Factors Influencing the Accuracy of Cephalometric Prediction of Soft Tissue Profile Changes Following Orthognathic Surgery

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Abstract The cephalometric prediction of orthognathic treatment outcome is an important part of the surgical planning and the process of informed consent. The orthodontic and surgical changes must be described accurately prior to treatment in order to assess the treatment's feasibility, to optimize case management and to increase patient's understanding and acceptance of the recommended treatment. The aim of the present article was to investigate on the factors that could influence the accuracy of cephalometric prediction in planning orthognathic surgery. Review of the literature revealed that, besides factors directly related to the prediction method and its use, there exist a considerable number of factors which could affect significantly the accuracy of soft tissue response. These factors could be biological ones such as relapse, centre of mandibular rotation and individual variation in response to treatment and others such as gender, race, pre-operative soft tissue thickness and data bases for mean ratios of soft to hard tissue movement changes. Some of the factors affecting the accuracy of prediction of soft tissue response following orthognathic surgery are inevitable and there are others, difficult to control and predict. However, patients should be informed that predictions are only a guide, may not represent the actual result of the surgical outcome, and as such they should be implemented.

Keywords Prediction · Accuracy · Validity · Orthognathic surgery · Cephalometrics

Introduction

In planning orthognathic surgery for patients with severe dentofacial deformities and occlusal discrepancies, the feasibility of visualization of the final treatment outcome is very important. The orthognathic approach is expected to lead to optimal functional, esthetic and stable results, thus satisfying the patient's needs, not only regarding physical appearance but also self-confidence and esteem. In view of this, it is essential to accurately predict the result of a proposed treatment plan for proper understanding and communication between the patient, the orthodontist and the oral surgeon involved.

Cephalometric prediction in orthognathic surgery allows direct evaluation of both dental and skeletal movements and can be accomplished manually or by computers, using several currently available software programs, alone or in combination with video images. With computer input of digital images and application of algorithms that relate soft tissue changes to underlying hard tissue changes, predicted profile images are attainable [1].

Historically, the first cephalometric treatment simulation was done manually. Several methods have been proposed for this type of prediction [2–8]. Wolford et al. [9] and Proffit [10] presented the most systematic approaches, either by moving templates (template method) or by repositioning an overlay tracing of the patient's cephalogram (overlay method).

With the advances in technology, a variable number of cephalometric prediction computer software programs currently exist in the market. Quick Ceph Image software

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(Quick Ceph Systems, San Diego, CA) was the first orthognathic surgical prediction software program available. Among the most popular computerized programs, there now exist Dentofacial Planner (DFP) (Dentofacial Software, Toronto, Ontario, Canada), Dolphin Imaging System (Dolphin Imaging & Management Solutions, Chatsworth, CA), Orthognathic Treatment Planner (GAC International, Birmingham, AL; predecessor of GAC's Vistadent program), CASSOS (Computer-Assisted Simulation System for Orthognathic Surgery) (Soft Enable Technology, LTD, Hong Kong, China), OPAL (Orthognathic Prediction Analysis) and others.

Nowadays, despite the release of improved versions of many of the afore-mentioned programs, the accuracy of the soft tissue prediction remains an issue. The aim of the article was to investigate on the factors that could influence the accuracy of cephalometric prediction in planning orthognathic surgery.

Factors Affecting the Accuracy of Predictions of Soft Tissue Outcomes

Gender

Females demonstrated higher ratios than males with a statistically significant difference of 11% for the lower lip and 12% for the soft tissue chin, as shown in a study on a Chinese sample that underwent mandibular setback surgery [11].

Similarly, soft tissue movement in response to skeletal repositioning was significantly greater in females than in males by 20% for the upper lip and 14% for the soft tissue chin in a study on mandibular prognathism patients having undergone mandibular setback surgery [12].

Despite the limited number of existing studies regarding this factor, it seems that gender plays an important role in the accuracy of soft tissue prediction.

Race

Since ethnic differences in soft tissue-to-hard tissue movement ratios have been reported in the literature, it has been suggested that racial variation in tissue response could be a reason for inaccuracy in the prediction of soft tissue outcome following orthognathic surgery. In particular, Clemente-Panichella et al. [13] conducted a study to create norms for soft to hard tissue movement ratios for patients of Hispanic descent having undergone orthognathic surgery and found differences when comparing their results to previously published data on European-American populations. When patients' data from different ethnic groups are entered in the cephalometric software programs, which are

based on algorithmic data already set for a specific race group, the accuracy of prediction becomes questionable. In the work of Koh and Chew [14] on Chinese Class III patients having undergone bimaxillary surgery, the CASSOS 2001 program was applied; however, as analyzed by the researchers themselves, since this software uses the soft tissue-to-hard tissue ratios derived from data consolidated by Betts and Fonseca [15] on white subjects, prediction errors could be the result of interpretation of inappropriate algorithmic data used.

