimensional (2D) lateral and frontal radiography, combined with the three-dimensional (3D) cephalometric examination, represents a distinctive method that complements standard clinical assessments used to assess and quantify dysmorphoses affecting the skull and face. The 2D cephalometric analysis can be categorized into dimensional and topological approaches. Dimensional analysis measures various craniofacial structures relative to a line or reference plane, while topological analysis compares the proportions of different craniofacial structures within a subject to establish facial and mandibular topology.3-D cephalometry involves geometric analysis of the head in three dimensions. To achieve this, precise volumetric head measurements are essential, along with tools capable of accessing this 3-D dataset reliably and consistently. It is crucial to integrate these capabilities into a toolset that ensures dependable access to the data of interest. Furthermore, there is a need to establish connections between traditional 2-D methodologies and emerging 3-D analysis techniques.

Keywords: Analysis, Imaging, Radiographs, 3-D Cephalometrics.

Address of Corresponding Author

Suchita Talmale; Department of Orthodontics and Dentofacial Orthopaedics, Nims Dental College and Hospital, Jaipur, Rajasthan, India.

E-mail: suchitatalmale47@gmail.com

Crossref Doi: https://doi.org/10.36437/irmhs.2024.7.3.D

Introduction

Radiographic cephalometry was initially introduced by Broadbent and Hofrath in 1931. This method evaluates both soft and hard tissues of the craniofacial anatomy by measuring X-ray images of the skull, offering more precise diagnostics compared to assessments based solely on facial anatomy.[11] However, traditional X-ray images of the craniofacial complex suffer from inherent limitations such as superposition, distortion, and magnification[12], which can compromise diagnostic accuracy. Three-dimensional (3D) imaging technology addresses these shortcomings of two-dimensional (2D) imaging by providing detailed anatomical information, thereby enabling more accurate diagnoses and achieving satisfactory clinical outcomes. Initially, computed tomography (CT) was employed for obtaining 3D images, but its use in orthodontic practice has been restricted due to cost, high radiation exposure, and relatively low resolution.[13] Conventional cephalometry has traditionally been a fundamental tool for diagnosing maxillofacial deformities and orthodontic issues, as well as for assessing growth and treatment outcomes. With the advent of cone beam CT (CBCT) technology, its popularity has surged due to its ability to provide realistic 3D representations of patients' heads, significantly enhancing diagnostic capabilities. This advancement allows for detailed 3D simulations of surgical and orthodontic procedures.[14]

History: The term "3D cephalometric analysis" has historically referred to approaches in craniofacial literature where the analysis was based on lateral, frontal, and transverse planes derived from 2D X-rays, such as in Grayson's three-dimensional cephalograms.[2] Swennen et al[3] proposed a modification involving the combination of a 3D CT surface model of a skull with two orthogonal 2D radiographic cephalograms. Classical 2D landmarks are identified on lateral and frontal cephalograms, while traditional planes, such as the sagittal plane based on nasion, sella, and basion cranial landmarks, can be constructed. In the 3D cephalometric analysis by Swennen et al.[3], measurements between landmarks on 2D cephalograms are calculated, indicating that this analysis is dimensional rather than topological in nature. Treil et al.[4] further advanced 3D cephalometric analysis.

Difference between 2D and 3D: Cephalometric analysis is a critical tool in orthodontic and cranio-maxillofacial surgery diagnoses. Two-dimensional cephalometric measurements derived from lateral and/or frontal cephalograms have been extensively researched across various ethnic groups[5-6], including Thai individuals.[7] However, 2D cephalometry presents certain drawbacks since it projects 3D structures onto a 2D image. These limitations include non-uniform enlargement and distortion of lateral structures, challenges in accurately locating landmarks due to overlapping structures, and discrepancies where landmarks visible in lateral views may not be discernible in frontal images, and vice versa. Incorrect head positioning can further lead to diagnostic errors.

Additionally, assuming symmetry by averaging measurements of left and right structures in 2D cephalometry does not reflect reality, as demonstrated by Kwon.[8] Olszewski et al. have shown that 3D analysis yields comparable diagnostic outcomes to 2D analysis using the same skull[9], while Adam et al. have highlighted the superior precision of 3D methods, which are approximately 4-5 times more accurate than their 2D counterparts.[10] However, the adoption of 3D cephalometric analysis remains limited.

For specific patient cases, such as those with craniofacial anomalies, orofacial clefts, or requiring orthognathic treatment, conventional cephalograms are no longer considered the most suitable diagnostic method. Despite CBCT scans generally having lower radiation doses compared to multi-slice CT (MSCT) scans, they are not typically recommended for routine orthodontic patients due to the necessity for devices with a large field of view to capture the entire skull height. Consequently, the radiation doses can range from 3 to 44 times higher than those from panoramic examinations, depending on the CBCT device used.

