Achieving the Prediction Results by Visualized Treatment Objective Following Anterior Maxillary Segmental Osteotomy. A Retrospective Study

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Abstract This study used the manual visualized treatment objectives (VTO) as a tool to evaluate the predictive value of the computer-assisted VTO. Presurgical cephalometric tracing predictions generated by oral and maxillofacial surgeons and computer-assisted VTOs were compared with the postsurgical outcome as seen on lateral cephalometric tracings. Ten measurements of the predicted and actual postsurgical hard tissue landmarks were compared statistically. A paired Student's *t* test showed that in nine of ten measurements, there were no statistically significant differences in the mean values of manual VTO (MVTO). Statistically significant differences were found in one of the four linear measurements (cant of upper lip $P = 0.0001$). For computer assisted (CAVTO) Student's *t* test showed that in nine of ten measurements, there were no statistically significant differences in the mean values. Statistically significant differences were found in one of the four linear measurements (nasolabial angle, $P = 0.0001$). From these data, it appears that both VTOs demonstrated good predictive comparative outcome, and are equally predictive, but CAVTO is precise.

Keywords Cephalometric analysis · Quick ceph · Orthognathic treatment planner

Introduction

Maxillomandibular harmony constitutes a major component of the ideal facial aesthetics. Improvement of facial aesthetics is one of the main reasons that patients request surgical correction of dentofacial deformities. Orthognathic surgery enables the correction of dentofacial skeletal or occlusal discrepancies. The need for this type of surgery has increased recently, as more adult patients are seeking orthodontic treatment [1]. Without a visual reference, it is hard for the patients to visualize the outcomes of the surgical procedures and to contribute to the treatment plan in the preoperative planning session [2, 3]. In this manner, visualized treatment objectives (VTO) are important predictive tools to interpret the patient's perspectives of aesthetics and to give an acceptable preview of the result. Furthermore, these VTOs facilitate the communication between the treatment team and the patient as well as provide guidance to the desired result. Accurately predicting surgical outcome is of paramount importance in treating dentofacial deformities. These predictions have a threefold purpose: (1) To guide the treatment to the desired result; (2) To give the patient a reasonable preview of the outcome; and (3) To serve as a communication tool between the orthodontist and surgeon, as well as the patient.

The computer assisted system is the current software program commonly used for the generation of surgical VTOs in our institution. Therefore, it is the overall aim of this retrospective study to compare the use of the computer assisted visual treatment objective with that of the present

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gold standard “the manual visual treatment objective” (MVTO). This was accomplished by first evaluating the prognostic value of each of these predictive tools to the final surgical outcome. We next compared the surgical manipulations established for the MVTO with the computer assisted visual treatment objective (CAVTO) generated from the same movements.

Aim

The aim of this retrospective study was to assess the accuracy and advantages of manual VTOs (MVTO) & CAVTO in correctly predicting the hard and soft tissues changes in facial and skeletal deformities and its ability to prepare prediction profiles by using the records of ten patients who had undergone maxillary anterior segmental osteotomy.

Materials and Methods

This retrospective study was conducted on ten adult orthognathic surgery patients from Oral and Maxillofacial Surgery Department. Twenty patient records were reviewed and ten patients were selected based on the following inclusion criteria: presence of preoperative and post-operative cephalometric radiographs, presence of manual surgical prediction tracing, records of the surgery performed and the amount and direction of the surgical moves (surgical prescription), no history of cleft lip and/or palate, no history of temporomandibular joint surgery.

The sample consisted of five males and five females with a mean age of 25 years and 5 months. The “gold standard” the manual surgical VTO was prepared by the operating surgeon as follows: the technique used an original cephalometric tracing and an overlay. On the original tracing, a small horizontal line was drawn to mark the ideal vertical position of the central incisor. An overlay was placed on the original tracing and all structures that will not change with surgery, the surgical reference lines and the small horizontal line were traced. A line representing normal maxillary depth was drawn (from nasion to A point which was perpendicular to the Frankfort horizontal plane). A small vertical line was drawn 4 mm anterior to the maxillary depth line. This line represents the ideal anterior-posterior position of the most labial aspect of the central incisor. At its inferior extent, this vertical line connects to the small horizontal line representing the ideal vertical position of the central incisor and thus creates a small backward “L.” The overlay was repositioned on the original tracing with the central incisor tip placed inside the “L.” The maxilla was oriented so that the occlusal plane was not changed. The new position of the teeth and maxilla

were traced onto the overlay. The mandible was then auto rotated into the appropriate occlusion and the proximal portion of the mandible was traced. If needed, the mandible was moved to obtain a Class I occlusion. The distal segment of the mandible was traced onto the overlay. At this point, the soft tissues were traced based on Wolford’s published ratio of soft tissue response to each particular procedure [4].

