ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)
IJDSIR : Dental Publication Service
Available Online at: www.ijdsir.com
Volume – 5, Issue – 3, June - 2022, Page No. : 457 - 464

The Evolution of Orthodontic Superimpositions from 2-D to 3-D - A Review

[1]Dr. Akanksha Goel, MDS Student Bharati Vidyapeeth Dental College and hospital, deemed to be university, Pune.

[2]Dr. Vinit Swami, Professor Bharati Vidyapeeth Dental College and hospital, deemed to be university, Pune.

[3]Dr. Vasanthi Swami, Assistant Professor Bharati Vidyapeeth Dental College and hospital, deemed to be university, Pune.

Corresponding Author: Dr. Akanksha Goel, MDS Student Bharati Vidyapeeth Dental College and hospital, deemed to be university, Pune.

Citation of this Article: Dr. Akanksha Goel, Dr. Vinit Swami, Dr. Vasanthi Swami, "The Evolution of Orthodontic Superimpositions from 2-D to 3-D - A Review", IJDSIR- June - 2022, Vol. – 5, Issue - 3, P. No. 457 – 464.

Type of Publication: Review Article

Conflicts of Interest: Nil

Abstract

Orthodontic super impositions are widely used in assessing the growth and treatment related changes in skeletal, dental and soft tissues. Till date various methods have been evolved, starting from cephalometric super imposition to digitalised 3-D model super impositions but still cephalometric super impositions remain as the gold standard for assessing and predicting the changes, though a lot of advancement has taken place in terms of the techniques used for super impositions. The aim of this review article is to present a comprehensive data on various techniques used for super impositions in orthodontics and how the paradigm shift has taken place over the years from 2D to 3D.

Keywords: Super impositions, Cephalometry, 3D imaging, 3D Models.

Conclusion

Super imposition techniques have evolved to a huge extent since last decade and thus familiarizing with them becomes important for a clinician.

Introduction

With the advent of Cephalometry by Broadbent[1] in 1931, its applications increased tremendously in various field of dentistry, including orthodontics. This tool has now been adopted by many clinicians, both practically and for research purposes, on a day-to-day basis to analyse and detect underlying dentofacial relationships.

Cephalometric superimposition, which is an analysis of lateral cephalograms of the same patient taken at different times, is one of the various ways of using cephalometry as a tool in assessing the dentofacial and skeletal changes occurring due to the normal craniofacial growth or as a result of changes caused by orthodontic, orthopaedic and surgical treatment. But cephalometric superimpositions offer several disadvantages like, errors generated because of inadequate patient head position, alignment of the imaging device, inherent geometric distortions, and differential magnification created by projection distance and beam divergence. [29] To overcome these inherent flaws of 2D cephalometric super impositions, various other methods of super impositions have been developed apart from cephalometric super impositions, like, 3D cephalometric super imposition, CBCT super imposition, Digital photographs super imposition and even 3D digital model super impositions. Also, the orthodontic practices are now moving towards a paperless environment especially for records storage [30] and using a 3D method of super imposition aids in achieving this goal.

The aim of this article is to put forward the recent techniques that have evolved for the clinicians to assess the growth and treatment outcomes.

Methods of cephalometric superimposition

The early traditional method was a bidimensional (2D) evaluation based on the comparison of linear and angular measurements on serial super impositions from cephalograms that have been taken at different times to evaluate the effect of growth or treatment. In this respect, tracings of the head films must be super imposed on relatively stable landmarks least affected by the growth, in order to be accurate and reproducible. [2]

According to Broadbent et al (1975), when tracing serial films, one may start with the youngest pair and follow the child towards maturity, or start at the most mature stage and work backwards. It is of great importance that exactly the same structures and their corresponding radiographic shadows be traced in the consecutive cephalograms that are to be evaluated. In order to facilitate identification of consecutive cephalograms the following colour code has been suggested by the American Board of Orthodontists [3] (1990):

- Pre-Treatment - Black
- Progress- Blue
- End Of Treatment – Red
- Retention - Green.

Over the time, several methods of superimposing cephalograms have been developed (e.g., Broadbent, 1931; Decoster, 1953; Steiner, 1953; Bjork, 1963; Ricketts, 1975; Bjork and Skieller, 1977; Pancherz, 1982; Johnston, 1986) depending on the different points or planes used for superimposing. Table 1 shows a brief description of the 2D techniques of cephalometric superimpositions.