To the best of the authors' knowledge, there are no studies examining the interchangeability of measurements between cephalometric radiographs and 3D measurements on models constructed from CBCT scans. OLSZEWSKI et al. reported on cephalometric measurements using 3D models derived from MSCT scans. MSCT offers very high image quality but comes with a radiation dose about ten times higher than CBCT. The image quality of CBCT, especially for soft tissues, is notably lower compared to MSCT.

Facial asymmetry is frequently observed in patients with craniofacial deformities. Traditionally, lateral and coronal cephalometric radiographs have been the primary methods to analyze the morphology of craniofacial bones. However, due to overlapping anatomical structures, these images often provide limited, if any, three-dimensional assessment of facial asymmetry.[12]

The introduction of spiral/helical computed tomography (CT) scanners has revolutionized clinical practice with the adoption of three-dimensional CT (3D-CT) imaging for diagnosing and planning surgical treatments in patients with craniofacial deformities. This technology allows clinicians to visualize craniofacial bones from multiple angles and interactively manipulate 3D images swiftly. Despite the advantages of 3D-CT imaging, its use for 3D image-based measurements in orthognathic surgery or orthodontic treatment remains relatively uncommon. The implementation of such measurements requires a high degree of accuracy, which has been rigorously investigated and confirmed for 3D-CT.[1]

Facial asymmetry is a common occurrence among patients with craniofacial deformities. Traditionally, lateral and coronal cephalometric radiographs have been the mainstays for assessing the morphology of craniofacial bones. However, these methods often fall short in providing a comprehensive three-dimensional evaluation of facial asymmetry due to the overlapping nature of anatomical structures. The advent of spiral/helical computed tomography (CT) scanners has transformed clinical practice by introducing three-dimensional CT (3D-CT) imaging for diagnosing and planning surgical interventions in patients with craniofacial deformities. This technology enables clinicians to view craniofacial bones from various perspectives and manipulate 3D images interactively and swiftly.

Despite the advantages of 3D-CT imaging, its application for 3D image-based measurements in orthognathic surgery or orthodontic treatment remains relatively uncommon. Achieving accurate measurements in these contexts necessitates a high level of precision, which has been extensively studied and validated for 3D-CT imaging.

Errors in 3 D Cephalometrics: These two types of errors, projection, and identification, highlight the challenges involved in accurately interpreting cephalometric radiographs and underscore the importance of careful technique and interpretation in clinical practice and research.

There are two main categories of errors associated with cephalometric analysis—projection errors and identification errors.

1. **Projection Errors:** Projection errors stem from the fact that headfilms, which are 2-dimensional representations, cannot fully capture the intricacies of the 3-dimensional object they depict. X-ray beams, originating from a small source and not parallel, lead to radiographs that are imperfect enlargements influenced by the distances between the X-ray source, the object being imaged, and the film itself. This can result in bilateral structures that are not aligned with the midsagittal plane appearing as dual images on the radiograph. In symmetric heads, these structures do not perfectly align due to the divergence caused by the fan-like spread of the X-ray beam through the head. Additionally, errors can arise from misalignment of the cephalostat or rotation of the patient's head during imaging, further contributing to projection errors.
2. **Identification Errors:** Identification errors involve inaccuracies in precisely identifying specific landmarks on the headfilms and are widely recognized as significant sources of error in cephalometry. Several factors contribute to these identification errors, including the quality of the radiographic image itself, the clarity and consistency in defining landmark points, and the reproducibility of landmark identification across different observers or imaging sessions.

These two types of errors, projection, and identification, highlight the challenges involved in accurately interpreting cephalometric radiographs and underscore the importance of careful technique and interpretation in clinical practice and research.

Conclusion

CBCT offers significant advantages for the aforementioned patient groups. Studies have indicated that CBCT scans, despite not being as established as conventional cephalometric radiographs (often regarded as the 'gold standard'), can provide comparable diagnostic information when carefully interpreted and utilized.16-17 CBCT scans can be used for longitudinal research. However, both conventional and constructed cephalograms provide a 2D representation of 3D structures, thereby losing the 3D characteristics. As new 3D technology gains popularity and the availability of software programs for analyzing 3D data increases rapidly, the next evolution in cephalometry is moving towards 3D cephalometry using radiographic models of patients' skulls. It is crucial to determine whether classic cephalometry, which has been performed since the early 1930s using 2D cephalometric radiographs, yields comparable measurements to those obtained from 3D constructed models of the patient's skull. For longitudinal studies on growth or treatment outcomes, understanding whether data from past 2D cephalometric analyses can be compared with data from future 3D cephalometric analyses is paramount.

