Accuracy and characteristics of cephalometric software programs for outcome prediction of orthognathic treatments: A Review

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Abstract

Objectives: Several software programs have been designed for outcome prediction of orthodontic and surgical treatments. This study aimed to review the accuracy and characteristics of cephalometric software programs for outcome prediction of orthognathic surgeries.

Methods: This study reviewed studies that compared cephalometric software programs in terms of accuracy and characteristics for outcome prediction of orthognathic surgeries. The results of studies regarding some two-dimensional (2D) and three-dimensional (3D) software programs for this purpose were collected and reported.

***Conclusion*:** Use of diagnostic software programs for prediction of treatment outcome is an inseparable part of orthognathic treatment. Some studies have reported acceptable diagnostic accuracy of these software programs and their optimal efficacy for guiding the patients towards accepting or rejecting a treatment. However, using the manual technique to demonstrate the outcome of orthognathic treatment is still efficacious. Several factors such as updating the primary versions, their compatibility with the new operating systems, education and customer service are important in continuation of use of these software programs.

***Key Words*:** Software; Orthognathic Surgery; Decision Support Techniques

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Introduction

Use of orthognathic surgeries for correction of skeletal and occlusal problems has recently increased due to the growing demand of adult patients for orthodontic treatments. Success of orthognathic treatment is measured based on optimal function, stability and esthetics. Definition of favorable esthetic results is highly specific and may vary from the perspectives of clinicians and patients. Therefore, methods should be used to visualize and illustrate the treatment plan and predict the outcome of treatment (1). Prediction of surgical outcome is beneficial since it serves as a route of communication among the individuals involved in the course of treatment namely the patient, orthodontist and maxillofacial surgeon. The treatment plan can be modified according to the esthetic demands of patients. Each patient has his/her own conception of beauty and there is a possibility that the dentist, surgeon and patient do not share the same esthetic goals (2).

Prediction of surgical outcome is done based on clinical, radiographic and cephalometric analyses as well as evaluation of the study casts. These predictions are highly important since they are used to guide the course of treatment towards the desired outcome and also to present a logical initial view of the treatment outcome to patients.

Lateral cephalometry is a valuable tool in orthodontic diagnoses, allowing angular, linear and proportional measurements. It allows assessment of the relationship between the functional components of the face, nose, skull, base of skull, maxilla, mandible and maxillary and mandibular teeth. Cephalometric analysis provides valuable information about dentoskeletal deformities as well. Moreover, serial cephalograms can show the progression of treatment and the trend of growth of patients and ensure the stability of treatment results (3).

The first method for prediction of orthognathic surgical outcome is to manually superimpose tracing of different skeletal parts on the traced preoperative lateral cephalogram to simulate the outcome of treatment. In this method, the general soft tissue profile after treatment according to the accepted ratios and soft and hard tissue alterations are determined. However, variations in soft tissue thickness, muscle tonicity, reaction of patients and individual differences in landmark manipulation can negatively affect the prediction of results. Moreover, in this method, linear drawing of soft tissue is performed to predict the surgical results, which is not understandable to patients (3). In the second method, suitable cephalometric landmarks are digitized and surgical displacements are simulated on the display monitor and then the results of different treatment options are compared. Simulated images are shown to patients to provide them with a general idea about the treatment outcome. However, these images also have a linear nature. In the third method, cephalometric images are computerized and video-taped image of the patient is also entered into the computer. These two images are combined and simulations are done yielding linear images and video clips. This method enables better communication between patients and clinicians to standardize the treatment objectives. In this method, different images can be compared to decide about the desired treatment outcome. Recently, a three-dimensional (3D) computerized technology was introduced for planning and predicting the surgical results. However, familiarity with the two-dimensional (2D) prediction techniques is imperative prior to using the 3D technique (4).

The significance of prediction of surgical results has been the topic of some orthodontic studies, and many software programs have been designed for this purpose. Using these software programs, desired changes can be made to dental arches and patient’s face. For this purpose, data are transferred to the software and the results are displayed on a monitor. Thus, there would be no need for drawing or oral explanation on photographs (5).

This study aimed to review the advantages, shortcomings and characteristics of software programs for prediction of the outcome of orthognathic treatments.