Superimposition technique	Reference landmark	Method
Broadbent Technique [4] (1931)	N-S-Bo	A triangle is constructed from Na-S-Bo and the centre of the triangle is marked as R point on which the serial cephalogram is superimposed.
Brodie's Technique [5] (1941)	Se-N	Superimposition is made on sella-nasion plane with the registration at S point.
Decoster Technique [6] (1953)	Anterior contour of the cranial base	The superimpositions are made on the bony anatomy of the anterior contour of the cranial base i.e., the anterior half of the Sella turcica to the foramen caecum and the internal outline of the frontal bone.
Coben's Technique [7,8] (1955)	Basion horizontal	The Basion Horizontal is a plane constructed at the level of the anterior border of the foramen magnum parallel to Frankfort horizontal. According to Coben, the relationships among the

		position of the head in normal posture, the visual axis of the eyes, and the anterior cranial base do not change. As a result, serial tracings should be registered at Basion and oriented with the S-N planes parallel
Rickett's Technique [9] (1979) FOUR POINTS METHOD BY RICKETTS [14]	Basion-Nasion Plane Corpus axis Palatal Plane Basion-Nasion Plane	The superimposition area is the Ba-Na line with registration at CC point (the point where the basion-nasion plane and the facial axis intersect). It is possible to evaluate changes in the facial axis (BA-CC-GN), in the direction of chin growth, and in the upper molar position using this plane of reference. For maxillary skeletal changes, superimposition is made on Ba-N plane registered at N whereas for dental changes, palatal plane (PP) from ANS to PNS is used registered at ANS. For mandibular skeletal changes, superimposition is made on Ba-N plane registered at Pt point and for dental changes, superimposition is made on corpus axis (Xi-Pm) registered at Pm.
Structural method	Anterior contour of zygomatic process	The anterior contour of zygomatic arch is traced and a line tangential to it is drawn which is the construction line. The superimpositions are made on this construction line to evaluate the changes in maxillary rotation.
Modified best fit method	Palatal plane/ nasal floor	The maxillary structures like palate, the first permanent molars, the entrance of the incisal canal (when it can be visualized), and the most labially positioned central incisor are traced. Then the serial cephalogram is superimposed with best fit alignment on the contour of the palate, the nasal floor or the entrance of incisal canal.
Bjork's method [11,12,13]	Implant line	For assessing maxillary skeletal and dental growth, superimposition is made on anterior surface of zygomatic process. For mandibular growth assessment, three stable reference areas have been suggested by Bjork and Skieller – (1) inner cortical structure of inferior border of symphysis, (2) detailed structures of mandibular canal and (3) lower contour of third molar germ before root development begins.
Pancherz method [15,16]	Sella-Nasion	First a reference grid is constructed using occlusal plane (OL) as X-axis and occlusal plane perpendicular (OLP) drawn from

		sella point as Y-axis. Then serial cephalograms are superimposed on S-N at S and maxillary and mandibular skeletal changes are measured from the movement of the representative landmarks along the initial OL plane to Olp. Similarly maxillary and mandibular dental changes are obtained from the movement of the dental landmarks along OL plane to Olp, subtracting the movement of their related skeletal basis.

Table 1: Various 2D techniques of cephalometric superimpositions.

3-Dimensional methods

Craniofacial three-dimensional (3D) digital records have become increasingly popular among orthodontists in the past decade. The specialty has progressed towards a 3D virtual representation of the patient for diagnosis, treatment planning, and surgical simulation. Recently, along the lines of 2D cephalometric tracings, CBCT images can be superimposed, allowing a 3D evaluation of growth changes, treatment effects, and stability over a certain time interval through registration points, angles, shapes, and volumes.

In the case of most software programs, a clinician is responsible for the initial alignment of the landmarks or anatomic structures of the two images which are to be superimposed, following which a computer software measures the changes in other anatomic structures relative to the registered points or structures. Changes that have resulted from growth or treatment are seen in the final superimposed images.

The various methods in which 3D images can be superimposed are voxel-based, landmark-based and surface-based registrations.