Pre-Operative Soft Tissue Thickness

Gjørup and Athanasiou [16] and Chunmaneechote and Friede [17] found low regression coefficients when testing if the soft tissue thickness at lip and chin regions could act as predictors of the ratios of soft to hard tissue changes in mandibular setback osteotomy.

Similarly, according to the study of Mobarak et al. [12], correlations of preoperative soft tissue thickness and the net change in soft tissue thickness as a result of mandibular setback surgery were too weak to provide clinically useful predictions. Preoperative thickness of both the upper and lower lip was significantly correlated with the net change in their thickness in the sense that, the greater the preoperative soft tissue thickness, the greater the expected change. No similar associations were found for preoperative soft tissue thickness of the mentolabial fold or chin. A significant correlation was, however, found between the preoperative mentolabial fold depth and the net change in its depth.

Lew [18] claimed that, in any case, the variation in lip response following treatment could be aggravated by lip morphology and posture and possibly by labiomental interferences.

As stated by Koh and Chew [14], highly variable factors such as the thickness, tonicity, posture and length of the soft tissue covering may have a negative effect on the accuracy of prediction.

Recently, Kaipatur and Flores-Mir [19] reported on the need to caution the candidates for orthognathic surgery about potential limitations in the prediction of horizontal and vertical changes in the lower lip area. As mentioned in the same article, stated reasons for discrepancies are different lip tonicity, length, posture and mass.

Mean Ratios of Soft Tissue to Hard Tissue Movements

Computer programs contain various data bases for mean ratios of soft tissue to hard tissue changes following orthognathic surgery [12]. According to Pospisil [20], there is no reliable knowledge of the factors which would enable to find out which patient in question will belong to the

group of patients with lower or to the group with upper extremes of soft tissue to hard tissue movement ratio. Furthermore, adequate data exist only for certain types or combinations of osteotomies [9, 10, 16].

Method Related Factors

The accuracy in prediction of soft tissue response could also be influenced by the reproducibility in landmark identification and further by computer digitization rather than by any discernible differences between software packages. This assumption was drawn as an explanation for the relatively large standard deviation evident with both Dentofacial Planner program and Quick Ceph in a study of 28 cases [21].

As summarized in the meta analysis of Trpkova et al. [22], density and sharpness of the image, anatomic complexity and superimposition of hard and soft tissues, observers' experience when locating a particular landmark and precise definition of the location of a landmark are important factors that may influence landmark identification. Besides, as stated by Athanasiou and Kragsskov [23], most of the errors take place during the procedure of landmark identification and not during tracing.

Biological Factors

Additionally to factors directly related to the prediction method and its use, certain biological factors that concern orthognathic surgery procedures may affect accurate prediction of post-surgical profile changes. The most important biological factors are the relapse and the mandibular center of rotation. Further, there exists the individual variation in response to treatment, which should be taken into consideration when predicting changes in patients [24].

Relapse

Type of surgery: single-jaw or bimaxillary osteotomy and surgical procedures involved Pospisil [20] investigated the reliability and feasibility of prediction tracing in orthognathic surgery and found prediction tracing errors to be more common in the bimaxillary osteotomy group than in the unimaxillary osteotomy group. In accordance to these findings, the systematic review of Kaipatur and Flores-Mir [19] in predicting orthognathic surgery soft tissue response showed that prediction programs for bimaxillary surgery are less predictable than for unimaxillary surgery. Further, according to Pospisil [20], the degree of relapse has been improved even with the event of bimaxillary procedures which achieve better distribution of masticatory forces and avoid excessive changes in the tone of the

musculature related to the osteotomized jaws in the case of unimaxillary procedures.

Based on the database from the University of North Carolina (UNC) Dentofacial Program, the most stable orthognathic procedure is superior repositioning of the maxilla, closely followed by mandibular advancement [25–27]. Surgical repositioning of the chin via lower border osteotomy also is highly stable and predictable. Advancement of the maxilla falls into the second category, described as stable. Due to the fact that the horizontal component has a good chance of being retained whilst the vertical is likely to relapse, a downward movement of the maxilla is placed in the problematic, less predictable, less stable category. The third category, that of acceptable stability only if combined with rigid fixation, involves combination of procedures, such as maxilla upwards plus mandible forward, maxilla forward plus mandible backwards, as well as major jaw asymmetries. Lastly, procedures such as mandibular setback, downward movement of the maxilla, and maxillary expansion, fall into the fourth category as problematic, least predictable and least stable.