Methods

A large number of orthodontic and surgical articles published from 1985 until 2015 in journals indexed in PubMed and ISI on most prevalent 2 and 3D software analyses were studied to compare their accuracy, validity, efficiency, clarity and simplicity and to assess the essence and quality of softwares in prediction of orthognathic surgery cases. Twenty-four articles were selected based on definition and efficiency of commonly used software programs. The inclusion criteria were as follows:

- Studies on humans

● Orthognathic surgery with or without previous orthodontic treatment
● Use of computer software programs to predict immediate surgical changes.

Results

Orthodontic treatment planning software programs:
I: Two-dimensional software programs:
A. Quick Ceph (QC; Quick Ceph Systems, San Diego, CA, USA):
Quick Ceph was the first orthognathic surgical prediction software program introduced. Recently, the latest version of this software, QC2000, was introduced with many advantages in comparison to the previous versions, including capture and storage of high-resolution images with customizable analysis, growth forecasts, treatment simulations, flexible soft tissue analysis, digital image enhancement for tracing accuracy, compatibility with any operating system, and export of images to Joint Photographic Experts Group format (6).
B. Dentofacial Planner (Dentofacial Software, Toronto, Canada):
This software is suitable for profile analysis, treatment planning and prediction of orthodontic and maxillofacial surgical treatment outcome (7). In this software, cephalograms are digitized and several analyses are performed for assessment of dentofacial morphology. The dentofacial showcase feature of this software is used to take and analyze photographs before entering them into the software. After image entry, it can be combined with the cephalogram, and changes in the cephalogram can also be applied and viewed on the photograph and vice versa. Thus, a suitable treatment plan can be achieved with the cooperation of orthodontist and patient. This program also enables tele-conference and long-distance consultation. Using the visual treatment objective feature of this software, changes in CO-CR, facial growth and skeletal and dental changes can be all combined to observe the results. Moreover, according to esthetic consultation, soft and hard tissue images can be predicted and presented to patients to find out their opinion about the images (8).
C. Orthognathic Treatment Planner (Pacific Coast Software, Pacific Palisades, CA, USA):
This software was manufactured by the Pacific Coast Software company for prediction of orthognathic surgical outcome. It can be used for diagnosis, treatment planning and communication with patients to determine the desired treatment plan and the outcome and consequences of treatment (9).
D. Prescription Portrait (Rx Data Inc.):
This software was manufactured by the Rx Data company for prediction of the outcome of orthognathic surgeries (10).
E. VistaDent AT (GAC International):
Using VisaDent AT orthodontic treatment planning software, landmarks can be easily transferred to cephalograms to see the results. It enables replacement of points/landmarks and tracing. Using this software, the results of 56 standard cephalometric analyses can be observed and compared. The virtual treatment objectives can be viewed in this software via saving the results of virtual treatment, prediction of virtual growth pattern and simulation of the results of surgical and orthodontic treatments. This software allows for superimposition of tracings on cephalograms and treatment goals as well as printing of the results (11).
F. Portrait Planner (RX Data Inc. Ooltewah, TN, USA):

It was among the first software programs to relate lateral cephalograms with lateral photographs. In this software, preoperative lateral photograph can be predicted in response to displacement of skeletal structures (11).

G. TIOPSTM (Total Interactive Orthodontics Planning System):

The TIOPS software is used for simulation of orthognathic surgery, treatment planning and assessment of postoperative accuracy or stability of orthognathic surgery. In this software, lateral cephalograms are digitized and morphologically traced. It also provides a list of corresponding values, prints and marks them. Simulation of orthognathic surgery is done on the display monitor and then surgical treatment planning is done graphically and numerically. Visual surgical images (performed treatment) is printed in a different color and superimposed on the preoperative surgical image to determine the changes in the sagittal plane and vertical dentofacial plane. The positional changes designed on the surgical model in a 3D articulator and the results of linear measurements made in the canine and molar areas are reported with ±0.5 mm accuracy (12).

