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AN OVERVIEW OF THE METHODS OF PREDICTION PLANNING FOR ORTHOGNATHIC SURGERY USING CEPHALOMETRICS

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ABSTRACT
Prediction planning for orthognathic surgery allows the orthodontist to anticipate changes in hard and soft tissue that may arise as a result of the surgery. This can be useful to accordingly plan the orthognathic surgery and also as a means for informed patient's consent and to communicate with the concerned maxillofacial surgeon. Cephalometric prediction in orthognathic surgery enables direct evaluation of both dental and skeletal movements, and can be performed manually or by computers, using several software programmes currently available. They can also be incorporated with video images. The aim of this article is to present and discuss the different methods of cephalometric prediction of the orthognathic surgical outcome.

KEYWORDS
Prediction, cephalometric, planning, orthognathic surgery, orthodontics.

1. INTRODUCTION

The aims and the objectives of orthodontic treatment have been summarized by Jackson as Jackson's triad. The three main objectives of orthodontic treatment are functional efficiency, structural balance and esthetic harmony. Orthognathic surgical cases require a combination of both orthodontics and orthognathic surgery to achieve a well-balanced occlusion, efficient functioning, and harmonious facial aesthetics. [1] Although occlusal goals, can be very objectively determined, definitions of ideal aesthetics are very subjective and can be interpreted very differently by the clinician and the patient. [2] Kiyak et al. found that 53% of female patients and 41% of male patients listed aesthetics as a major factor in their decision to proceed with orthognathic surgery. [3] Rivera et al. stated that patients reported undergoing orthognathic surgery primarily for esthetic, functional, and TMJ improvements, 71%, 47%, and 28%, respectively. [4] Therefore, the need arises for the outcome of a proposed treatment plan be predicted accurately for proper comprehension and coordination between the patient, the orthodontist and the oral surgeon concerned. [2][4]

2. HISTORICAL BACKGROUND

Since Tweed in 1954 first presented his 'diagnostic triangle', many orthodontists including Steiner, Holdaway and Hilgers have developed the concept of using cephalometric tracings to establish precise treatment objectives. [5][6][7]

Historically, the first method to determine the amount of posterior movement of the mandible following mandibular surgery needed to produce satisfactory esthetic outcome was described by Cohen. [8] He proposed a method in which tracings of the maxilla, maxillary teeth, mandible, mandibular teeth, and soft tissue profile was made from the original cephalogram and a divider was used to record the posterior movement of the mandible. A regional tracing of the the mandible and mandibular teeth alone 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 required that was recorded with the divider. The soft tissue changes were then inspected. The cut-out section is outlined in a different colour than the original tracing and thus it was easier to visualize the soft tissue changes. [4][8]
McNeill et al. proposed a cephalometric prediction technique for the soft tissue profile after mandibular surgical repositioning [9] including the following steps: (a) Use of dental casts to establish the tentative post-treatment dental relationship using an articulator. (b) Construction of an overlay cephalometric tracing of 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, reach their desired position as shown on the articulated casts. Molar and incisal relationships on the casts serve as guides for correct overlay positioning. The preferable skeletal relationship is traced in a different color, on the overlay sheet. (d) The prediction tracing is completed 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. [4][9]

Henderson 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 transparent photograph along the projected osteotomy lines. This method was advantageous because it allowed the patient to view and understand a graphic image of the predicted outcome. [10] Another 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. in which both lateral and frontal cephalograms and photographs were taken. [11]

Another method of cephalometric soft tissue prediction for orthodontic-surgical tracing for single jaw and bi-jaw surgery was proposed by Fish and Epker. [12] Their method was partly adapted from Ricketts' cephalometric analysis, growth prediction and visual treatment objective construction as presented by Bench et al. [13] 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 mandibular surgery. The teeth were placed as described by Bench et al. [14] The change in lower incisor position was found and marked by superimposing the mandible on the corpus axis at pterygo-maxilla fissure. For the prediction tracing for maxillary superior repositioning, auto-rotation of the mandible is done clockwise around the condyle.

