Cephalometric Methods of Prediction in Orthognathic Surgery

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Abstract Over the past decade the growing number of adult patients seeking for orthodontic treatment made orthognathic surgery popular. Surgical and orthodontic techniques have developed to the point where combined orthodontic and surgical treatment is now feasible to manage dentofacial deformity problems very satisfactorily. The prediction of orthognathic treatment outcome is an important part of orthognathic planning and the process of patient's informed consent. The predicted results must be presented to the patients prior to treatment in order to assess the treatment's feasibility, optimize case management and increase patient understanding and acceptance of the recommended treatment. Cephalometrics is a routine part of the diagnosis and treatment planning process and also allows the clinician to evaluate changes following orthognathic surgery. Traditionally cephalometry has been employed manually; nowadays computerized cephalometric systems are very popular. Cephalometric prediction in orthognathic surgery can be done manually or by computers, using several currently available software programs, alone or in combination with video images. Both manual and computerized cephalometric prediction methods are two-dimensional and cannot fully describe three-dimensional phenomena. Today, three-dimensional prediction methods are available, such as three-dimensional computerized tomography (3DCT), 3D magnetic resonance imaging (3DMRI) and surface scan/cone-beam CT. The aim of this article is to present and discuss the different methods of cephalometric prediction of the orthognathic surgery outcome.

Keywords Orthognathic surgery · Orthodontics · Prediction · 2D cephalometry · 3D cephalometry

Introduction

Over the past decade a growing number of adult patients are seeking orthodontic treatment. The advances in orthognathic surgery, computer imaging, rigid internal fixation, and shorter hospital stays, made surgery a realistic option for many patients [1–3]. The skeletal component of the malocclusion of these patients cannot be corrected without orthognathic surgery. The indication for surgical-orthodontic treatment is that a skeletal or dentoalveolar deformity is so severe that the magnitude of the problem lies outside the envelope of possible correction by orthodontics alone [4].

The differential diagnosis process generates a problem list and treatment planning options to discuss with the patient. The selection of the appropriate procedure must be based on the clinician's anticipated objectives with regard to esthetics, function, and stability [5, 6], but also on the patient's objectives, expectations, and perceived needs [7–9]. Important factors in the selection of orthognathic surgical procedures and treatment plan are the stability of the results, the predictability of hard and soft tissue changes to achieve facial balance and the patient's response.

Patient's decision to undergo orthognathic surgery is based on several needs and motives. Improvement in appearance is an important motivation for patients to seek orthognathic treatment [10–13]. Motivation for treatment affecting facial esthetics is related to psychological and social factors. Patients' concern before treatment appears to be self-consciousness regarding their facial body image. Those who choose surgical correction of a dentofacial

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deformity tend to regard their dentofacial deformity as more severe than do those patients with similar problems that have decided against surgical treatment and are undergoing orthodontics only [14]. Major changes in facial appearance appear to be readily integrated into the individual's self-concept. Improvement in appearance is associated with improvement in psychosocial adjustment [15–17]. Quality of life has been found to improve for the patients who underwent surgery because of increased self-esteem and confidence [18–21]. Social and psychological concerns, improved function, appearance, and self-esteem can encourage a patient to pursue surgery. Therefore, is of great importance the patient's understanding of the treatment outcome. The prediction of orthognathic treatment outcome is an important part of orthognathic planning and the process of patient's informed consent. Cephalometric prediction plays an important role in orthognathic surgery by increasing patient understanding and acceptance of the recommended treatment.

Cephalometrics is a routine part of the diagnosis and treatment planning process and also allows the clinician to evaluate changes following orthognathic surgery. Traditionally cephalometry has been employed manually; nowadays computerized cephalometric systems have been developed and used to analyze and predict the outcome of orthognathic surgery. The aim of this article is to present and discuss the different methods of cephalometric prediction of the orthognathic surgery outcome.