Magnitude of skeletal repositioning In mandibular setback surgeries, soft tissue changes following small setbacks are less predictable compared to large setbacks. According to Mobarak et al. [12], the reason for the poor predictability with the small setbacks may be related to the fact that there usually is a relatively greater rotation of the distal segment with a greater component of vertical repositioning in such cases. Also, based on results of the same study, changes in the vertical dimension are less predictable than in the horizontal plane. In addition, soft-tissue to hard-tissue ratios for the lower lip and chin gradually decrease with decreasing magnitude of setback.

Further, as stated by Pospisil [20], in cases of genioplasties, a periosteal stripping, which is a minimal stripping of soft tissue from the bone, brings about high soft tissue to hard tissue ratio movement and thus the predictability of post-surgical profile is greatly improved.

Number of oral surgeons involved In the study of Semaan and Goonewardene [28], it was shown that surgical treatment in a teaching hospital produced greater variation between the prediction and the outcome when compared with surgery delivered in the private environment. The environment in which the surgery is performed significantly influences the accuracy of a surgical procedure. According to the investigators, a possible reason might be the surgeon's decision to decline from the predicted treatment plan either because he could not execute the surgical procedure exactly as planned or because he chose not to follow the surgical plan.

Pre-surgical orthodontics In order for relapse to be minimized, it is important during pre-surgical orthodontics to eliminate dental compensations, to properly manage tooth-size discrepancies, to adequately level both arches and manage transverse discrepancies [29, 30].

Condylar displacement Condylar displacement can occur when perimandibular soft tissues are not adequately mobilized or because intraosseous wire placement and tightening are improper [29]. When condylar displacement occurs in surgery, relapse is inevitable. Rigid internal fixation (RIF) has been suggested as factor in post-surgical temporomandibular dysfunction because placement of its devices can displace the condyles [31]. According to White and Dolwick [32], temporomandibular dysfunction, occurring in a minority of orthognathic surgery patients, is related to the degree of condylar displacement and particularly whether it is in the transverse direction.

When intermaxillary stabilization is inadequate, the condyles are chronically compressed into their glenoid fossae during the entire period of fixation [30]. Excessive compressive loading leads to decreased nutrition of the condylar surface and subsequent condylar resorption. Condylar resorption is most apparent in mandibular advancement procedures that rotate the mandible in a counterclockwise direction [29]. Preliminary data from the computed tomography images collected from the UNC dentofacial patients suggest that much of the condylar rotation resulting in remodeling occurs from the surgical procedures, alone. However, further studies are required to determine the long-term effects of condylar changes relative to patient outcomes before definitive conclusions about condylar resorption and its relationship to the types of surgical procedures performed, can be assessed [26].

Type and duration of intermaxillary fixation Superior repositioning of the maxilla is a stable procedure. Instability is predominantly an early phenomenon and occurs during fixation. Vertical changes, greater than 2 mm, in a superior direction occur in 10% of patients posteriorly, and in 30% of patients anteriorly when wire fixation techniques are employed [33]. Correction of horizontal maxillary deficiency by anterior repositioning of the maxilla may be compromised by posterior relapse. However, a 20% posterior relapse was reported after release of fixation using interosseous wires and 10% with the use of suspension wires [34]. Suspension wires in conjunction with Maxillo Mandibular Fixation (MMF) have been found, in a study of comparison of combined wire fixation with Rigid Fixation (RIF), to improve stability of Le Fort I osteotomy cases [35], long before RIF was implemented. In that study, MMF was used with circumzygomatic wires that were attached to the most posterior maxillary brackets.

A characteristic pattern of early relapse on vertical ramus osteotomies has been recognized by several studies. These recommended the use of adjunctive skeletal suspension wires in an attempt to improve stability and minimize dental compensations observed when only MMF was used [36, 37]. Others considered such wiring to be of no difference [38], or of no difference in long term stability [39].

More recently, according to the UNC Dentofacial Program database [26, 27], RIF does not appear to be required in patients who have only one-jaw surgery; that is, for procedures in the highly stable or stable categories. In these cases, there is no difference between RIF and wire osteosynthesis/MMF [40]. However, for simultaneous repositioning of both jaws, such as combination of maxilla upwards plus mandible forward and maxilla forward plus mandible back, RIF has to be used for these procedures to be considered stable. For asymmetry patients, RIF is equally important for acceptable stability.