Landmark based method

The standard to evaluate changes occurring between two time points due to treatment or growth has long been super imposition of conventional cephalometric radiographs based on stable anatomic landmarks (landmark super imposition). In this landmark-based method, as reported by McCance et al. in 1992. [31] 3D CBCT images can be superimposed with the help of manual registration of homologous landmarks or through best fit of stable anatomic regions.

Surface based method

The Surface-Based Registration (SBR) method is the first method described in the literature for superimposition of 3D datasets. Hajeer et al. proposed this method which helped study the facial asymmetry before and after orthognathic surgery. [18]

This technique deals with the surface mesh of the 3D structure and uses an ICP (Iterative Closest Point) algorithm. It is also called “best fit” algorithm given that the ICP algorithm minimizes the surface distance between the two surfaces which previously was manually approximated. SBR minimizes the mean square distance between the models’ mesh points to calculate an estimation of the optimal rotational and translational movements between the surface of 3D models.

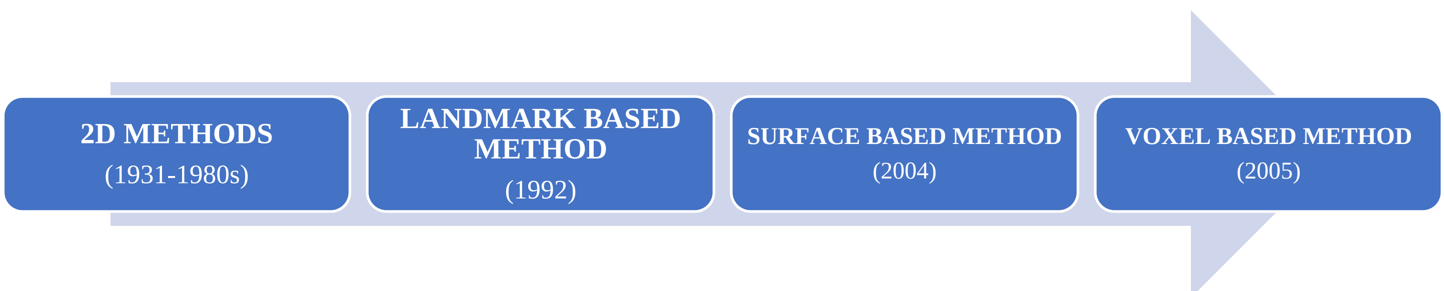
Voxel-based method

This method was introduced by Cevidanes et. al. It involves the matching between the grayscale values of the voxels within the selected Volume of Interest (VOI) of two or more volumetric datasets (i.e., CBCT and CT).

Unlike landmark-based and surface-based registration, this method does not depend on the accuracy of landmark identification or on errors in the surface segmentation process. This is one of the most important advantages of this technique. Here, a completely automated registration method helps in avoiding any observer-dependent errors. Currently, there are two software applications available for performing voxel-based registration, namely Dolphin and Slicer 3D, both of which have shown both high accuracy as well as reliability. [10,17,32]

According to the studies which compare these methods of 3D superimpositions, the landmark-based method is considered to be the least reliable method as it requires manual landmark selection by the operator in addition to the lack of precise definition of 3D coordinates of cephalometric landmarks. On the other hand, surface-based and voxel-based superimposition methods using the anterior cranial base as a reference structure are considered to be more accurate and reliable in detecting changes in landmark positions when superimposing. [19] Figure 1 displays the gradual change in era of superimpositions from the conventional 2D techniques to modern 3D techniques.

Figure 1: Flow chart depicting gradual change in superimposition techniques.



Digital model superimposition

The typical three-dimensional (3D) patient record for monitoring linear changes in the dental arch is the dental cast. Orthodontic tooth movement by means of pre- and post-treatment dental casts have been evaluated by various studied. [20] The use of 3-dimensional (3D) digital models of dental casts for diagnosis and treatment planning has been researched for since the emergence of 3D technologies [21]. Additionally, 3D superimposition of dental casts can now be used to assess tooth movements [22].

Stable anatomical structures are necessary as references in any superimposition. The palatal rugae were employed as reference landmarks even for the earliest attempts to superimpose 3D models because the medial points of the third palatal rugae were shown to be stable enough in untreated individuals and in patients treated with premolar extractions and *en masse* retraction [23].