Cephalometric Prediction

Cephalometric analysis was done, for decades, by hand. The tracing was performed using acetate paper taped to the radiographs. Currently, there are three methods for cephalometric analysis: hand tracing and direct measurement of the desired angles and distances with the use of a protractor and ruler, and direct and indirect computer digitization of the radiograph. For direct computer digitization the anatomical points are entered from the cephalometric radiograph into computer memory using an electronic pen or the crosshair cursor. For indirect digitization, a scanner or a video camera captures an image of the radiograph and stores it in the computer. The video camera is calibrated with the cephalometric radiograph. Another method of cephalometric film entry into the computer and analysis is the use of digital radiology. Computerized cephalometric analysis is rapid and the clinician can run as many analyses as the computer program allows to arrive at a diagnosis [22].

Cephalometric prediction in orthognathic surgery can be performed, as well, manually or by computer. Several methods of prediction have been suggested.

Manual Methods

Traditionally, acetate tracings have been used for cephalometric determination of the movement of hard tissue and the prediction of the response of the soft tissue to those movements. Historically, the first method to determine the amount of posterior movement of the mandible needed to produce satisfactory facial esthetics following mandibular surgery was described by Cohen [23]. A tracing of the maxilla, maxillary teeth, mandible, mandibular teeth, and soft tissue profile was made from the original cephalogram. A divider was used to record the posterior movement of the mandible. A regional tracing of the lower face alone including only the mandible and mandibular teeth as well as the soft tissue outline of the upper throat, chin, and lower lip was made and cut-out. This cut-out section was moved distally along the plane of occlusion following the amount of posterior movement of the mandible recorded with the divider. The soft tissue changes were then inspected. The cut-out section is outlined in a different color than the original tracing and thus it was easier to visualize the soft tissue changes.

Another cephalometric prediction technique for the soft tissue profile after surgical repositioning of the mandible has been proposed by McNeill et al. [24] including the following steps: (a) Use of dental casts to establish the tentative post-treatment dental relationship. This could be done easily by using an articulator on which the casts could be mounted. Sometimes a diagnostic set-up before repositioning of the casts was necessary. (b) Construction of an overlay cephalometric tracing that included the outlines of the hard and soft tissues, which would not be affected during treatment. (c) Sliding of the overlay tracing until the parts that are to be changed in the treatment, duplicate their desired position as shown on the pre oriented casts. Molar and incisor relationships on the casts serve as guides for correct overlay positioning. The preferable skeletal relationship is traced in a different color, on the overlay. (d) Completion of the prediction tracing by adding soft tissue profile outlines. According to this technique lip thickness will vary inversely with changes in facial vertical dimension and soft tissue chin thickness will not be affected by treatment.

Henderson [25] has introduced a method that differs slightly from all previously described procedures. This author combined the patient's cephalometric tracing with a profile photographic transparency of 1:1 ratio of magnification. The assessment of the effect of different osteotomies on the profile was made by sectioning the transparency along the projected osteotomy lines. This method offered an advantage because it allowed the patient to view and understand a graphic image of the predicted outcome.

In the prediction method of Worms et al. [26], important guidelines in the planning procedures were Cutcliffe's unpublished data for soft tissue vertical proportions, incisor position in relation to the jaw bases and the high correlation between the movement of soft tissue and hard tissue pogonion.

A photo cephalometric technique for the prediction and evaluation of skeletal and soft tissue changes following dentofacial and craniofacial surgery was advocated by Hohl et al. [27]. Lateral and frontal cephalograms and photographs were taken. Photographic negatives were enlarged allowing the photographic images to be superimposed upon the radiopaque images on the cephalograms. Transparent photographs were produced from the projection of the enlarged negatives that can be superimposed over the cephalometric films. By drawing the line from nasion to pogonion onto the photograph, soft tissue measurements could be made directly in vertical and horizontal directions. This technique allowed detailed soft tissue analysis in the lateral projection that was difficult to obtain by standard cephalometric techniques.

Another method of surgical-orthodontic cephalometric soft tissue prediction tracing for mandibular advancement, maxillary superior repositioning and combined maxillary and mandibular surgery was proposed by Fish and Epker [28]. Their method was adapted in part from Ricketts' cephalometric analysis, growth prediction and visual treatment objective construction as presented by Bench et al. [29]. The Frankfort horizontal and a perpendicular line from nasion were drawn to indicate the optimum facial depth as a guide to begin the prediction for either mandibular advancement or set-back surgery. The teeth were placed as described by Bench et al. [30]. The change in lower incisor position was found and marked by superimposing the mandible on corpus axis at pterygo-maxilla fissure. The prediction tracing for maxillary superior repositioning, auto-rotates the mandible clockwise around the condyle.