The duration of fixation may vary from no postoperative fixation at all (i.e. immediate intraoperative removal of wires at completion of surgery) to 2–3 weeks of maxillo-mandibular fixation. The length of time patients' teeth are wired depends on the type of procedure performed, the method of osseous fixation, and the surgeon's clinical judgement [41].

Mandibular Center of Rotation

After maxillary impaction surgery, the mandible autorotates to a new position anterior and superior to its original one. At times, different points have been proposed as rotation centers.

Initially, the center of the condyle was named as the point of mandibular autorotation [42, 43]. Long time later, the concept of an instantaneous center of rotation was introduced [44] according to which, the mandible translates as it rotates for any movement. For any small movement of the mandible, a point can be located which could be considered the center of rotation for that movement. Results of a study evaluating a group of cases of maxillary impaction against non surgical controls found that the mandible rotated through an arc close to the highest point on the head of the condyles called condylion [45]. This work was cited by Fish and Epker [46] as justification for using the condylion as a point of mandibular autorotation in cephalometric prediction tracings in orthognathic surgery. The hinge-axis angle, formed by the intersection of the Frankfort horizontal plane and a line between the condyle center and pogonion, was proposed to be used for the prediction of the horizontal changes of the mandible following maxillary segmental impaction [47]. According to findings in 15 patients by means of pantographic hinge-axis-locating

equipment, there is greater than 50% chance that the center of the condyle is located below and behind the cephalometric center of the condyle [48]. It has been also suggested that the most representative physiologic center of rotation of the mandible during autorotation should be expected to be located in the mastoid area, inferior and posterior to the condyle [44, 49–51].

More recently, the center of mandibular autorotation in maxillary impaction was found to be away from the condyle and not within the body of the condyle [52, 53]. As concluded in the work of Nattestad and Vedtofte [53], in some cases, a very large discrepancy found between the centre of the condyle and the calculated center of mandibular rotation may cause considerable error in the position of the maxilla at surgery. According to another research work that used computer simulation and a surgical model [54], a 20 mm discrepancy between the true center of autorotation and the center of autorotation used in the prediction could result from an autorotation of 5 mm in a discrepancy of 2 mm anteroposteriorly between the planned result and the operative result.

These findings clearly show that there is a controversy in the literature regarding the role of the condyle as center of mandibular autorotation following maxillary impaction. The accurate representation of that center is important in the prediction of the orthognathic outcomes [55]. However, unless the prediction rotates the mandible around the true axis of autorotation, there will be a horizontal discrepancy between the predicted and the achieved position of the mandibular incisors, which will be proportional to the vertical movement [56]. The inability of the software programs to take into account postoperative mandibular rotation can account for the inaccuracies in describing the sagittal and vertical relationships [57].

Discussion

Cephalometric prediction of surgical soft tissue outcomes is an integral part of orthognathic surgery treatment plan. The accuracy of soft tissue predictions has been studied by various authors [12, 18, 19, 45, 56–78]. 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 [20, 63–65, 69, 70, 77]. The present review of the literature revealed that besides factors directly related to the prediction method and its use, there exist significant factors that can influence the accuracy of soft tissue outcomes in predicting orthognathic surgery (Fig. 1).

Nowadays a variety of computerized prediction programs are available. Their ability to predict the postoperative facial profile is based on database derived from

studies with reported mean ratios of soft tissue to hard tissue movements or from linear regression equations [12, 79]. Soft tissue response to skeletal movement is simulated by computer software that is based on preprogrammed hard to soft tissue ratios, and these differ among programs. This is a component of variability among programs which can count as a factor influencing the accuracy of their predictability. Besides, since already there exists a large individual variability in soft tissue response such as soft tissue thickness, tonicity, posture, muscle pull and others, the computerized prediction of soft tissue profile changes following orthognathic surgery is likely to be only as accurate as the ratios of hard to soft tissue utilized by the program. Since most of the software systems are based on ratios derived from studies in Caucasians subjects, the accuracy of prediction for different ethnic groups becomes questionable [14]. However, the current literature has no evidence to support this hypothesis. It also seems that gender plays an important role in the accuracy of soft tissue prediction and should be taken into consideration by utilization of separate prediction data by the computer software program based on gender. The individual variability of prediction of soft tissue is expressed by the standard deviation in prediction ratios [78], but clinicians have no method to judge which patients fall in the greater or lower value of the range of prediction ratios [18]. Additionally, the individual variation in response to treatment should be considered as an important source of error when using means to predict changes in individual cases [24].