Holdaway proposed a method of overlay prediction tracing for a patient requiring orthodontic treatment to form a Visualised Treatment Objective (VTO). [6] It was Wolford who used the VTO for surgical-orthodontic treatment planning and coined the term Surgical Treatment Objective (STO). [15] He combined the manipulation of hard tissue elements and the generation of consistent soft tissue predictions ratios in a manageable format. They proposed various hard tissue and soft tissue interplay ratios and integrated them with the template method for various types of osteotomies. The use of cephalometric prediction to anticipate

changes in bony relationships and associated soft tissue changes has been also systematically advocated by Proffit. [16] According to the author, cephalometric prediction can be done manually by moving templates or by repositioning an overlay tracing of the patient's cephalogram.
Taylor gave the following objectives to be met by the prediction techniques: [4]

- Plan dental movements
- Assess need for extractions
- Plan mechanics
- Plan type of surgery and nature of osteotomies
- A basis for communication
- A basis for informed consenting.
- A basis for splint construction.
- Provide a reasonable prediction of soft tissue changes.

3. METHODS OF PREDICTING SURGICAL OUTCOMES USING CEPHALOMETRICS

There are various methods available for planning and predicting surgical outcomes such as: [4]
1. Manual acetate tracing techniques.
2. Photo cephalometric method.
3. Computerized cephalometric prediction.
4. Videocephalometrics.
5. Three-dimensional cephalometric prediction.

Cephalometric prediction methods for orthognathic surgery include a set of 2 predictions:

(1) An orthodontic prediction illustrating the desired presurgical orthodontic tooth movement and the resulting soft tissue changes. The presurgical position of the teeth redirects the surgical movement of the jaws and, ultimately, the soft tissue facial balance. Correct planning of orthodontic tooth positioning before surgery and accurate execution of the presurgical orthodontic plan will amplify the surgical potential and, thus, the esthetic result.

(2) A surgical prediction, predicting the surgical repositioning of the jaws and subsequent soft tissue changes. The immediate presurgical prediction is created a few days before surgery and plans the definitive surgical movements and predicts the resultant soft tissue changes.

If more than one surgical or orthodontic option is under consideration, a series of prediction tracings can be made and all advantages and disadvantages of each treatment possibility should be weighed against the other.

The use of the prediction planning has several advantages:

- It can accurately predict the soft tissue changes that will result after the proposed orthodontic tooth movements and surgical jaw repositioning.
- The predicted soft tissue profile can be assessed and the treatment plan modified accordingly.
- It helps analyse the postsurgical skeletal movements.
- It helps the orthodontist and surgeon to investigate treatment options and evaluate the advantages and disadvantages of each option before treatment commences.
- It monitors the progress of orthodontic treatment using the prediction.
- It helps assess the need for adjunctive surgical procedures, such as genioplasty or rhinoplasty. [17]
- It helps analyse the need for tooth extractions and the decision to extract which teeth.
- It acts as a communication medium between the orthodontist and the surgeon, as well as between the clinician and the patient.

4. MANUAL CEPHALOMETRIC PREDICTION- OVERLAY METHOD

The overlay method of tracing is the simplest way to simulate the effects of mandibular surgery. The final prediction tracing is produced without any additional intermediate tracings. This method is limited to surgery that does not affect the vertical position of the maxilla (i.e., the mandible does not rotate around the condylar axis). The steps in preparing a prediction tracing are as follows: [18][19]

- Trace the film being sure to include all teeth or at least their occlusal surfaces.
- With a new sheet of tracing paper over the original tracing, trace the structures that will not be changed by the mandibular surgery: the cranial base, maxilla and maxillary teeth, mandibular ramus down to the angle. and soft tissue profile upto the supratip break. Do not trace the mandible or the soft tissue below the nose (structures that will change with surgery).
- Slide the overlay tracing so that the mandibular teeth can be seen through it in their desired post-surgical position and trace the lower teeth and jaw in this position.
- Superimpose the overlay tracing back on the cranial base and complete the soft tissue profile, using Table 1 as a guide. This completes the prediction tracing.