The CAVTO was generated by reproducing the conventional prediction tracing on an HP Deskjet F4185 Color Graphics Scanner, so that a direct comparison with the postoperative radiograph could be made. Entering the surgical prescription for jaw movements into computer assisted surgical treatment planning function generated the prediction.

The CAVTO was generated using a Proprietary Cephalometric Software ‘ProCeph v2.1’ that was developed using Microsoft Net Framework 3.5 SP1 for research purpose at the Department of Orthodontics. The advantage of this particular software is that it is highly customizable and allows scripting. Any particular measurements to be performed, as planned for a research study, can be written as a script (using C# Language) and the software provides the necessary visualizations with little effort.

All patients had a combination of the following surgical procedures: anterior segmental osteotomy (five patients), anterior segmental osteotomy and mandibular subapical osteotomy (five patients). The post-operative position of the anterior maxilla and mandible were stabilized with rigid fixation or wire osteosynthesis.

The surgeries were performed by one or two surgeons. Preoperative and postoperative cephalometric radiographs were obtained. Head position was oriented such that the Frankfort horizontal plane was parallel to the floor.

Preoperative radiographs were taken 1 month before surgery. No active orthodontic therapy was ongoing at this time. Postoperative radiographs were taken no more than 1 month after surgery and before any post-operative orthodontic therapy. The preoperative cephalometric radiograph was traced onto acetate paper. Fourteen cephalometric landmarks were identified and marked on the tracing [5] (Table 1; Fig. 1). The post-operative radiograph and conventional surgical prediction tracing were each superimposed on the preoperative tracing using the cranial base as a guide for the superimposition. The landmarks basion, porion, sella, pterygomaxillary fissure, orbitale, and nasion were marked on the post-operative radiograph and the manual surgical prediction tracing. This was done to ensure that the cranial base structures would be coincident.

The preoperative radiograph and tracing, conventional and computer generated surgical prediction tracing, and post-operative radiograph were scanned into the computer assisted VTOs on an HP Deskjet F4185 Color Graphics

Table 1 Landmarks used

1.	Sella
2.	Nasion
3.	Porion
4.	Orbitale
5.	Pogonion
6.	Point A
7.	Point B
8.	Incisal tip point of upper central incisor
9.	Apical point of upper central incisor
10.	Incisal tip point of lower central incisor
11.	Apical point of lower central incisor
12.	Anterior point of tangent to base of nose
13.	Subnasale
14.	Inferior point of tangent to upper lip

Table 2 Measurements used

Angular measurements	Linear measurements
1. Facial angle (ang)	1. Upper incisor to NA (U1-NA)-(Linear)
2. Angle of convexity (AOC)	2. Nasion perpendicular to A point (Nperp-A)
3. SNA	
4. ANB	
5. Nasolabial angle (NLA)	
6. Upper incisor to NA (UI-NA) (ang)	
7. Cant of upper lip (Cant)	
8. Interincisal angle (Interinc)

Fig. 1 Cephalometric landmarks used for digitization

Scanner. Each image was digitized using the previously noted cephalometric landmarks. A custom cephalometric analysis [5] was developed to measure both angular and linear measurements (Table 2). For this study, soft tissue was unpredictable because of prolonged post-operative edema. Cephalometric analysis of the conventional prediction tracing and the post-operative radiograph were done by the computer.

Results

Manual Visualized Treatment Objective

The predictive value of the MVTO for skeletal changes associated with orthognathic surgery was evaluated as described in the “Materials and Methods” section. Comparison of the mean values from the MVTO with those from the post-operative cephalometric radiograph is given in (Table 3; Fig. 2). Student’s *t* test showed that in nine of ten measurements, there were no statistically significant differences in the mean values. Statistically significant differences were found in one of the four linear measurements (cant of upper lip $P \leq 0.0001$).