H. OPALTM (Orthognathic Prediction Analysis):

It is a more comprehensive version of COGSOFTTM (Consultant Orthodontists Group) software designed in 1982 according to the Eastman analysis. This software allows for simulation of the effects of dental corrections and jaw movements following surgical procedures. These changes can also be reported quantitatively according to the ratios of the soft and hard tissues. In this software, prints of tracings are digitized and the X and Y coordinates of some points in the hard and soft tissues and the angles are determined and used to observe the actual dental and skeletal changes that occur as the result of treatment (13,14). OPAL software can digitize lateral cephalograms of the skull and most numerical and graphic manipulations and show the tracings. It can easily save the data, replace and show patient files, automatically adjust the magnifications and facial features, use multiple analysis such as Eastman, Downs, Ricketts and McNamara and undo/redo all predictions (13,14).

I. Dolphin Imaging System (Dolphin Imaging, Canoga Park, CA, USA):

Dolphin software can indirectly digitize dental, skeletal and soft tissue landmarks in scanned cephalograms using a cursor. It helps the orthodontist in identification of landmarks. It can accurately locate the landmarks and predict their location; thus, error in landmark identification is minimized. After completion of digitization, the software connects the respective points and provides the orthodontist with a traced, recognizable image. This image can be modified manually if necessary (15).

J. Orthoplan (Practice Works, Atlanta, GA, USA):

This software is the replacement version of Orthognathic Treatment Planner, designed for prediction of the outcome of orthognathic surgery (16).

II: Three-dimensional software programs:

A. Dolphin 3D:

Following the introduction of cone beam computed tomography (CBCT) and increased use of 3D photography, many software manufacturers added the 3D feature for prediction. Dolphin 3D software can reliably simulate the movements of the maxilla and mandible three-dimensionally (hard tissue) (17).

B. Maxilim:

This software provides a 3D imaging environment for assessment of the skull anatomy, treatment planning prior to maxillofacial surgery and simulation of soft tissue outcome (18).

In contrast to Dolphin software, which uses linear indices for prediction of soft tissue response, Maxilim uses computerized strategies that can predict soft tissue alterations and postoperative appearance of patients (18). Maxilim was designed based on simulation of biomechanical model, and does not use soft and hard tissue movements for prediction; instead, it benefits from the elastic deformation behavior of soft tissue for this purpose (18).

C. V work:

Using this 3D software, axial images are converted to 3D images. This software is used to create 3D models. First, landmarks are identified on the superficial 3D model and their position is confirmed in multiple planar reformat. The positive value of coordinate demonstrates the front, superior and left side and the negative values demonstrate sides vice versa (19).

Discussion

Following the introduction of diagnostic software programs for orthodontic treatment planning, the accuracy of computerized predictions of treatment outcomes must be compared (20). Prisse et al. (21) evaluated the accuracy and reliability of manual cephalometric tracing technique for prediction of soft tissue profile and showed that manual cephalometric tracings can be accurate and reliable. Another study compared Dolphin software and manual technique on 40 patients including 35 females and five males (32 class III and 8 class II) with no previous history of surgery. Manual tracing was compared with indirect digitation by the Dolphin software, and reliability of the two methods was compared using paired t-test. The least accuracy in the vertical plane was noted in subnasal and upper lip areas. No significant difference was noted in prediction of outcome in groups with/without gingivoplasty. Nose type had the least prediction error and highest reliability. However, attempts are still ongoing to improve the accuracy and reliability of this program and include change in tissue thickness and muscle tonicity in it (22). Hing (20) (1989) compared the results of prediction by QC software with actual postoperative results in 16 patients who underwent mandibular advancement. The software overestimated the position of horizontal landmarks and underestimated the position of vertical landmarks in the anterior mandible. Errors during superimposition and errors during landmark identification and marking were among the reasons for prediction errors. The precision of the digitizer and computer manipulation are among other possible reasons for such errors (20). In the mentioned study, for soft issue prediction, the ratio of labiomental fold (LMF'x) to point B (Bx) was variable, which could be related to morphological differences of the lower lip preoperatively, labiodental interferences and radiographic position of the lips. Some differences were also noted in some points in comparison with the mean values, which could be related to small sample size and post-surgical observations at different time points. According to the authors, the accuracy of surgical procedure, post-surgical relapse, and different soft tissue responses to surgery cannot be completely controlled for. Thus, it is important to determine the maximum values and inaccuracies bearable by patients. By doing so, computer software programs can be quickly and reliably used for tracing by orthodontists without emphasizing on the artistic aspects of the topic (20).

