Computerized Prediction of Orthognathic Surgery

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Abstract: Orthognathic surgery has become increasingly popular over the past decade, due to the growing number of adult patients seeking orthodontic treatment. An accurate objective prediction analysis of the final treatment outcome has become an important part of the consultation and the preop surgical workup. Lately, computer software programs have been developed and used to analyse and predict the outcome of orthognathic surgery. These software programs require time, practice, and precision to use the different tools available for predictable results, and the novice user would find this challenging. Improving the accuracy of such software's and consequently improving the confidence in the surgical prediction is a crucial factor in the widespread use of such programs. The aim of this review article is to investigate the accuracy of these computer programs in predicting soft tissue response subsequent to skeletal changes after orthognathic surgery.

Keywords: Software, predictions, orthognathic surgery, orthodontics.

INTRODUCTION

Computer technology has become an integral part of the world we live in. It has not only advanced the areas of day-to-day communication and education but has taken the clinical world into a new realm of achievement. Various diagnostic and planning tools have been available to us as clinicians in the treatment for our patients; however, it is the advancements in these areas through computer technologies that have provided an incredible advantage to the clinical world [1].

Cephalometric is a routine part of the diagnosis and treatment planning process and also allows the clinician to evaluate changes following orthognathic surgery. Traditionally cephalometric has been employed manually; nowadays computerized cephalometric systems have been developed and used to analyse and predict the outcome of orthognathic surgery [2]. Computerized cephalometric analysis uses manual identification of landmarks, based either on an overlay tracing of the radiograph to identify anatomical or constructed points followed by the transfer of the tracing to a digitizer linked to a computer, or a direct digitization of the lateral skull radiograph using a digitizer linked to a computer, and then locating landmarks on the monitor. Afterwards, the computer software completes the cephalometric analysis by automatically measuring distances and angles [3].

Computerized orthognathic predictions

In the 1970s, planning for orthognathic surgery was through clinical examination, photographs, freehand surgical simulation based on cut-and-paste profile cephalometric tracings, and study model surgery [4,5]. In the 1980s, the integration of computer technologies in orthognathic surgery planning allowed for digitization of cephalometric tracing and simulation of surgical outcomes, permitting the patient to view and better appreciate the surgical treatment plan[1].

Schendel, Eisenfeld, Bell, and Epker[6] were among the first to employ a computer system for the analysis of preoperative and postoperative soft tissue profile. Later, Harradine and Burnie [7] 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 [8]. 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[9] 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 aesthetic prediction generated by the computer.

At present, several software systems allow clinicians to manipulate digital representations of hard and soft tissue profile tracings and subsequently morph the pre-treatment image to produce a treatment simulation. How well these predictions match the actual outcome of treatment has not been carefully evaluated, but anecdotal evidence suggests that the predictions might be less accurate when major vertical changes in jaw positions are planned. Most previous research involving computer simulation has focused on the accuracy of the predicted changes in the soft tissue points, by measuring the differences in soft and hard tissue landmarks on prediction and postsurgical tracings [10].

The prediction of treatment outcome is an important part of orthognathic planning. The orthodontic and surgical changes must be accurately described prior treatment in order to assess the treatment feasibility and optimize case management. Currently, there are several computer software packages programmed for such planning, claiming to predict the soft tissue outcome from surgical intervention [11].

Nowadays, a variety of computerized analyses of lateral cephalograms are used to predict treatment changes in the antero-posterior and vertical facial planes like Quick ceph, Vistadent AT (GAC International), Dentofacial Planner@ (Dental Facial Software Inc., Toronto, Canada), Dolphin Imaging Software), Nemoceph, Orthognathic Treatment Planner (Pacific Coast Software, Pacific Palisades, CA), Prescription Portrait (Rx Data Inc).

However, most of these systems are still based on the lateral cephalometric radiographs. It is now possible to make large corrections of the jaws in the three planes of space and so pre-treatment planning is of paramount importance. More recently, there have been exciting developments in 3D and video imaging techniques but as yet the 2D profile system still remains the most widely employed prediction method[11].

Quick Ceph

In 1986, Quick Ceph (San Diego, California) was developed by a German orthodontist, Gunther Blaseio, and introduced as one of the first orthognathic surgical planning software programs in the marketplace. Since then, numerous advancements in software design have led to the development and release of QC2000, which is marketed for orthodontists and oral and maxillofacial surgeons. This integrated system allows the clinician to capture and store high-resolution images, produce many predefined and customizable analyses, and generate growth forecasts and treatment simulations on line tracings and real images of patients.

Quick Ceph also allows the clinician to perform a model analysis to measure the arch length discrepancy (true and Moyers), the Bolton discrepancy, and the tooth size discrepancy. It comes with 10 lateral predefined analyses. The software also allows the practitioner to superimpose the initial, the growth phase, or the standard tracings during the treatment simulation to allow for realistic predictions. A flexible soft tissue analysis is included and allows the orientation of vertical reference lines to the natural head position, to the Frankfurt, to the sella-nasion minus 7, or to the glabella-nose minus 15. They are also compatible with any digital radiographic machine that can export images in the Joint Photographic Experts Group (JPEG) format [1].