Initially, a crude alignment was achieved by manually selecting a few corresponding locations. 'Raw Matching' or 'Coarse Matching' was the term used [24]. Although most orthodontic treatment planning and analysis software products use raw matching, the manual selection and measurement of matchings can be a source of mistake.

Using a best-fit method, the following generation of superimposition approaches employed the palatal vault or sections of it as a reference [25]. This 'fine matching' technique, which is based on 'iterative nearest point algorithms,' uses thousands of reference points instead of a few landmarks (ICP).

Then came a procedure known as deformation analysis, in which all structures with the potential to change or that do not remain stable are screened away, leaving only stable structures for superimposition.

After multiple rounds of testing, it was discovered that a combination of ‘raw matching’, ‘fine matching’, and ‘deformation analysis’ have produced the greatest results. RFD-superimposition is a new method that can manage variations in local point resolution, distinguish outliers from morphological changes, and use a variety of sample size reduction techniques. This approach is tolerant of morphological changes in the palate and provides good precision and accuracy. [26]

Conclusion

Researchers and clinicians have used superimposition of Cephalometric head films to help in orthodontic diagnosis and treatment planning and to obtain a general view of growth changes and treatment outcomes in the Dentofacial complex. Though the conventional 2-D radiographs have been a valuable part of orthodontic diagnosis, they still suffer from several drawbacks. [27,29]

Therefore, during the past decade, craniofacial three-dimensional (3D) digital records gained popularity among orthodontists. Similar to 2D cephalometric tracings, CBCT images can be superimposed, allowing a better evaluation of growth changes in 3D, visualisation of post treatment effects. Another benefit is its ability to register in a stable manner, points, angles, shapes, and volumes over a certain time interval through registration. Studies have shown that methods for 3D superimposition provide an acceptable level of reliability when assessing changes in craniofacial hard tissues [28] and the 3D superimposition methods are more convenient for craniofacial assessment than conventional 2D methods. [28]

Considering the changes and updates that are still being done in the 3D imaging, a clinician must get familiarize with these evolving techniques under use and make help in achieving paperless practice.

References

1. Broadbent BH. A new X-ray technique and its application to orthodontia. Angle Orthod. 1931; 1(2):45-66.

2. Lo Giudice A, Ronsivalle V, Zappalà G, Leonardi R, Campagna P, Isola G, Palazzo G. The Evolution of the Cephalometric Superimposition Techniques from the Beginning to the Digital Era: A Brief Descriptive Review. Int J Dent. 2021;6677133.

3. American Board of Orthodontics. Examination Information Manual. St. Louis, Mo: The Board; 1990: ppA23-A31.

4. Broadbent BH. Bolton standards and technique in orthodontic practice. Angle Orthod. 1937; 7:209-233.

5. Steiners CC. Cephalometrics in clinical practice Angle Orthod. 1959; 29:8-29.

6. de Coster L. The familial line studied by a new line of reference. Trans Eur Orthod Soc. 1952; 28:50-55.

7. Coben SE. The integration of facial skeletal variants. Am J Orthod. 1955; 41:407-434.

8. Coben SE. Basion Horizontal: An integrated Concept of Craniofacial Growth and Cephalometric Analysis. 1st ed. University of Michigan: Computer Cephalometrics Associated; 1986: pp 54-63.

9. Ricketts RM, Bench RW, Gugino CF, Hilgers JJ, Schulhof RJ. Bio progressive Therapy. 1st ed. Denver, Colorado: Rocky Mountain Orthodontics; 1979: pp170-182.

10. Han G, Li J, Wang S, Liu Y, Wang X, Zhou Y. *In-vitro* assessment of the accuracy and reliability of mandibular dental model superimposition based on

voxel-based cone-beam computed tomography registration. Korean J Orthod. 2019; 49(2):97-105.