The different pre-operative soft tissue thickness especially at the lip area, as well as the length, tonicity, posture and mass of the lips have been recognized as factors affecting the predictability of soft tissue profile after surgery and contributing to inaccuracies [12, 16, 19]. It is for this reason that patients should be informed by the clinicians about potential limitations in the prediction of the lips area.

Another variable that should be taken into consideration in planning orthognathic surgery is the alteration of the basic nasal morphology which, although it can occur in conjunction with a maxillary procedure, it cannot, however, be predicted [80]. Typically, in a Le Fort I osteotomy there is widening of the base of the nose and associated flattening and thinning of the upper lip, especially noticeable in loss of the visible vermilion border. A maxillary advancement or an impaction can cause the nasal tip to rise whilst a maxillary downgraft or retrusion can result in a parrot's beak appearance with the alar bases pulled down along with the nose tip. However, these relative changes in the nasal tip structure and dorsum are not predictable and may or may not accompany the maxillary surgery, depending on the direction of skeletal movement, the handling of soft tissues, the skin thickness, and the

Fig. 1 Diagram showing factors influencing the accuracy of cephalometric prediction of soft tissue profile changes following orthognathic surgery

preexisting nasal structure. Overall, changes representing any alternation of the nasal structure, nasiolabial and paranasal areas and fullness of the lip cannot be predicted in any prediction method. Nevertheless, since these changes contribute a lot to the patient's facial esthetics following surgery and are, thus, important, possible alternation of the nasal morphology should be discussed with the patients as well.

Certain biological factors that concern orthognathic surgery procedures may affect accurate prediction of post-surgical profile changes. Stability of occlusion and esthetics following orthognathic surgery depends on relapse. Thus, the type of surgery, the magnitude of skeletal repositioning, the proper intra-operative management of hard tissue, the pre-surgical orthodontics, the condylar displacement, and, the type and duration of intermaxillary fixation constitute factors that determine post-surgical success. Another important biological factor involved is the centre of mandibular autorotation. The search of the literature revealed that there is a controversy regarding the true centre of rotation. Since the accurate representation of that centre plays an important role in an accurate prediction, unless the prediction rotates the mandible around the true centre of rotation, there will be inaccuracies when predicting the soft tissue outcomes of maxillary surgery.

Both manual and computerized cephalometric prediction methods are two-dimensional and cannot describe accurately three-dimensional phenomena. Thus, prediction

changes in patients with facial asymmetries and clefts and, edentulous patients cannot be successfully interpreted.

Today, with the evolutionary steps in three-dimensional technology, 3D prediction methods are available and soft tissue changes can be quantified by stereophotogrammetry and/or laser scanning. 3D reconstructed images can provide the possibility of preoperative treatment simulation and prediction, especially in cases of head and neck abnormalities, craniofacial anomalies and craniofacial trauma surgery [81]. Recently, preliminary results from a study on patients with craniomaxillofacial deformations having undergone cone beam computed tomography (CBCT) preoperatively and 6 months after surgery showed that simulations in orthognathic surgery are reliable and, in addition to the low radiation exposure, they could become the reference standard to plan surgical treatment [82].

However, despite the promising capabilities of 3D technology, barriers still exist for its widespread use, such as absence of significant patient databases, limitations of available software programs to manage 3D data, lack of a full and proper understanding of how to analyze and manage these data [19, 83].

As shown in the present review, the accuracy of the prediction of soft tissue outcomes of orthognathic surgery is influenced by a number of factors. Some of these factors are inevitable whilst some others are difficult to control and predict. However, patients should be informed that the actual outcome of the orthognathic surgery might not be as

accurate as the predicted one due to uncontrollable factors affecting the prediction.

Conclusions

The accuracy in predicting soft tissue response to orthognathic surgery is influenced by a number of factors. Besides factors directly related to the prediction method and its use, research of the literature showed that biological factors such as relapse, the centre of mandibular rotation and the individual variation in response to treatment, as well as, factors including gender, race, pre-operative soft tissue thickness and the various data bases for mean ratios of soft tissue to hard tissues could influence the accuracy of prediction of soft tissue outcome. Some of these factors are inevitable to exist and there are others, which are difficult to control and predict.

Accurate prediction is highly critical, because it is related to proper treatment decision-making, appropriate treatment planning and post-treatment facial appearance anticipated by the patient. Nevertheless, these predictions will always have limitations, because they are based on correlations between single cephalometric variables and cannot fully describe a three-dimensional biological phenomenon. However, patients should be informed that predictions are only a guide and not the actual result of the surgical outcome and as such, they should be implemented.

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