Limitations

Loh and colleagues [12] conducted a retrospective study to analyze the accuracy and reliability of predictions generated in 28 heterogeneous patients treated with orthognathic surgery by comparing Quick Ceph Image Pro predictions with postsurgical lateral cephalograms. They found that 10 of the 14 parameters measured in this study had no significant differences between the predicted and actual postsurgical hard tissue landmarks. The 4 parameters that showed statistically significant differences were ANB (P ¼ .008), FMA (P ¼ .001), SN-Mx1 (P ¼ .03), and Wit's analysis (P ¼ .0001).

In 1997, Aharon and colleagues [13] compared Dentofacial Planner and Quick Ceph Image software and found that both programs performed well in simulating single-jaw and double-jaw operations. With Quick Ceph Image, only the predicted value of the horizontal position of the upper lip differed significantly from the actual postsurgical outcome [13].

Vistadent AT (GAC International)

Vistadent is another orthognathic software treatment planning program developed by Technocenter (GAC International, Birmingham, Alabama), which has the ability to locate orthodontic landmarks on cephalometric radiographs. It has the option of selecting 1 of 56 standard cephalometric analyses or creating a custom analysis. It is also possible to perform virtual

growth prediction and centric occlusion–centric relation corrections. Treatment simulation for surgery and orthodontics is possible from a single screen. This software system can also superimpose tracings done from any record series or virtual treatment, superimpose using landmarks or structures, and print superimpositions in single or segmented view. It is also compatible with all digital cameras and with most popular digital x-ray systems and digital model software packages.

Limitations

In 2000, Curtis and colleagues [14] evaluated Orthognathic Treatment Planner (GAC International, Birmingham, Alabama), a predecessor of Vistadent. The predicted position of the upper lip was accurate at 80%, but that of the lower lip was less than 50% accurate.

Dentofacial Planner (Dental Facial Software Inc., Toronto, Canada)

Dentofacial Planner software (Dentofacial Planner Software Inc., Toronto, Ontario, Canada) was initially developed by an orthodontist as a computer-assisted instrument for diagnosis and planning for orthodontic treatment purposes only[15,16]. With further development of the system, the software was modified to allow for simulation of surgical operations. Dentofacial Planner software uses nonlinear ratios with pattern recognition to predict soft tissue response. This approach is used to account for lip trap, incompetence, and mentalis strain more accurately. One of the limitations, however, is that although the ratio settings for other programs can be changed by the user, those for Dentofacial Planner software are hard-coded, and therefore cannot be customized [7].

Limitations

In the line drawings era, Dentofacial Planner was found to be accurate in predicting the nose and chin position, but a significant difference in lip predictions was noted[1]. Schultes and colleagues studied the soft tissue prediction in the vertical plane of 25 patients with mandibular retrognathia with Dentofacial Planner and found that the nose and the chin position were accurate, whereas the highest degree of error occurred in the submental area.

In 1997, Aharon and colleagues[13] compared Dentofacial Planner and Quick Ceph Image software and found that both programs performed well in simulating single-jaw and double-jaw operations. With Dentofacial Planner, the positions of the lower lip and soft tissue menton were significantly different.

OPAL TM

Orthognathic prediction analysis (OPAL) is software that enables simulation of surgical jaw movements and dental decompensation and illustrates theses 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 [2].

Limitations

The accuracy of preoperative OPALTM orthognathic predictions was assessed by retrospective analysis of 25 Class II patients who had orthodontic treatment combined with mandibular advancement osteotomy. There was a bias towards under-prediction of the vertical skeletal changes when there was more backward mandibular rotation than anticipated. Immediate postoperative cephalograms were also affected by a 2.1 mm mean downward displacement of the mandible as a result of the surgical wafer [17].

Dolphin imaging software

Dolphin imaging software developed by Dolphin Imaging and Management Solutions (Chatsworth, California) allows the clinician to use standard and customized analyses for treatment planning purposes. The lateral analyses include Ricketts, McNamara, Steiner (Tweed), Jarabak, Roth, Sassouni, McLaughlin, Bjork, Alexander (vari-simplex), Downs, Holdaway, Alabama, Burstone, Gerety, and many combinations and variations. Frontal analyses include Ricketts, Grummons, and Grummons simplified. Bolton and arch length discrepancy analyses are also possible using this software. The software is designed to allow for superimposition of cephalometric tracing over the patient's photograph and for superimpositioning of patient tracings at different time points with standard superimposition. It also provides a special visual norm (''Profilogram'') superimposition. The software calibrates radiographs for accuracy and automatically generates anatomic structures and profiles. It can be used for orthodontics and surgical applications. Specifically from a surgery standpoint, simulation of LeFort osteotomies, bilateral sagittal split osteotomy (BSSO), multiple jaw surgery, and genioplasty is easily visualized. Cosmetic rhinoplasty procedures and zygomatic implants can also be simulated on this software with image touch-up and morphing tools. It is also network ready for image access anywhere in the office, and it exports images to any standard file format[1].