Moshiri et al. [31] reported on the construction of the VTO (visual treatment objectives) prediction tracings for anterior maxillary osteotomy, mandibular sub apical osteotomy, combined anterior maxillary, and mandibular sub apical osteotomy, total maxillary advancement, craniofacial dysostosis, mandibular advancement, mandibular setback, asymmetrical case, and combination of two jaw surgery. Lateral cephalograms with the lips at rest were taken and four tracings were made for each case: the initial tracing, the VTO prediction tracing, the superimposition of the surgical template on the initial tracing and, the final result. Soft tissue responses were predicted for all types of surgery, except for two jaw surgery, using data from Harris [32].

In the middle 1980s a systematic approach for prediction tracings was developed by Wolford et al. [33] which

combined the manipulation of hard tissue elements and the generation of consistent soft tissue predictions ratios in a manageable format. In their textbook, hard tissue and soft tissue interplay ratios are presented and integrated with the template method for various types of osteotomies.

The use of cephalometric prediction to forecast changes in bony relationships and associated soft tissue changes has been also systematically advocated by Proffit [34]. According to the author, cephalometric prediction can be done manually by moving templates or by repositioning an overlay tracing of the patient's cephalogram.

The template method should be used in any case where vertical maxillary surgical movement is planned and it is very useful when large dental movements are planned, as well as in chin repositioning. It is not widely used because it is time-consuming. Typically, this method is used in maxillary osteotomies and in double surgeries (bi-maxillary surgery). In one- or two-piece osteotomies, the entire maxilla outline is drawn. In three-piece osteotomies, the outlines of anterior and posterior maxillary pieces, as well as two mandibular outlines (extraction and non extraction) are drawn. During the prediction course, the mandible rotates around the condyle.

The overlay method is the simplest prediction method for mandibular osteotomies. Its use is limited to surgeries that do not affect vertical maxillary position and the method is not time consuming. For this method there is no need for intermediate tracings. Steps to be followed by using the overlay method are: (a) The initial cephalogram is traced and the surgical reference line is drawn. (b) All structures that will not be affected by the mandibular osteotomy are traced on a second paper placed over the original pre-surgical tracing, so called the overlay tracing. (c) The overlay tracing is held stable and the underlying pre-surgical tracing is moved backwards until desired overjet, overbite and proper occlusion are achieved. The mandible and lower teeth as well as the surgical reference line are drawn. (d) The two tracings are superimposed on the cranial base and the distance of mandibular incisor backward movement is measured in mm. Data regarding ratios of soft tissue changes relative to respective skeletal movements is used to estimate the predicted lower lip position relative to surgical incisor movement. The distance between surgical references line will be measured to determine the surgical movement in mm. (e) Tracings are superimposed on the mandible and lower lip outline and soft tissue chin are drawn. (f) Superimposition on the cranial base and completion of predicted soft tissue profile by using the data from Jensen et al. [35].

Wolford and Proffit have presented the most systematic approaches for prediction tracings. In these prediction methods the cephalogram is obtained, in natural head position, teeth at maximum intercuspation and with the

patient's lips in repose. VTO are important predictive tools to visualize and predict orthognathic treatment changes before, during and at the end of treatment [36].

However, acetate tracings are of lesser value for visualization of the profile outcome. The final esthetic outcome is heavily dependent on the experience and the artistic skill of the clinician who makes the treatment plan [37]. Moreover, the manual methods of cephalometric prediction of the orthognathic outcome are time consuming [38].

Computerized Methods

Prediction of the orthognathic surgery outcome can also be done by computer, using various available software programs, alone or in combination with video images.