Gennaro et al. (23) evaluated the differences in prediction of jaw repositioning by Dolphin and VTO. Twenty patients were evaluated by manual tracing of cephalograms for VTO and Dolphin version 11.7 software. No significant difference was found between manual cephalometric tracing and Dolphin software ($P>0.05$ for anterior repositioning, anterior open bite and posterior open bite). Peterman et al. (24) (2016) evaluated the results of using Dolphin software for prediction of treatment outcome in class III patients undergoing maxillary advancement and mandibular retraction. Pre- and postoperative cephalograms were traced and superimposed. These data were used for surgical simulation by the software and prediction of final tissue profile of patients. Images predicted by the software were compared with actual profile images of patients after treatment. The results showed that the performance of Dolphin software for most landmarks was acceptable with ±2 mm error range in the X axis; lower lip predictions had the least accuracy. They did not recommend this software for perdition of the outcome of precise surgical procedures.

Magro-Filho et al. (25) evaluated the standard profile pictures of 10 patients with class III malocclusion and convex facial profile requiring bimaxillary surgery. The patients had maxillary deficiency and mandibular prognathism in the horizontal plane. Dentofacial Planner Plus and Dolphin version 9 were used for prediction of post-surgical profile. Predicted images were compared with actual photographs. A total of 101 orthodontists, maxillofacial surgeons and general dentists evaluated the images. They were requested to use the software programs for treatment planning and instruction of patients. Significant differences were noted between groups. Dolphin software had a better prediction of the position of nasal tip, chin and submandibular region. Dentofacial Planner Plus was superior for prediction of nasolabial angle and upper and lower lips. No significant difference was noted between the software programs in general comparison of profile (25). Nam and Hong (26) (2015) evaluated the efficacy of Simplant Pro software in prediction of surgical results with special emphasis on soft tissue movements. They used computed tomographic images taken before and after the procedure in 29 patients undergoing orthognathic surgery. According to the preoperative computed tomographic data, predicted soft tissue images of patients were evaluated. The results showed that the position of landmarks in use of software had been changed towards the left, forward or downward compared to their actual position. This software was highly accurate for prediction of craniofacial soft tissue landmarks such as pronasale but had very low accuracy in anterior-posterior predictions. Smith et al. (16) (2004) evaluated the ability of Dentofacial Planner Plus (DFP), Dolphin Imaging (DI), Orthoplan (OP), Quick Ceph Image (QCI) and Vistadent (GAC) for simulation of the results of orthognathic surgery and reported that DFP was the most accurate simulation software. Difference between DFP and other software programs was in algorithms connecting the soft and hard tissues during movements, linking techniques, programming and operative controls in determining simulated boundaries and efficient image compatibility tools.

All simulation programs are based on algorithms that calculate the position of soft tissue in response to changes in hard tissue. Changes in soft tissue in response to skeletal movements are simulated by the software, which has been pre-programmed and this ratio is different in different software programs (16). In the past, software programs used linear ratios for calculation of soft tissue movements. It was believed that soft tissue response had a fixed ratio to the amount of skeletal movement. Except for DFP, all other programs used in the afore-mentioned study use linear ratios. But DFP uses non-linear ratios to determine the pattern of soft tissue change in response to hard tissue alterations. The second reason explaining the difference between programs is the difference in method and complexity of technique of relating radiograph-photograph. Several factors affect this ability including the number of soft tissue points and the ability to well superimpose the images during rotation. Although all programs try to achieve the best fit (superimposition) between the digitized cephalogram and lateral photograph, some differences exist between them. QC1, GAC, DI and DFP superimpose the digitized cephalogram on lateral photograph using the commonly used conventional points. DFP, DI and QCI then allow suitable manipulations and size change on cephalograms for better fit and closer superimposition (19). However, GAC does not allow for more efficient correction of soft tissue. Although the correlation of cephalogram-photograph is highly efficient in DI and QC, DFP better allows for fitting the curve by adding points to the soft tissue outline (16).