Limitations

In 2003, Lu and colleagues [18] evaluated the accuracy of the outcome in soft tissue prediction by using Dolphin Imaging system software (version 6) after bimaxillary orthognathic surgery. In the 30 patients who underwent combined Wassmund and Kole procedures with an optional genioplasty to correct bimaxillary protrusion, they found that the nasal tip, soft tissue a point, and upper lip presented the least amount of predicted errors in the sagittal plane. Contrary to the findings with the nasal tip, the lower lip prediction was the least accurate and was mostly

positioned more anterior to the actual position. The predictions were generally more accurate in the vertical plane as opposed to the sagittal plane. There was no statistical significance between the predictions of the groups with or without genioplasty [18].

Smith and colleagues [10] chose 10 difficult test cases with vertical discrepancies and ''retreated'' them using the actual surgical changes to investigate perceived differences in the ability of current software to simulate the actual outcome of orthognathic surgery. They evaluated five programs Dent facial Planner Plus, Dolphin Imaging, Orth plan (Orthographic Inc., Salt Lake City, Utah), Quick Ceph Image, and Vistadent by using the default result and a refined result created with each program's enhancement tools. Three panels consisting of orthodontists, oral maxillofacial surgeons, and laypersons judged the default images and the retouched simulations by ranking the simulations in side-by-side comparisons and by rating each simulation relative to the actual outcome on a six-point scale. Dent facial Planner Plus was judged the best default simulation software. It also scored best when the retouched images were compared with Dolphin Imaging and Quick Ceph.

CASSOS 2001 software

The City University of Hong Kong (CityU) and the University of Hong Kong (HKU) have developed a computer assisted surgical planning system for orthognathic surgery. Called CASSOS 2001, the software is designed to provide a comprehensive range of functionality for maxillofacial surgeons to manage and produce surgical plans prior to the surgery. It helps surgeons to evaluate their surgical plans, predict the outcome and compare pre-operation and post-operation appearances of the patient.

Limitations

A study (2004) was done to evaluate the accuracy of soft tissue profile predictions generated by the CASSOS 2001 software in Chinese skeletal Class III patients treated with bimaxillary surgery. More errors were found in the vertical than in the horizontal measurements, with the majority of these errors occurring with landmarks of the upper and lower lips. It was found that most of the significant errors of prediction were found in the region of the upper and lower lips[19].

NemoCeph

It includes the most frequently used Lateral and Frontal analysis, with personalization tools which allows the creation of new cephalometric analysis. Nemo Ceph permits the best localization of the cephalometric points, due to the huge quantity of tools for basic and advanced image processing. It permits the tracing of different analyses at the same time. These allow the correction of the frame during the tracing process. It includes Growth prediction tracings,

cephalometric conversion CO-CR, VTO and STO. The cephalometric VTO is combined with a dental VTO, which allows you to make predictions. These predictions may be combinations of mixing the profile and space analysis, assessing the possibility for extractions, stripping, expansions, etc. STO allows for surgical, pre-surgical and pre-orthodontics predictions. These include all types of osteotomies: BSSO, Vertical Mandibular, Maxillary, Occlusal Plane Alterations, Seminary and Genioplasty; resulting in total control of the fulcrums using the chosen osteotomies. Lateral and frontal Morphing can be done.

Limitations

According to a study[20] on comparison of manual and digitized method, amongst the linear measurements, Anterior facial height (AFH), Posterior facial height (PFH), Upper lip length (ULL), Lower lip length (LLL), Anterior cranial base length (ACBL), Posterior cranial base length (PCBL), Maxillary length (MxL), Mandibular length (MdL), Lower incisor to NB line (L1 to NB) and Lower lip protrusion (LLP) showed statistically significant difference but were clinically acceptable. While amongst the angular measurements, only occlusal plane angle showed statistically significant difference between the two techniques that was not clinically acceptable.

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 [21] 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 [22]. Both manual and computerized cephalometric prediction methods are two-dimensional and cannot fully describe three-dimensional phenomena.

Limitations

Head positioning, rotational and geometric errors mean that there is not accurate representation of the anatomy; some elements can be obscured. A basic problem associated with prediction methods is that prediction changes in patients with craniofacial anomalies, facial asymmetries, and orofacial clefts cannot be interpreted because most cephalometric measurements are distorted in the presence of facial asymmetry. 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. 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 item [2].

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 analyse the shape of a facial unit only from the side but not from the frontal or submento-vertex view. Regarding orientation, they permit the measurement of pitch but not of yaw or roll[23].

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 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.

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