Soft Tissue/Hard Tissue Ratios, Manual Prediction

Treatment	Soft Tissue Change	Notes
Anteroposterior movement of incisors: maxillary or mandibular, forward or back, surgical or orthodontic	60% to 70% of incisor movement	1, 2
Vertical movement of incisors	Minimal unless jaw rotates	3, 4, 5
Mandibular advancement	Soft tissue: chin 1:1 with bone, lower lip; 60% to 70% with incisor	6
Maxillary advancement	Nose: slight elevation of tip Base of upper lip: 20% of point A Upper lip: 60% of incisor protraction, shortens 1 to 2 mm	7, 8
Mandibular setback	Chin: 1:1 Lip: 60%	5
Maxillary setback	Nose: no effect Base of upper lip: 20% of point A Upper lip: 60% of incisor Advancement lower lip: variable, may move back	3
Mandibular setback plus maxillary advancement	Changes similar to a combination of the two procedures separately	
Maxillary superior repositioning	Nose: usually no effect Upper lip: shortens 1 to 2 mm Lower lip: rotates 1:1 with mandible	7
Mandibular advancement plus maxillary superior repositioning	Chin: 1:1 Lower lip: 70% of incisor Upper lip: shortens 1 to 2 mm 80% of any incisor advancement Nose: slight elevation of tip	9
Mandibular inferior border repositioning	Soft tissue forward: 60% to 70% bone Chin: Up—1:1 with bone Back—50% bone Laterally—60% bone Down—?	

From Proffit, White[1].
1. Little difference with surgery or orthodontics.
2. If both upper and lower incisors are retracted (bimaxillary protrusion), lip movement stops when lips come into contact.
3. Lip shortens 1 to 2 mm with vestibular incision (more if surgical technique is poor).
4. Lip rotates with mandible 1:1.
5. If face height increases, lip may uncurl and lengthen.
6. If lip uncurls, it will go forward less.
7. Nose change is usually temporary.
8. Less soft tissue change occurs after cleft lip repair.
9. Data from Jensen AC, Sinclair PM, Wolford LM: Soft tissue changes associated with double jaw surgery, *Am J Orthod Dentofac Orthop* 101:266-275, 1992.

Table 1: Soft tissue / hard tissue ratios for manual prediction (Contemporary Treatment of Dentofacial Deformity by William R. Proffit, Raymond P. White, David M. Sarver- Mosby, 2003)

It is helpful to have dental casts available when the cephalometric prediction is carried out. The crucial step in the prediction is orienting the repositioned mandibular teeth to the opposing arch when the overlay tracing is moved to its new position. Observing the dental relationships when the casts are repositioned helps make it easier to place the overlay tracing in the most suited position. It is important to trace the incisal and cuspal outlines of all the teeth so that the occlusal plane is visible. The dental casts also aid in doing this task. If major orthodontic tooth movement is anticipated before surgery, such that the orientation of the incisor teeth will change, it helps to have this simulated on dental casts in the form of an orthodontic diagnostic setup. In patients with severely malaligned teeth, it is not possible to reposition the casts to simulate surgery until tooth interferences have been eliminated, as they will be by presurgical orthodontics. It is possible to reorient cephalometric tracings even though some teeth overlap, but it is much easier to do this when you can refer to casts on which the teeth have been repositioned. The diagnostic setup also provides a guide to the amount that the mandibular incisors should be retracted or flared forward on the prediction tracing before movement of the overlay begins. Whatever the prediction method, producing the predicted soft tissue outline is more of an art form than a scientific exercise. At best, the estimates for change in lip position shown in Table 1 are rough guidelines. It is important to remember that these estimates are based on changes in the position of the lips at rest. If the original cephalometric film was taken with the patient straining to bring the lips together, prediction of the postsurgical relaxed lip position is not impossible. [18][19]