Computerized Cephalometric Methods

Historically the first computer program designed by Bhatia and Sowray [39] to aid diagnosis and treatment planning in orthognathic surgery and prediction of postoperative soft tissue profile. The general software could collect, store and analyze graphic data such as radiographs of the skull and photographs of the face and dentition. The operator manipulated graphics to attempt different possible surgical procedures and was able to produce different predicted profiles. To predict soft tissue changes, the program first produced a bodily movement of the soft tissues corresponding to the hard tissue movement and then produced a change in the soft tissue shape. For the upper and lower lip, data from Engel et al. [40] were used for the prediction of soft tissue profile in cases of maxillary surgery.

Later, Harradine and Burnie [41] described a computer program that was capable of providing the user with superimposition tracings in order to visualize where and how much the patient deviates from "Bolton's standard" and with quantitative measurement of the hard and soft tissue changes for comparison. Prediction could be carried out after the user selects the surgical procedure and enters the required vertical and horizontal dimensions of change. Soft tissue change predictions were performed automatically using hard to soft tissue ratios.

Another computerized program for the planning of maxillofacial osteotomy and its applications was developed by Walters and Walters [42]. A suggested operation was generated spontaneously by the computer. The computer then adjusted the position of the soft tissue according to the degree of the bone movements as suggested by Freihofer [43] and produced the predicted soft tissue profile. The surgeon or the patient had the option to accept or reject the suggestion of the computer in part or whole by altering the esthetic prediction generated by the computer.

Currently there is a wide variety of computerized cephalometric software systems for orthognathic surgery prediction. Quick Ceph was the first commercially available software for orthognathic surgery prediction. The Quick Ceph Image (Quick Ceph Systems, San Diego, California) it is designed for Macintosh computers. It permits a wide range of functions based on a 28-point digitization. When orthodontic and surgical movements are simulated, horizontal and vertical changes are recorded by the computer. The soft tissue adjusts automatically according to predetermined ratios. The majority of these ratios are derived from Wolford et al. [33, 38]. Recently, the release of the latest version (Quick Ceph2000) incorporated many advantages, including capture and storage of high resolution images, treatment simulations, growth forecasts, compatibility with any operating system and digital image enhancement of tracing accuracy [44].

The dentofacial planner is a product of Dentofacial Software Inc. (Toronto, Canada). It has been designed for IBM-compatible computers. The program is capable to perform a variety of cephalometric analyses including Steiner, Downs, McNamara, Ricketts, Grummons, Harvold, Legan, and Jarabak. It is also capable to perform CO–CR conversions, to estimate facial growth, simulate any combination of orthognathic surgery procedures including one piece or segmental maxillary surgery, mandibular advancement or setback, total or anterior mandibular sub apical surgery and chin surgery. When a surgical movement is manipulated, vertical and horizontal changes are calculated by the computer. The soft tissue profile is automatically displayed after each treatment planning manipulation, according to predetermined ratios [45, 46].

Vistadent (GAC International, Birmingham, AL) it has been developed by GAC TechnoCenter. It is an orthognathic surgical program that uses Ricketts, VTO for treatment simulations. It is compatible with all digital X-ray systems and digital cameras.

Orthodontic treatment planner (OTP) (Pacific Coast Software, Inc., Wayzata, MN) is a surgical prediction program distributed by ortho-vision technologies.

Orthognathic prediction analysis (OPAL) is software that enables simulation of surgical jaw movements and dental decompensation and illustrates these changes in terms of quantitative values. Using established hard to soft tissues ratios predicts the post-treatment soft tissue profile. OPAL software is widely use in United Kingdom [47].

Dolphin imaging software (Dolphin Imaging and Management Solutions, Chatsworth, CA) is another popular software orthognathic surgical program, presently commercially available. The version 8.0 software involves the indirect digitization of multiple dental, skeletal and soft tissue landmarks of the scanned cephalogram, using a mouse-controlled cursor. An aid in landmark location is the

capability of the image to be enhanced and enlarged. The program can also demonstrate landmarks expected position, thereby minimizing errors in landmark definition. The software links up the points to give a trace image, which can be manually manipulated for improved fit. The user can then select the analysis of choice [48].