References

1. Reychler A (1990) Notions d'orthopédie dento-maxilo-faciale. In: Piette E, Reychler H (eds) Traité de pathologies buccale et maxillo-faciale. De Boeck Université, Bruxelles, pp 1659–1668.
2. Grayson BH, Cutting C, Bookstein FL, Kim H, McCarthy JG (1988) The three-dimensional cephalograms: theory, technique, and clinical application. Am J Orthod Dentofac Orthop 94:327–337; doi: https://doi.org/10.1016/0889-5406(88)90058-3
3. Swennen GJ, Schuytser FA, Hausamen JE (eds) (2005) Three-dimensional cephalometry: a color atlas and manual. Springer, Berlin; doi: http://dx.doi.org/10.1007/3-540-29011-7
4. Treil J, Casteigt J, Borianne P, Madrid C, Jaeger M, De Bonnecaze P (1999) L'équilibre architectural de la face: un concept céphalométrique 3D. Rev Stomatol Chir Maxillofac 100:111–22. https://pubmed.ncbi.nlm.nih.gov/10522322/
5. Moldez M. A., Sato K., Sugawara J. et al. (2006) Linear and Angular Filipino Cephalometric Norms According to Age and Sex. Angle Orthod 76:800-805; doi: https://doi.org/10.1043/0003-3219(2006)076[0800:laafcn]2.0.co;2
6. Hamdan A.. M., Rock W.P. (2001) Cephalometric Norms in an Arabic Population. J Orthod 28:297-300; doi: https://doi.org/10.1093/ortho/28.4.297
7. Dechkunakron S., Chaiwat J., Sawaengkit P. et al. (1994) Thai Adult Norms in Various Lateral Cephalometric Analysis. J. Dent. Assoc. Thai, 44:202-214 4.
8. A Comparison of craniofacial morphology in patients with and without facial asymmetry a three-dimensional analysis with computed tomography. Int J Oral Maxillofac Surg 35:43-8, doi: https://doi.org/10.1016/j.ijom.2005.04.006
9. Olszewski, R., Cosnard, G., Macq, B. et al. 3D CT-based cephalometric analysis: 3D cephalometric theoretical concept and software. Neuroradiology 48, 853–862 (2006). https://doi.org/10.1007/s00234-006-0140-x
10. Adams G., Gansky S., Miller A. et al. (2004) Comparison between traditional 2-dimensional cephalometry and a 3-dimensional approach on human dry

skulls. Am J Orthod Dent Orthop 126:397-409; doi: https://doi.org/10.1016/j.ajodo.2004.03.023
11. Broadbent BH. A new X-ray technique and its application to orthodontia. Angle Orthod 1931;1:45–66. https://www.scienceopen.com/document?vid=8c188ea3-8833-41ee-9b68-1384f1c706cb
12. Kumar V, Ludlow J, Mol A, Cevidanes L. Comparison of conventional and cone beam CT synthesized cephalograms. Dentomaxillofac Rad 2007;36:263–9. doi: https://doi.org/10.1259/dmfr/98032356
13. Williams FLE, Richtsmeier JT. Comparison of mandibular landmarks from computed tomography and 3D digitizer data. Clin Anat 2003;16:494–500; doi: https://doi.org/10.1002/ca.10095
14. Swennen GR, Schutyser F. Three dimensional virtual approach to diagnosis and treatment planning of maxillo-facial deformity. In: Bell W, ed: Distraction Osteogenesis of the Facial Skeleton. Hamilton: BC Decker Inc 2007.
15. JB Ludlow, LE Davies-Ludlow, SL Brooks, WB Howerton, Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT, Dentomaxillofacial Radiology, Volume 35, Issue 4, 1 July 2006, Pages 219–226, doi; https://doi.org/10.1259/dmfr/14340323
16. Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol, Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2008 Jul;106(1):106-14. doi: https://doi.org/10.1016/j.tripleo.2008.03.018
17. Olszewski R, Zech F, Cosnard G, Nicolas V, Macq B, Reychler H. Three-dimensional computed tomography cephalometric craniofacial analysis: experimental validation in vitro. Int J Oral Maxillofac Surg 2007: 36: 828–833. doi; https://doi.org/10.1016/j.ijom.2007.05.022

How to cite this Article: Talmale. S, Rai. D, Jhakar. A, Verma. M, Saude. T, Sharma. M; "Dimensional Perspectives: A Comprehensive Review of 3D Cephalometrics"; Int. Res. Med. Health Sci., 2024; (7-3): 34-38; doi: https://doi.org/10.36437/irmhs.2024.7.3.D
Source of Support: Nil, **Conflict of Interest:** None declared.
Received: 16-5-2024; **Revision:** 14-7-2024; **Accepted:** 23-7-2024