5. MANUAL CEPHALOMETRIC PREDICTION- TEMPLATE METHOD

The use of templates for intermediate tracings between the original and final prediction tracing is mandatory when the maxilla will be repositioned vertically; very helpful when major movements of the teeth must be simulated or when the chin is repositioned; and quite possible when only the mandible is being moved. Templates can be used for any type of surgical prediction. The only disadvantage of this method is that it is more time-consuming to prepare a template than to proceed directly to a finished prediction tracing, as is done with the overlay method in uncomplicated mandibular surgery. The steps in preparing templates for maxillary surgery are as follows: [18][19]

- Prepare the maxillary templates by tracing the posterior (premolars/ molars) segment, and similarly tracing the maxillary anterior (incisors/canine) segment.
- In case of crowding, prepare two mandibular templates, one with the crowding resolved without extraction (the incisors therefore must be advanced slightly), and one with extraction (the incisors retracted).
- The four templates are ready.
- Place the maxillary anterior template in approximately the desired position which is about 2 mm below the lip line and in approximately the original anteroposterior position. Use the two mandibular templates to see which fits better and which result is feasible to achieve.
- You can also rotate the mandible by placing firm finger pressure at the condyle and rotating it.
- Position the maxillary posterior template.
- With a clean sheet of tracing paper over the original and the templates, complete the prediction tracing.
- Use the guidelines in Table 1 to complete the soft tissue outline.

It is very helpful if the templates are a different colour from the original tracing. The completed prediction tracing is easier to interpret if different colours are used to indicate what structures were repositioned.

Typically, templates are made for the entire maxilla if a one-piece or two-piece maxillary osteotomy is planned (the two-piece osteotomy is used to change width). If a three-piece maxillary osteotomy is planned, it is necessary to make an anterior and a posterior maxillary template. Usually, first premolars are extracted, therefore the posterior template would show the palatal plane from the posterior nasal spine to the second premolar. The anterior segment includes the anterior nasal spine, the bony contour through point A, and the lingual contour of the alveolar process behind the incisors. In the mandibular arch, the template includes the mandibular teeth and the entire outline of the mandible, including as accurate a representation of the mandibular condyle as close as possible. If the possibility of repositioning the chin via an inferior border osteotomy is to be explored, a template of this region is made by tracing the anterior and inferior outlines of the chin up to a mark that represents the tentative osteotomy cut. [18][19]

6. PHOTOMETRIC PLANNING

A photo cephalometric technique for the prediction and evaluation of skeletal and soft tissue changes following orthognathic surgery was advocated by Hohl et al. [11] Manipulation of the patient photographs (cut and paste technique) was done to illustrate the treatment outcomes. In this method the lateral cephalogram was traced and superimposed onto a profile picture in a ratio of 1:1; called a "photometric plan". The photograph, with the hard tissue points marked, was then cut to simulate the pre-surgical orthodontic phase of incisor decompensation. The necessary surgical movements were then simulated; followed by the soft tissue response to the hard tissue movements. The advantage of this method is it gives the patient better visualization of the profile changes than the acetate tracing. However, failure to predict the changes in the soft tissue contours that occurs with treatment is a major drawback. Also, gaps in the photographs give an unnatural appearance. This method also requires an experienced clinician with artistic skill.

7. COMPUTER SOFTWARES FOR CEPHALOMETRIC PREDICTION

Historically the first computer program was designed by Bhatia and Sowray [20] to aid in diagnosis and treatment planning of orthognathic surgery and prediction of postsurgical soft tissue profile. In order to use a computer software to plan orthognathic treatment, the radiograph has to be digitised prior to analysis. Two methods are described: [21]

1. Direct computer digitisation of the radiograph in which the radiograph is placed on a digitizing light box and digitization is done using a cursor or an electronic pen.
2. Indirect computer digitisation of the radiograph in which the radiograph is captured on the computer screen and then digitized.

There are advantages to using the indirect method such as use of magnification, alteration of brightness and contrast allow more detailed visualisation of the image.