Various computer software programs allow the orthodontists and oral surgeons to rapidly manipulate digital representations of hard and soft tissue profile tracings and subsequently morph the pretreatment profile to produce a predicted treatment simulation. Prediction of the patient's soft tissue profile is performed by the program automatically using selected hard to soft tissue ratios [49].

Video Imaging

More recently, the introduction of computer software programs with video imaging by Sarver et al. [50], surgery has greatly facilitated and improved the communication of the final predicted esthetic outcome and allowed the clinician to rapidly analyze, plan, perform the simulated surgery.

Orthographic software was first used in the mid 1980s. With this software an image of known size was captured and then calibrates the imaging software so that the computer was capable of internal software measurement of image on the screen in real size. However, direct visualization of the bony structures in coordination with soft tissue profile was not easily accomplished [50]. Another method of video imaging technology used computer graphics and video camera, output the patient's profile on a personal computer display as an analog or/and of a digital image [51]. The patient's video image was superimposed over the soft tissue line of a digitized cephalogram. Then, every part of the digitized video image could be modified according to average ratios of the hard and soft tissue changes based on reported data. The image produced allows the patient to visualize the postoperative facial appearance and permits the orthodontist to select the optimal mode of treatment.

The use of true vision image processing system (TIPS) and orthographic software in the superimposition of the lateral cephalometric tracing or cephalogram over a profile image as an aid of planning and predicting the orthognathic surgery outcome was further evaluated [52]. The main advantages of the systems were found to be the capability of the software to overlay images, the calibration of the images on the computer screen to actual dimensions and the quantification in x and y axis of the movement of defined areas. The last two advantages allow the clinician to relate the video graphic treatment goals to a directly numerical surgical plan and the patient to better visualize the predicted aesthetic result.

Another computer software program with video imaging was used by Grubb [53]. Preselected skeletal and soft tissue

landmarks were digitized and then anatomic areas were traced. If desirable, an occlusogram could be created by digitizing the photocopy of the occlusal view of each dental arch. After cephalometric and study cast data were entered into the system, a variety of analyses and treatment options could be selected and simulated. To simulate anatomic structures, electronic templates were created. Orthognathic surgical treatment planning was based on diagnostic set-up and surgical cephalometric prediction tracings.

In the treatment planning process with video imaging, calibration of the patient's cephalogram to the patient's profile video image is automatically accomplished by the computer. The purposes of calibrating the cephalogram to the profile video image are to: (a) relate the underlying hard tissue to the soft tissue, (b) allow quantification of movements needed for occlusal correction and aesthetic ideal to be achieved, (c) allow realistic movements to be planned and, (d) permit the treatment plan to be designed as close as possible to the patient desires. The cephalogram is superimposed over the profile image. The profile projections are applied in an algorithmic mathematical fashion. An "auto-treatment" function which adjusts the video image to the limits of the profile prediction, projects the predicted outcome in video graphics form. The movements on the video screen are in terms of "real size". There are two major aspects of treatment planning process with video imaging; counseling (communication) and video cephalometric treatment planning. The counseling phase is a graphic way of communicating concepts that are difficult to present to the patient verbally [54]. The planning phase permits a quantification of the treatment plan for the surgery. The superimposition of the cephalogram to the profile video image, coupled with algorithmic predictions, permits the clinician to plan the surgery to closely match the desired result [54, 55]. However, there are inherent errors in all the component parts of the superimposition of facial images and cephalometric radiographs [56].

Video imaging represents a major addition to the role of computers in orthognathic surgery and is described as a powerful tool for communicating with candidates of orthognathic surgery treatment in order to evaluate and assess potentially desirable goals. Although, is not a precise tool for mensuration, but it is suitable for supplying information to patients and motivate them and also for teaching, helping orthodontic residents to better understand three-dimensional structural relationships [57].

The use of computerized cephalometric prediction compare to manual cephalometric prediction facilitates and speeds the performance of the visualized treatment objective [38, 54]. Several research studies in the literature evaluate the validity of prediction of different systems. According to these studies, the computer programs used to predict the soft tissue outcomes are fairly accurate. It has

been shown that most of the inaccuracies were apparent at the upper and lower lip [58–64]. Despite certain inaccuracies involving mainly the lip area, cephalometric prediction is a valuable communication tool between orthodontist, maxillofacial surgeon and the patient [36, 48, 63–69].