OP identifies some soft tissue landmarks on the cephalogram and some points such as the lips on the photograph. Then, it electronically combines both images and thus, the need for soft tissue adjustment on the photograph to match the lateral cephalogram is eliminated. According to Upton et al, (27) (1997) OP has problems when the head position on the cephalogram and photograph is not the same. Undoubtedly, the quality of correlation between photograph and cephalogram affects the ability of programs for tracing the soft tissue, and poor connection leads to tissue tag, elimination or tracing of sharp angles (27).

Control of the upper and lower lip responses (their control by the program rather than by the operator for lip position) is the most important factor for ranking of simulation by the software programs. It seems that DI and QCI moderately place the lip in correct position but at the same time allow the operator to do some custom manipulations. DI has a feature for automatic superimposition of the lip, allowing the operator to manually adjust the actual vertical position of the lips (27).

The accuracy and efficacy of image enhancement tools affect the ability of the operator in adjusting simulations based on the personal image about the soft tissue response to surgery. DI and QCI have highly efficient image manipulation tools; using these tools, soft tissue contour and positional corrections can be well performed. Also, DFP tools have less complexity while being efficient because this software requires less manual adjustment. GAC and OP rank third since they have limited tools with difficult usage. OP only has the ability to move the soft tissue points (27).

Several factors should be taken into account when choosing a software such as the ability to simulate and predict, implementation, easy to use, cost, compatibility with the exiting software programs, image enhancement tools and activities. DI and QCI ranked second

(after DFP); however, they have been recommended for use due to their compatibility with the operating systems and advanced functional management (27).
Power et al. (15) (2005) evaluated the accuracy of Dolphin version 8.0 for prediction of treatment results following maxillofacial surgical procedures such as mandibular advancement. They showed that significant differences existed between all predictions with the software and actual postoperative results. The least correlation between the actual and predicted results was noted in ANB (0.32) with a mean difference of 2.48 ($P<0.05$). This was clinically significant. In fact, the horizontal plane underwent greater movement than predicted, which may be related to the distal movement performed by the surgeon, which was greater than the desired amount. Another possibility would be that the software could not well predict the magnitude of distal movement. Considering the fact that the surgeons precisely control movements during surgery, the magnitude of surgical movement assumed to be correct. It seemed that the software did not perform calibration to compensate for radiographic magnification. Absence of calibration had similar effects on the vertical dimension as well and the predicted amount of SNMx angle was significantly less than the actual change probably due to systematic errors. Similar differences were noted for LAFH% and MxMn. Lack of information on how to compensate for the radiographic magnification in the software did not affect the diagnostic objectives of Dolphin software for angular measurements but it affected orthodontic movements. Thus, significant differences were noted in predicted measurements in the vertical (MxMn, SnMx, LAFH%) and horizontal (ANB, SNB, SNA) dimensions. This program has yet to become a reliable technique for prediction of orthodontic movements (15).
Syliangco et al. (10) (1997) evaluated the accuracy of prediction of soft tissue changes in mandibular advancement surgery using two software programs namely Prescription Portrait and Orthognathic Treatment Planner. This prediction was performed on 39 patients undergoing surgical treatment. Preoperative cephalograms and profile photographs of patients were entered into the computer, predictions were made and were then compared with actual postoperative results. No significant difference was noted in the accuracy of prediction of the two software programs in horizontal dimension. OTP and Portrait both predicted a more anterior position compared to actual results. Both programs had adequate precision in prediction of the position of the upper lip and the chin (mean error of 6 mm) and the least accuracy was noted for the lower lip (mean error of 1.3 mm). The results of predictions of the two programs were compared with clinical results and both showed to have the same prediction pattern such that in the upper lip zone, both had an insignificant error in 80% of the cases, which was expected because in mandibular advancement surgeries, only the mandible is surgically manipulated. Clinically significant errors were noted in only 3% of the predictions. For the chin, prediction error was less than 1 mm in 74% of the cases and it was more than 2 mm in 7%. The lowest accuracy belonged to the lower lip; in 46% of the cases, its clinical error was not significant and in 23%, its prediction error was more than 2 mm. In their study, insignificant clinical error was considered as <1 mm, which would not affect the treatment plan or communication with patient. However, questionable clinical