At present, there is a wide variety of computerized cephalometric software systems for orthognathic surgery prediction. Some of them are:

• Dolphin imaging 10
• Dentofacial Planner 8.05
• Quick Ceph Image
• OPAL image version 2.2
• FACAD software
• Total Interactive Orthodontic Planning System (TIOPS)
• Vistadent
• Computer assisted simulation system for Orthognathic surgery (CASSOS)

Arslan et al. compared and evaluated the accuracy of manual and digital cephalometric prediction methods in orthognathic surgical planning in their study. They reported that dental predictions were inaccurate in both methods due to the effects of intermaxillary elastics, but both methods yielded similar predictions for skeletal parameters. Cephalometric points that are difficult to distinguish using the manual method can be visualized through digital images by adjusting contrast settings. The impact of applying strong elastics for postoperative intermaxillary fixation should be considered when making surgical predictions. [22]

Abreu et al., in their study, compared manual techniques versus the computerized cephalometrics using the softwares dolphin imaging and dentofacial planner. The computerized cephalometric method using the Dentofacial Planner software showed the highest reliability, followed by the manual method, while the Dolphin Imaging software was the least effective and more likely to produce systematic errors in the identification of points. [23]

Power et al. compared the accuracy of cephalometric digitisation and orthognathic prediction of Dolphin Imaging 8 with manual tracing (the "gold standard"). Both methods were found to be reliable at identifying cephalometric points. Of note, manual tracing was more reliable for SNA, SNB, SNMx and MxMd. In contrast Dolphin imaging 8 was more reliable for UIMx and LIMd, although systematic error in the software meant that LAFH% was 4% larger than manual tracing. [24]

A study by Loh et al. analysed the accuracy and reliability of Quick Ceph Image software (version 3). There was good correlation between repeated digitisation for all measurements. The only variables to show statistically significant differences were ANB, FMA, SN-Mx1 and Wit's but only the Wit's analysis showed clinically relevant differences between the two measurements. The authors concluded that clinicians should be cautious when using this system; it may not be possible to achieve the planned surgical result based upon this system's information. [25]

The ability of prediction imaging software to simulate the actual outcome of orthognathic surgery was investigated by Smith et al. Comparisons were made between five programmes - Dentofacial Planner Plus, Dolphin imaging, Orthoplan, Quick Ceph Image and Vistadent. Ten challenging cases of vertical discrepancy were chosen and "retreated" with the programmes using the actual surgical changes. Dentofacial Planner Plus was perceived the best default simulation. [26]

A systematic review by Kaipatur et al. on accuracy of computer programs in predicting orthognathic surgery hard tissue response reported that the computer programs were unable to precisely predict all the skeletal changes. Most of the prediction inaccuracies were within 2 mm or 2°. They showed that Dentofacial Planner was the best-judged software in comparison to the Quick Ceph or Dolphin Imaging systems. [27]

8. VIDEOCEPHALOMETRICS

Computerised diagnostic and planning software that integrates video images with the patient's lateral cephalograph to aid in planning and predicting surgical orthodontic procedures have popularised. 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 postsurgical facial appearance and also enables the orthodontist to select the optimal choice of treatment. Visualisation of facial changes has been enhanced and so is patient/clinician communication. Alternative treatment plans can be evaluated with ease, and realistic patient expectations may be achieved with the help of video imaging. [28][29]

Sinclair et al. assessed the accuracy of the video image predictions using the actual initial, the actual final and the predicted final images were displayed simultaneously on the monitor. These three images were carefully evaluated and scored independently by an oral surgeon and an orthodontist, for the similarity between the actual final and the predicted final images. The mean differences on the posttreatment soft tissue profile was small and statistically insignificant for measures other than the lower lip. The computer predicted lip was significantly more retrusive when compared with the E-line and a vertical through subnasale. [29]
Phillips et al. found that the presentation of video images appears to be a valuable adjunct for conveying treatment options to patients, but warned that caution may be needed to avoid elevated or unrealistic treatment expectations. Video imaging was found to heighten patients' expectations of improvement in self-image following treatment. [30]