Computer Assisted Visualized Treatment Objective

The predictive value of the CAVTO for skeletal changes associated with orthognathic surgery was evaluated (Table 4; Fig. 3). Comparison of the mean values from the CAVTO with those from the postoperative cephalometric radiographs. Student’s *t* test showed that in nine of ten measurements, there were no statistically significant differences in the mean values. Statistically significant differences were found in one of the four linear measurements (nasolabial angle, $P \leq 0.0001$).

MVTO versus CAVTO

The results from the two prediction methods are presented in (Table 5; Fig. 4) by comparing the differences from the final outcomes and calculating the mean difference between these discrepancies. The height of the bars represents the amount of average discrepancy when compared with the final outcome. A bar in the positive direction represents overestimation, and a bar in the negative direction represents underestimation.

Table 3 Average results of ten patients using the manual prediction method (MVTO)

S. no.	Parameters	Count	Mean MVTO	Mean final	Mean difference	SD	P value difference
1.	ang	10	89.8000	90.2300	−0.43000	0.30552	0.193
2.	aoc	10	2.1000	2.2300	−0.13000	0.20224	0.536
3.	SNA	10	83.0000	83.3500	−0.35000	0.27049	0.228
4.	ANB	10	2.5000	3.6100	−1.11000	0.43626	0.108
5.	UI-NA	10	23.6000	25.9100	−2.31000	1.2382	0.0122
6.	Intreinc	10	129.6000	128.0600	1.54000	1.2917	0.264
7.	U1-NA	10	2.2000	3.3800	−1.18000	0.64667	0.0222
8.	Nperp-A	10	1.4000	2.0500	−0.65000	0.51039	0.235
9.	NLA	10	100.7000	101.6400	−0.94000	0.89768	0.322
10.	Cant	10	12.4000	13.6900	0.99	1.1560	0.0001

Angular measurements: *ang* facial angle, *aoc* angle of convexity, SNA, ANB, *UI-NA* upper incisor to NA, *inc* interincisal angle. Linear measurements: *UI-NA* upper incisor to NA, *Nperp-A* nasion perpendicular to A point, *NLA* nasolabial angle, *Cant* cant of upper lip

Fig. 2 Manual visual treatment objective (MVTO). Angular measurements: *ang* facial angle, *aoc* angle of convexity, SNA, ANB, *UI-NA* upper incisor to NA, *inc* interincisal angle. Linear measurements: *UI-NA* upper incisor to NA, *Nperp-A* nasion perpendicular to A point, *NLA* nasolabial angle, *Cant* cant of upper lip

Student's *t* test showed that in eight of the ten measurements, there were no statistically significant differences in the mean values. However, statistically significant differences were found in the mean values for nasolabial angle ($P \leq 0.0001$) and cant of upper lip ($P \leq 0.0001$).

A quick summary of the significant differences are given in (Table 6; Fig. 5). If one method is not significantly

different from the final outcome and the other is, the first is preferred. If both methods are significantly different from the final outcome and not each other, either could be used with caution. Similarly, if the two methods are not significantly different from the final outcome or from each other, there is no preference.

Discussion

Cephalometric Surgical Predictions

Cephalometric surgical predictions are an integral part of orthognathic surgery treatment plans and several methods of prediction have been described [6–10]. The accuracy of some of these methods has been verified in previous studies [9–13].

The cephalometric prediction tracings have evolved gradually. Their development has been slow but more or less gradually grew to near perfection. Lateral cephalometric radiographs are commonly used to predict the surgical treatment outcomes. Visualized treatment prediction

Table 4 Average results of ten patients using the computer assisted visualized treatment objective (CAVTO)

S. no.	Parameters	Count	Mean CAVTO	Mean final	Mean difference	SD	P value difference
1.	ang	10	89.9700	90.2300	−0.26000	1.45224	0.606
2.	aoc	10	1.7300	2.2300	−0.50000	1.13142	0.577
3.	SNA	10	83.1400	83.3500	−0.21000	1.45071	0.277
4.	ANB	10	3.4900	3.6100	−0.12000	0.92400	0.0386
5.	UI-NA	10	25.2600	25.9100	−0.65000	1.01023	0.244
6.	Intreinc	10	127.8300	128.0600	−0.23000	0.98793	0.918
7.	U1-NA	10	3.5000	3.3800	−0.01	1.68024	0.0422
8.	Nperp-A	10	2.1200	2.0500	−0.07	2.15520	0.809
9.	NLA	10	102.3100	101.6400	0.67000	2.53818	0.0001
10.	Cant	10	13.1700	13.6900	−0.52000	3.41799	0.572