Systematic reviews investigating the accuracy of computer programs in predicting skeletal and soft tissue changes after orthognathic surgery showed that computer programs cannot consistently predict the skeletal changes occurring after orthognathic surgery but their results may be considered inside a clinically acceptable range [44] and that the most significant area of error in prediction of soft tissue profile is the lower lip area, error that could have clinical implications. No software program was shown to be superior in prediction accuracy compared with its competitor [70]. Both manual and computerized cephalometric prediction methods are two-dimensional and cannot fully describe three-dimensional phenomena.

2D views have limitations: head positioning, rotational and geometric errors mean that there is not accurate representation of the anatomy; some elements can be obscured [71]. The limitations of 2D imaging techniques are particularly apparent in complex cases which require a multidisciplinary approach, as clefts and syndromes. These cases involve correction of deformity in the transverse as well as antero-posterior and vertical plane [72]. A basic problem associated with 2D prediction methods is that prediction changes in patients with craniofacial anomalies, facial asymmetries, and orofacial clefts cannot be interpreted because most 2D cephalometric measurements are distorted in the presence of facial asymmetry [73]. The interpretation of the facial asymmetry cause can be misleading with conventional radiographic images because complex 3D structures are projected onto flat 2D surfaces creating distortion of the images and subsequent magnification errors [74, 75]. A common form of facial asymmetry is chin deviation. The most possible cause of chin deviation is the right and left side difference in ramus length. Difference of body length in the mandible could be also another possible cause. It is extremely important in treatment planning to distinguish the causing structures and to properly and accurately measure them [76].

Another problem is that the parameters of different facial units cannot be fully measured with 2D cephalometric methods of prediction and thus, the information provided is limited. More specifically, regarding size, they allow measurement of the height and length but not the width. Regarding position, they permit the measurement of the anteroposterior and vertical dimension but not the transverse. Regarding shape, 2D cephalometric methods are capable to analyze the shape of a facial unit only from the side but not from the frontal or submentovertebral view.

Regarding orientation, they permit the measurement of pitch but not of yaw or roll [73].

Three-Dimensional Prediction Methods

The extension from two- to three-dimensional imaging was ideally suited to computer methods. Computer methodology integrating cephalometric data with three-dimensional (3D) computerized tomographic (CT) data has been found to aid in the clinical planning of orthognathic surgery, especially in craniofacial anomalies cases. Three-dimensional data were derived from conventional anatomic landmarks which could be identified on both lateral and posteroanterior cephalometric films by converting two-dimensional representation into a three-dimensional representation by a variant of a ray intersection method commonly used in stereophotogrammetry [77]. A patient's 3D tracing is compared to a similarly generated "ideal" for every age and sex corresponding Bolton tracing. After the type and number of osteotomies to be performed have been selected, the program calculates the postoperative movements of all osteotomy fragments required to have the surgical outcome most closely approximate the Bolton "ideal" form. The user can modify the orientation and position of each osteotomy fragment, if needed. The surgical planning cephalometric treatment may be performed on 3DCT scan reconstructions for superior visualization of the planned surgical changes.

The integration of voxel volume and surface modeling has been also used for planning and predicting maxillofacial surgery. A laser scanning system and a computer system were used to scan facial surface contours and record three-dimensional surface anatomies as a patchwork of triangles or facets. The computer system was developed for the simulation of the surgery on the hard tissues through dynamic manipulation of surgical segments and on the soft tissues. Modeling of the soft tissue for predictions of the postoperative facial appearance was estimated in the midline based on retrospective cephalometric studies of surgical soft tissue change in midline. Estimation in the midline gives a more realistic postoperative image because along the midline the movement of the soft tissue is decreased in a linear fashion. The system is capable of performing quantitative measurements on both the hard and soft tissue images and of superimposition of images over fixed points or areas. These capabilities allow postoperative changes of the face to be easily monitored in three-dimensions. Thus, both the surgeon and patient can visualize the postoperative facial result [78].