error was 1-2 mm, which would probably only affect the treatment plan. Significant clinical error would affect both the treatment plan and communication with patients (10). In vertical dimension, the two programs showed a significant difference in prediction of the results. The accuracy of Portrait was slightly higher than that of OTP (+ 0.2 mm). However, the prediction pattern of the two programs was the same and the upper lip was the most accurate and the lower lip was the least accurate point. Both programs showed overestimation of the lower third of the face. Different accuracies were noted in different points of the face. In the upper lip, 88% of prediction errors were less than 1 mm and only 3% of prediction errors were more than 2 mm. Prediction of the chin point also had lower accuracy; 72% had 1 mm errors and 7% had errors over 2 mm. Lower lip also had the least accuracy; errors were less than 1 mm in 48% and over 2 mm in 29% (10). In general, the quality of prediction of videotaping modality of the two programs was moderate to good and scored 55%. In specific areas, the results of prediction by the two programs were the same except for the upper lip at which, Portrait showed better performance while prediction of lower lip point was better by OTP. The best predictions were noted in the upper lip, chin and submental area (score of 64 out of 100) and the worst prediction was noted in the lower lip (score of 51 out of 100). In scoring of prediction results in the form of videotapes, orthodontists and surgeons gave similar scores while laypeople gave a better score to predictions overall. However, laypeople gave a lower score to the chin and submental area predictions compared to specialists. As expected, the most accurate predictions belonged to the upper lip and the chin. About 75% of the cases had errors less than 1 mm and about 10% had errors over 2 mm. These findings can be explained by the fact that upper lip did not undergo surgery and the chin has a fixed, predictable hard to soft tissue ratio of 1:1 (13). On the other hand, only 50% of the samples had errors less than 1 mm in the lower lip and 20% had errors over 2 mm. the mean error of the lower lip in the horizontal plane was 1.3 mm; this value was 1.4 mm in the vertical plane. In general, it seems that lower lip is the most difficult area for soft tissue prediction (11,28,29). The actual position of the lower lip after treatment is often more posterior and more superior than predicted (28). Hing (20) (1989) reported that the actual position of the lower lip is more posterior than predicted by Quick Ceph software (mean of 1.9 mm). Sinclair et al. (11) (1995) used Portrait software for prediction and showed that actual position of the lower lip was significantly more anterior than predicted (mean of 0.9 mm). These results highlight the need for further investigations to find an acceptable soft to hard tissue ratio in the lower lip to accurately predict postoperative results in this region. This is because the lower lip is flexible and influenced by several variables (such as the position of upper incisors, inclination of lower incisors, soft tissue thickness and consistency, muscle strength, etc.). Also, it should be noted that in mandibular advancement surgeries, lower lip often becomes prominent and is held behind the maxillary incisors. Change in the anterior position of the mandible releases the lip and gives it a more natural appearance. However, this is very hard to predict.

In prediction of soft tissue results, postoperative tracings in OTP and Portrait had almost equal accuracy; however, Portrait was superior in prediction of vertical position (by 0.2 mm). Regarding clinical judgment, the two programs had the same performance except for the upper lip, for which, Portrait had a better performance while OPT had better results for the lower lip. Cousley et al. (30) (2003) evaluated the accuracy of OPAL software for prediction of hard tissue results in mandibular advancement osteotomy. Slight differences were noted in prediction and actual surgical results regarding LAFH%, SNA, ANB, OJ and OB. This was expected for SNA since mandibular advancement surgery is only performed on the mandible. LAFH% was the most accurately predicted variable. These findings were in line with the results of other software programs (Dentofacial Planner (8), Quick Ceph (7) and TIOPS (12)).

However, the highest inaccuracy was noted in prediction of L1/MnP. Vertical skeletal measurements (LAFH, LPFH and MxP/MnP) were significantly underestimated such that for example, MxP/MnP was underestimated while it actually showed long-term increase in 43% of the cases (mean of 4.1). Regarding the underestimated results, 3.8 mm reduction in LPFH (40%) and 2.9 mm increase in LAFH (55%) were seen. In fact, mandible underwent backward rotation during advancement but its magnitude was less than that predicted by OPAL software.