Fig. 3 Computer assisted treatment objective (CAVTO)

began with manual profile predictions. Whatever the prediction method is, producing the predicted soft tissue outline is more of an art form than a scientific exercise [14]. Although, manual prediction methods are relatively informative to the professionals, as they presented only the “line drawing” profile of the surgical simulation and they cannot provide a realistic image of the treatment results to the patients [12].

Later on, computer-based analysis was introduced in the 1980s, where cephalometric landmarks could be digitized and the repositioning could be monitored. This has facilitated the prediction, shortened the time and was more practical and accurate than the manual techniques [7]. With these programs, measurements, calculations and analyses were performed by the computer. These cephalometric radiographic digitizing programs use the data from the published studies of the soft tissue reaction to the hard tissue movements. They incorporate these data into prediction algorithms that can provide excellent single-line profile drawings predicting the final treatment goal. Patient is often essentially interested in determining what he or she will look like after treatment [2, 15–19].

Fig. 4 Differences between the computer assisted VTO and MVTOs when compared with final outcome

Studies on the accuracy of these computer-assisted predictions were started with Hing in 1989 [20]. In this study, the accuracy of Quick Ceph [20] is evaluated and the results indicated that the horizontal landmark positions were overestimated and the vertical landmark positions were underestimated for the anterior mandible. Kazandjian et al. [21] compared the accuracy of two video imaging systems (Quick Ceph Image and Portrait Planner). Again, both programmes were noted to underestimate the amount of lower lip retraction and prediction was more superior than the actual result. Also the prediction errors in the vertical plane were greater than those in the sagittal plane [10, 21].

At present, a wide variety of computer-assisted cephalometric prediction softwares are available. This has prompted us to carry out a study on the computer assisted software (CAVTO) versus manual VTOs (MVTO) in our institution. For the present we restricted our study to only anterior maxillary osteotomies. This was done because we wanted to get acquainted with the system first and then study the genuine difference between MVTOs and CAVTOs.

Table 5 Average results of ten patients using the computer assisted VTO to manual visualized treatment objective (MVTO)

S. no.	Parameters	Count	Mean CAVTO-final	Mean MVTO-final	Mean difference	SD	P value difference
1.	ang	10	-0.4300	-0.2600	-0.17000	1.98049	0.792
2.	aoc	10	-0.1300	-0.5000	-0.1200	0.82334	0.189
3.	SNA	10	-0.3500	-0.2100	-0.14000	0.82219	0.603
4.	ANB	10	-1.1100	-1.7600	-0.15000	2.37545	0.409
5.	UI-NA	10	-2.3100	-0.6500	-1.66000	3.20978	0.136
6.	Intreinc	10	1.5400	-0.2300	-1.54000	6.16226	0.0430
7.	UI-NA	10	-1.1800	0.1200	-1.30000	1.43527	0.0158
8.	Nperp-A	10	-0.6500	0.0700	-0.72000	1.12230	0.073
9.	NLA	10	-0.9400	0.6700	0.67000	2.95125	0.0001
10.	Cant	10	-1.2900	-0.5200	0.99000	3.25817	0.0001

Table 6 Statistical results summary: comparison of final outcome to prediction method for orthognathic surgical changes

S. no.	Parameters	CAVTO-final	MVTO-final	CAVTO-MVTO	Preferred method
1.	ang	NS	NS	NS	either
2.	aoc	NS	NS	NS	either
3.	SNA	NS	NS	NS	either
4.	ANB	NS	NS	NS	either
5.	UI-NA	NS	NS	NS	either
6.	Intreinc	NS	NS	NS	either
7.	U1-NA	NS	NS	NS	either
8.	Nperp-A	NS	NS	NS	either
9.	NLA	<0.5	<0.5	NS	MVTO
10.	Cant	<0.5	<0.5	NS	CAVTO

Fig. 5 Comparisons of final outcome to prediction methods for orthognathic surgical skeletal changes

One Aspect of the Current Study

One aspect of the current study was to evaluate the CAVTO and MVTOs to the postsurgical cephalometric measurements. The second aim was to determine the prognostic usefulness of the CAVTO as compared with the MVTO. The main findings were that the CAVTO is comparable to the MVTO in its prognostic usefulness and has good predictive value.