Today, three-dimensional prediction methods are available, such as three-dimensional computerized tomography (3DCT), 3D magnetic resonance imaging (3DMRI) and surface scan/cone-beam CT. The combination of surface

scanning and cone-beam CT scan uses hard tissue imaging data from the tomogram and soft tissue data from the surface scan, which are processed through special software.

Nowadays software systems fuse the 3D image with the CT/cone-beam CT image, and/or digitized dental study model, to assess, plan, monitor, evaluate and simulate possible patient treatments. An image fusion model is defined as a composition of at least two different imaging techniques. The principle of image fusion is the development of a single data set that contains all three structures such as bone volume, soft tissue surface and dentition [79]. 3D data can be fused using point based matching with or without a reference frame, surface based matching [80–82], and vomex based matching [83–85]. Different methods are used to display the facial skeleton in combination with the dentition, to determine the exact localisation of the digital dental model in a cone-beam (CB) CT data set, and to fuse the facial soft tissue surface and the facial skeleton [86]. The most applied technique currently is fusing a 3D textured surface derived from a 3D photograph or 3D surface laser scan with reconstruction of multislice CT (MSCT), CBCT data or MRI slices [80–82, 87].

The first complete 3D model for prediction of orthognathic surgery developed by Nakasima et al. [88], which can be adjusted to the patient's head from cephalograms, 3D stereophotographs and dental casts.

The fusion model replaces the need for model surgery, since the virtual head can be used to design a surgical wafer, which can be used as a surgical guide.

Many important issues with 3D cephalometry remained to be addressed. These include the reference systems, the method used to measure the distances and angles in three-dimensions, and the assessment of symmetry. Internal reference systems are unreliable because they can be difficult to define and can be distorted by craniofacial deformity or asymmetry. 3D measurements, for 3D cephalometric analysis, might have different meaning than its 2D counterpart and can be distorted by adding roll or moving a unit transversely in 3D space [73]. Thus, in pts with facial asymmetry, direct 3D measurements could be unreliable. 3D shape analyses are difficult to interpret because there is a lack of necessary normative data.

Additionally, measurements on 3D models of human skulls, derived from cone beam CT (CBCT) data found that can differ significantly from measurements on conventional cephalometric radiographs of the same skull. The measurement error for 3D measurements is larger than that for conventional 2D measurements. An additional source of inaccuracy is introduced by adding the third dimension [89]. Also, it was found that the measurements on 3DMSCT, were less reliable than measurements on 2D images [90].

In contrast, the results derived from a study of soft tissue aesthetic predictions pre-surgically and 6 months after

surgery showed that the validation in craniofacial surgery with cone-beam computed tomography (CBCT) is reliable [91].

A limitation of routine clinical application of 3D cephalometric assessments is the lack of reference and normative data [72]. Long term follow up of various deformities will deliver data which will be used to enhance the accuracy of predictions [92]. All currently available fusion models are expensive and in order to meet the demands of prediction and simulation need improvement [50]. Although, 3D digital model is a valuable aid to clinicians in order to communicate with an interdisciplinary team, the patients and their parents [71].

Despite advances in surgical techniques concerning function, stability and aesthetics, and the promising capabilities of 3D technology, oral maxillofacial surgeons and orthodontists have not been able to yet develop an objective method to predict the soft tissue outcome after orthognathic surgery [44, 57, 93].

Conclusions

Cephalometric prediction in orthognathic surgery can be performed manually or by computer, using several currently available software programs, alone or in combination with video images. The manual methods of cephalometric prediction of the orthognathic outcome are time consuming, whereas, computerized methods facilitate and speed the performance of the visualized treatment objective. Both manual and computerized cephalometric prediction methods are two-dimensional and will always have limitations, because they are based on correlations between single cephalometric variables and cannot fully describe a three-dimensional biological phenomenon.

Today, three-dimensional prediction methods are available, such as three-dimensional computerized tomography (3DCT), 3D magnetic resonance imaging (3DMRI) and surface scan/cone-beam CT. Despite the promising capabilities of 3D technology there is not yet a reliable technique for orthognathic prediction. Although, the different method of prediction are useful tools for orthognathic surgery planning and facilitates patient communication.

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