Nadjmi et al. (18) assessed the accuracy of Dolphin 2D and Maxilim 3D software programs for prediction of soft tissue profile in patients undergoing LeFort I osteotomy. The CBCT-synthesized lateral cephalograms before and after surgery were collected and postsurgical profiles were predicted by Dolphin and Maxilim. The position of soft tissue landmarks in profile views was compared with post-surgical landmarks on photographs. The results showed that the alpha value for internal consistency of each landmark in X and Y axes varied between 0.96 and 0.99 except for the superior stomion in Maxilim (0.83). The actual mean of error and 95% confidence interval revealed that errors in Dolphin software were greater than those in Maxilim but the differences were not significant (P>0.05) except for the soft tissue point A. The greatest errors were seen in the chin area. Errors in prediction of nasolabial and mentolabial angles were greater such that the prediction error in Dolphin software was 9°, which was clinically significant. Accordingly, both programs were suitable for clinical use but their inaccuracy for the chin area must be taken into account during complex surgical treatment planning (18).

Kaipatur et al, (31) in a systematic review indicated that computer software programs could not accurately predict all skeletal changes. However, most inaccuracies were within the range of 2 mm or 2°; part of it could be due to measurement errors in cephalometric tracings. They showed that these programs cannot uniformly predict the skeletal changes following orthognathic surgery but their results are within the clinically acceptable range.

The ability of the software programs to determine orthodontic and surgical treatment plans and predict the results has made them an inseparable part of the treatment process. Patients are often satisfied with these programs showing the outcome of treatment. Sarver et al. (32) (1988) reported that 89% of patients who viewed video clips of their treatment outcome and then underwent surgery were completely satisfied at six months postoperatively while this rate was 45% for those who had not seen their predicted treatment outcome. Despite the advantages of these software programs, it should be noted that showing the virtual treatment results to patients must be done with caution in order not to create unrealistic expectations. Development of unrealistic expectations in patients following the use of these programs has been described as a common concern (33). Phillips et al. (34) (1995) reported that patients who saw video clips of their treatment outcome had higher expectations of treatment compared to the standard control group. Sarver et al. (32) (1988) showed that 89% of patients believed that the video images were real and 83% used these images to make a decision regarding their treatment. Sarver et al. (32) raised some concerns and questioned that whether showing the treatment outcome images to patients guarantees achieving them or the surgeon may show the same images to patients as the actual treatment result. Also, patients must be ensured that the shown images are not manipulated by an expert programmer in any way. However, Sarver et al. (32) reported satisfactory results, which eliminated these concerns to a great extent.

Concerns that exist regarding the selection and use of these software programs include compatibility of the software with advances in technology, designing suitable features necessary to make changes, efficient customer service and provision of educational services on how to work with the software. Moreover, updating and adding new features to the software can increase its popularity; although maintenance and upgrading of advanced software programs can be costly for the users.

Despite the availability of many studies comparing the diagnostic accuracy of software programs for orthodontic and surgical treatment planning, it should be noted that these studies were undertaken using the available technologies at the time. Considering the ongoing advances in computer technology, further studies are required using novel technologies to compare the most recent version of software programs. Also, since the newer versions of the software programs have additional features for prediction of the outcome of orthodontic treatment and orthognathic surgeries, future comparisons using these features are imperative.

Conclusion

Use of diagnostic software programs for orthodontic treatment planning is now considered as an inseparable part of treatment. Many software programs are available to serve this purpose. Studies comparing the diagnostic accuracy of these software programs have reported their acceptable accuracy and acknowledged their benefits in guiding and helping patients in accepting or rejecting a treatment. However, the manual method of showing the orthodontic or surgical treatment results is still efficacious. It should be noted that use of these software programs may raise unrealistic expectations in patients regarding the treatment outcome, which highlights the need for caution when showing patients the predicted outcome of treatment. Last but not least, many factors affect the continuation of use of these programs such as updating the primary version, compatibility with the current operating systems, education, customer service and troubleshooting services.

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