The CAVTO is one of a number of computer-assisted cephalometric prediction programs available. Cephalometric radiographs and photographs are scanned into the program. The images are digitized resolution, fixel and cephalometric analysis can then be performed. If it is deemed necessary, a surgical prediction can be performed using the program's treatment planning function. When movements of the hard tissues are programmed into the system, concomitant changes are made to the soft tissue profile. These changes are based on ratios that have been

previously elucidated and incorporated into the software System. Because the change in soft tissue profile is directly related to the hard tissue changes, it is important that the system accurately predict hard tissue changes. For the computer assisted system to be clinically useful, the prediction of the hard tissue must be accurate [5].

Various authors have studied the accuracy of soft tissue predictions, and a few have studied the accuracy of hard and soft tissue predictions [19–21]. Generally, these studies show that computer systems used to create the surgical predictions are fairly accurate. Therefore, this study was designed to evaluate the accuracy of computer assisted system since computer usage has seen a tremendous growth in its use in the recent past.

Comparing the MVTO with the actual post-operative tracing performed, an assessment of the prognostic accuracy of the MVTO versus the CAVTO. One of ten measurements were noted to have a statistically significant difference between the predicted and actual values. The MVTO overestimated cant of upper lip. This is because the soft tissue changes that occur following AMO cannot be accurately predicted due to the fact that the adaptability of soft tissue changes is doubtful to the changes occurring in the underlying hard tissue skeleton. Further the prolonged post-operative edema, however minor it may be can also hamper with the post-operative tracing leading to inaccurate prediction. Further the influence of incisor position and angulation, soft tissue thickness and tonicity, perioral musculature and muscle attachments were considered as possible explanations for the low accuracy rates for lip predictions [9, 22].

When the CAVTO is compared with the post-operative cephalometric radiograph, one of ten measurements was noted to have a statistically significant difference. As with the MVTOs, computer assisted VTO overestimated nasolabial angle. This is because the soft tissue changes that occur following AMO cannot be accurately predicted due to the fact that the adaptability of soft tissue changes is doubtful to the changes occurring in the underlying hard

tissue skeleton for the reasons already mentioned there by affecting the angle measurements.

These data demonstrate that when comparing CAVTO and MVTO systems to the final outcome, the two prediction methods are often in close agreement. Except for the soft tissue parameters like cant of upper lip and nasolabial angle. Nasolabial angle prediction was close to reality in CAVTO while the cant of upper lip was nearer to the final outcome in MVTO. This again may be attributable to the prolonged post operative edema and unpredictable soft tissue adaptability to the changes that occur in the underlying skeleton. Therefore further prediction of nasolabial angle the MVTO seems to be preferred method while for the cant of upper lip prediction CAVTO was better method of preference. For the hard tissue prediction either method is preferred. Based on these results, it appears that both the MVTOs and CAVTO have a high level of reliability for the maxillary hard tissue than the soft tissues.

Now a day's due to technology advancement and necessity of data mobility, the manual method is becoming handicap. According to a research which was carried out by Collins et al. [23] who, on 20 cephalograms, confirmed that analysis of digital cephalogram is comparable with that of the scanned one. Their research showed the unreliability in evaluating the linear parameters which partially correlate with our results.

Landmark identification is one of the sources of measurement of error in conventional cephalometric analysis. Baumrind and Frantz [24] indicated that the geometric form of the error distribution around a landmark is reflected by the definition of the landmark, that a point situated on a curvature will be relatively well defined in one direction or axis, whereas its other axis will be uncertain. Thus, the cephalometric variables will display a varying degree of measurement error, depending on how the lines, constituting the linear or angular variable, intersect the reference points. Mostafa et al. [25] suggested that angular measurements have more error than linear measurements. This is in agreement with our findings in which nasolabial angle showed the greatest differences.