9. LIMITATIONS OF 2D PREDICTION TECHNIQUES

2D views have some limitations: Head positioning, rotational and geometric errors mean that the anatomy is not accurately represented. A fundamental problem associated with 2D prediction methods is that prediction changes can not be perceived in patients with craniofacial defects, facial asymmetries and orofacial clefts because most 2D cephalometric measurements are affected in the presence of facial asymmetry. [31][32]

10. 3D CEPHALOMETRIC PREDICTION

Three-dimensional prediction methods are now available, such as three-dimensional computerized tomography (3DCT), 3D magnetic resonance imaging (3DMRI) and surface scan/cone-beam CT. [4] The first complete 3D model for prediction of orthognathic surgery developed by Nakasima et al. which can be adjusted to the patient's head from cephalograms, 3D stereophotographs and dental casts. [33] 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. 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. Facial scanners provide a complete 3-dimensional topography of the facial surface structures, analysis of the symmetry and facial proportions. Thus it provides a qualitative and quantitative assessment of the treatment outcome of various esthetic and reconstructive procedures. [34] In 1967, Bruke and Beard introduced the concept of stereophotogrammetry as a prediction method that uses means of triangulation and camera pairs in stereo configuration to recover the 3-dimensional features of the facial surface. It provides high-resolution representation of the face without direct exposure. [35]

Donatsky et al used a computerised cephalometric surgical programme in simulation, treatment planning and postsurgical records, to assess precision and stability of bimaxillary surgery. They concluded that this progamme is useful in orthognathic surgical simulation, planning and prediction, and also in evaluation of surgical precision and stability. The simulated treatment plan can be transferred to model surgery and then on to surgical procedures. The results suggest that this technique yields acceptable postoperative precision and stability. [36]

Image fusion model is a new 3-D prediction technique which can capture the complete 3D view with optimal quality. This technique involves 'image fusion' of different imaging techniques to create a 3D virtual head that can display all triad elements. These methods are accurate and reliable tools for documentation, analysis, treatment planning and long-term follow-up. An image fusion model is a composition of at least two different imaging techniques. The principle of image fusion is based on the creation of a single data set that contains all three structures that is the facial soft tissue, the skeleton and the dentition using segmentation by thresholding. 3D data can be fused using three different methods: 1. Point-based matching without the use of a reference frame. 2. Point-based matching with the use of a reference frame. 3. Surface-based matching. The advantages of the image fusion model include multiple simulations of different osteotomies and skeletal movements within the virtual operating room, aiding decision-making regarding aesthetic and functional predictions. This fusion model replaces the need for model surgery, since the virtual head can also be used to design a surgical wafer. Post-operative evaluation will give feedback on the performed procedure and can be used for teaching purposes. The data is acquired with an 'all in one' imaging technique, which would reduce the differences in facial expression at the moment of acquisition. However, all currently available fusion models are expensive and need improvements for improved prediction and simulation. [37] 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.

DOES THE PREDICTION IMAGE CREATE AN UNREALISTIC EXPECTATION OF THE FINAL RESULT?

Phillips et al found that the presentation of prediction images to patients appears to be a valuable adjunct for conveying treatment options.[30] Kiyak et al. showed that fewer than 45% of non-imaged patients were satisfied with their aesthetic result.[3] However, Sarver et al found that 89% of the patients believed that the image predictions were realistic and that desired results were achieved. Furthermore, 83% of the patients believed that the imaging process helped them to decide whether to have surgery or not, 72% believed the process allowed them to take part in specific treatment decisions. [28] Fear that the patients' expectations may be too high do not appear to be supported.

11. CONCLUSION

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 methods of cephalometric prediction are two-dimensional and will always have their limitations. Today, three-dimensional prediction methods are available. Despite the promising capabilities of 3D technology there is not yet a reliable technique for orthognathic prediction. Despite this, the different methods of predictions are useful tools for orthognathic surgery planning and facilitates patient communication.

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