11. Bjork A. Prediction of mandibular growth rotation. Am J Orthod. 1969; 55:585-589.
12. Bjork A. Variations in the growth pattern of the human mandible: longitudinal radiographic study by the implant method. J Dent Res. 1963; 42:400–411.
13. Bjork A, Skieller V. Normal and abnormal growth of the mandible: a synthesis of longitudinal cephalometric implant studies over a period of 25 years. Eur J Orthod. 1983; 5(1):1-46.
14. Ricketts RM. A four-step method to distinguish orthodontic changes from natural growth. J Clin Orthod. 1975; 9(4):208-15, 218-228.
15. Pancherz H, Hansen K. The nasion-sella reference line in cephalometry: a methodologic study. Am J Orthod. 1984; 86(5):427-434.
16. Pancherz H. The Herbst appliance--its biologic effects and clinical use. Am J Orthod. 1985; 87(1):1-20.
17. Cevidanes LH, Bailey LJ, Tucker SF, Styner MA, Mol A, Phillips CL, Profit WR, Turvey T. Three-dimensional cone-beam computed tomography for assessment of mandibular changes after orthognathic surgery. Am J Orthod Dentofac Orthop. 2007; 131(1):44-50.
18. Hajeer MY, Ayoub AF, Millett DT. “Three-dimensional assessment of facial soft-tissue asymmetry before and after orthognathic surgery,” Br J Oral Maxillofac Sur. 2004; 42:396-404.
19. Ghoneima A, Cho H, Farouk K, Kula K. Accuracy and reliability of landmark-based, surface-based and voxel-based 3D cone-beam computed tomography superimposition methods. Orthod Craniofac Res. 2017; 20(4):227-236.
20. Hoggan BR, Sadowsky C. The use of palatal rugae for the assessment of anteroposterior tooth movements. Am J Orthod Dentofac Orthop. 2001; 119:482-488.
21. Motohashi N, Kuroda T. A 3D computer-aided design system applied to diagnosis and treatment planning in orthodontics and orthognathic surgery. Eur J Orthod. 1999; 21:263-274.
22. Cha BK, Lee JY, Jost-Brinkmann PG, Yoshida N. Analysis of tooth movement in extraction cases using three-dimensional reverse engineering technology. Eur J Orthod. 2007; 29:325-331.
23. Bailey LT, Esmailnejad A, Almeida MA. Stability of the palatal rugae as landmarks for analysis of dental casts in extraction and none traction cases. The Angle Orthod. 1996; 66:73–78.
24. Diez Y, Ferran R, Llado X, Salvi J. A qualitative review on 3D coarse registration methods. ACM Computing Surveys. 2015; 45:1–36.
25. Choi DS, Jeong YM, Jang I, Jost-Brinkmann PG, Cha BK. Accuracy and reliability of palatal superimposition of three-dimensional digital models. Angle Orthod. 2010; 80(4):497-503.
26. Ganzer N, Feldmann I, Liv P, Bon demark L. A novel method for superimposition and measurements on maxillary digital 3D models-studies on validity and reliability. Eur J Orthod. 2018; 40(1):45-51.
27. Jacobson A, Sadowsky L. Superimposition of Cephalometric Radiographs. In: Jacobson A, Jacobson R. Radiographic Cephalometry. Chicago, IL: Quintessence; 2006:145–151.
28. Ponce-Garcia C, Lagravere-Vich M, Cevidanes LHS, de Olivera Ruellas AC, Carey J, Flores-Mir C. Reliability of three-dimensional anterior cranial base superimposition methods for assessment of overall hard tissue changes: A systematic review. Angle Orthod. 2018; 88(2):233-245.

29. Adams GL, Gansky SA, Miller AJ. Comparison between traditional 2-dimensional cephalometry and a 3-dimensional approach on human dry skulls. Am J Orthod Dentofac Orthop. 2004; 126:397–409.
30. Hamula W, Hamula DW. Orthodontic office design. The paperless practice. J Clin Orthod. 1998; 32(1):35-43.
31. McCance AM, Moss JP, Wright WR, Linney AD, James DR. A three-dimensional soft tissue analysis of 16 skeletal ClassII patients following bimaxillary surgery. Br J Oral Maxillofac Surg. 1992; 30:221–232.
32. Ruellas ACO, Yatabe MS, Souki BQ, Benavides E, Nguyen T, Luiz RR. 3D Mandibular Superimposition: Comparison of Regions of Reference for Voxel-Based Registration. PLoS ONE. 2016; 11(6): e0157625.