The manual method required higher time expenditure and has a high possibility of error. With the advent of the computer-assisted method, a decrease in the differences of cephalometric measurements began to be observed, as the precision of the measurements became significantly more accurate due to the intrinsic characteristics of measuring computer pixels. The computer reduced, although discretely, the possibility of differences, as it is more secure than the manual method. When locating landmarks defined as being more inferior or deep in a given bone contour—for instance, points A, B and N—the computerized method proved to be more reliable than the manual method.

However, besides the several advantages of these systems, it should be kept in mind that the presentation of these predictions to patients should be done carefully, to avoid unrealistic expectations of the surgical outcome, as some authors have some concerns that predictions may imply a guaranteed outcome [26]. Sarver et al. [16] found that 89 % of a sample of patients judged video images to be realistic and 83 % benefited from image analysis in determining whether to undergo the operation.

Although we have attempted to provide standardized material for this current study, with the precautions described and with the facilities of a newer version of the software, it may still be prone to some errors due to individual inter subject variations; differences in the exact time period from preoperative to post-operative imaging for each case, or soft tissue profile changes due to effects other than surgery (weight gain or weight loss), variations in the image quality or prediction algorithms may be considered as the possible sources of errors.

The present study indicates that both MVTO and CAVTO are accurate in predicting hard tissue profile. Soft tissue profile predictions are subjected to variations for the reason already mentioned above. Hence one can use these techniques for communication between surgeon, orthodontist and the patient. As far as hard tissue predictions are concerned, they can also be used as a tool to give the patient a reasonable preview of the outcome. However one should keep in mind that the presentation of these predictions to patients should be done carefully to avoid unrealistic expectations of the surgical outcome.

The progression in computer science is a rapid and ongoing process. Novel techniques use 3D colour photographs, algorithms and reconstructed 3D CT scans to enhance the prediction accuracies of these systems [27, 28]. Comparing 3D prediction based on finite element method with a 2D prediction program (Dentofacial Planner PlusTM) it was found that the prediction accuracy was satisfactory. In addition to profile prediction, they reported that the procedure allowed a differentiated 3D assessment of aesthetically important regions such as cheeks, nasolabial folds and the nasal wings without an additional X-ray radiation [28]. Further investigations are required to incorporate individual patient variability in order to integrate these systems into our current use.

Summary and Conclusion

During the last few decades there has been a tremendous expansion of orthognathic surgery as a method of treating dentofacial deformities and at the same time the need to predict the end results has increased and retrospective studies of treated patients have provided the clinician with

guidelines for estimating the affect of hard tissue surgery on the soft tissues.

Human error associated with cephalometric land mark location might eventually be eliminated with fully automated digitization of cephalogram. Utilization of computer prediction techniques in routine orthognathic procedure offers a less time consuming, efficient, managable and systemic way to handle relatively difficult procedures. Speed and accuracy being the hallmarks of this modern technique, it is only logical and advisable to incorporate this technique routinely in our assessment procedures. From the results of this study both MVTO and CAVTO have shown promising results with respect to predicting surgical changes in maxilla. The incorporation of cephalometric digitization and analysis offered the clinician several advantages that were quickly recognized. (a) The use of computerized prediction speeds the process of constructing the visualized treatment objective (VTO) of the profile at the initiation of treatment. (b) Construction of VTO by hand, using acetate tracing is decidedly more laborious than the computerized VTO. (c) The laborious measurement of angles and distances by the manual use of a protractor was eliminated. (d) The computer programs contain data bases for gender, age, and racial and ethnical differentials. Individual measurements can be applied to the appropriate data base. (e) Furthermore the computer assisted system has the advantage of eliminating errors that might occur with human hand in MVTO.

As the difference between both predictions is more or less not significant, as far as hard tissues are concerned, one tends to incline towards computer assisted systems. However soft tissue changes are unpredictable in both the techniques. These are not accurately predicted due to the fact that the soft tissue adaptability is always doubtful to the changes that occur on the underlying hard tissue skeleton but with advent of new technologies and development of new software programmes the computer assisted VTOs will definitely overcome these shortcomings in future and hope that they will definitely have an edge over MVTOs.

However further studies are needed and in future there is a need to further investigate the development of new software programmes integrated with 3D predictability.

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