CONTINUING EDUCATION

Evaluation of video imaging prediction in combined maxillary and mandibular orthognathic surgery

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The purpose of this study was to evaluate the accuracy of the soft tissue profile "line drawings" predicted by Quick Ceph Image in combined maxillary and mandibular orthognathic surgical procedures. Preoperative (mean = 27.7 days presurgical) and posttreatment (mean = 11.5 months postsurgical) lateral cephalograms of 40 white patients (10 males and 30 females) who had completed treatment that involved orthodontics, one-piece LeFort I osteotomy, and mandibular advancement by bilateral sagittal split osteotomy with or without genioplasty were used in the study. Forty-five lateral hard and soft tissue landmarks were digitized, using the "on-screen" digitizing option, for each cephalogram and for each computer predicted posttreatment tracing. A customized analysis consisting of 24 linear and 4 angular measurements was used to analyze the differences between the actual posttreatment cephalometric landmark measurements and computer predicted landmark measurements. Statistically significant differences between the posttreatment cephalometric soft tissue profiles and the computer predicted soft tissue profiles were analyzed for the total sample, patients grouped according to: magnitude and direction of maxillary movements, adjunctive genioplasty procedure, V-Y closure of the LeFort I incision, and gender and age differences. The results indicated that for some of the soft tissue landmarks, differences were found between the posttreatment and the computer predicted profiles. Differences between the predicted and actual posttreatment soft tissue profiles may be attributed to the inaccuracy of Quick Ceph Image's default soft to hard tissue ratios when predicting the soft tissue response to combined maxillary and mandibular orthognathic surgical procedures. (Am J Orthod Dentofac Orthop 1997; 112:656-65.)

Success of surgical orthodontic therapy is determined by such factors as function, stability, and esthetics. Defining ideal esthetic results is very subjective and may be viewed differently by the clinician and the patient. Establishing common goals and expectations concerning the outcome of proposed surgical orthodontic therapy is a crucial part of the treatment planning process.

There are five general methods of visualizing, planning, and predicting surgical orthodontic outcomes:

1. Manual acetate tracing "cut and paste" techniques as described by Cohen,[1] McNeill et al.,[2] and Henderson.[3]
2. Manipulation of patient photographs to illustrate treatment goals.[4]
3. Computerized diagnostic and planning software that produces a soft tissue profile "line drawing" as a result of manipulation of digitized structures of lateral cephalometric radiographs.
4. Computerized diagnostic and planning software that integrates video images with the patient's lateral cephalogram to aid in planning and predicting surgical orthodontic procedures (Videocephalometrics). Visualization of the facial changes by the patient and clinician is enhanced, alternate treatment plans are evaluated with ease, clinician and patient communication is enhanced, and more realistic patient expectations may be achieved.[5-10]
5. Three-dimensional computer technology for planning and predicting orthognathic surgery. Moss et al.[11] expanded on the early methods of three-dimensional planning by including

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Table I. Statistically significant mean differences between actual and predicted soft tissue landmark positions of previous studies

		Areas of discrepancies (mm)		
	Type of surgery	*Nasal tip*	*Lower lip*	*Chin*
Quick Ceph Hing, 1989[13]	Mandibular Advancement *n = 16*		*Horizontal:* 1.9 ± 0.38 *p ≤ 0.01*	*Vertical:* 0.5 ± 0.78 *p ≤ 0.05*
Rx Portrait/Planner Sinclair et al.[8]	Mandibular Advancement with and without genioplasty *n = 56*		*Horizontal:* −0.76 ± 2.05 *p = 0.01* *Thickness:* −0.86 ± 1.76 *p = 0.001*	
Dentofacial Planner Konstantina et al.,[14]	LeForte I *n = 21*	*Horizontal:* −0.50 to −0.95 *Vertical:* −0.80 to −1.64 *p < 0.0004*	*Horizontal:* −1.57 *p < 0.0004*	

− indicates predicted landmarks more retrusive (horizontal) or inferior (vertical).
+ indicates predicted landmarks more protrusive (horizontal) or superior (vertical).

laser scanning to model the soft tissue response to hard tissue movements.

Studies investigating the validity of methods predicting the soft tissue outcomes after orthognathic surgery are relatively few. Pospisil,[12] comparing hand-drawn acetate tracings, found that 60% of his prediction tracings were inaccurate when compared with 6-month postoperative radiographs. He stated that the soft tissue profiles in 83% of two-jaw and 40% of one-jaw cases were inaccurately predicted by the methods he tested. The magnitudes and directions of discrepancy reported by Pospisil[12] were not described. Hing,[13] and more recently Sinclair et al.,[8] investigated the accuracy of computerized soft tissue profile line drawings, using records of patients who had undergone mandibular advancement surgery. In addition, Sinclair et al.[8] compared the accuracy of the line drawings of subjects who had mandibular advancement with those who had both mandibular advancement and advancement genioplasty. With the Quick Ceph (Orthodontic Processing) diagnostic software program, Hing[13] found that the largest amount of discrepancy between the computer predicted profile outline and the posttreatment radiographic tracing was in the horizontal position of the lower lip and the vertical position of soft tissue Pogonion (Pg′). The predicted position of the lower lip was more anterior and the position of Pg′ was more superior than the actual movements. Sinclair et al.,[8] using the Prescription Planner/Portrait (Rx Data Design, Inc.) cephalometric and imaging system, found that the lower lip on the predicted soft tissue profile outline was significantly more retrusive and thinner than the lip on the posttreatment radiographic profile. He also found no statistically significant differences when comparing the computer predicted outlines and the posttreatment radiographic profiles in subjects who had undergone an additional genioplasty procedure with those who had not received a genioplasty. Konstiantos et al.[14] investigated the accuracy of computer predictions of patients who had undergone a LeFort I procedure using the imaging system of DentoFacial Planner (Dentofacial Software, Inc.). In this study's comparison of prediction and final treatment profiles, the nasal tip (Pronasale) and nasal base (Subnasale) on the prediction were posterior to those of the final treatment profile. Also, the position of the lower lip in the prediction was more retrusive than the lower lip on the final treatment profile (Table I).

Although computerized diagnostic and treatment planning methods are rapidly gaining in popularity, the validity of the information gained from using these computerized methods has not been thoroughly investigated. The purpose of this study was to test the accuracy of the computer-generated surgical predictions of one commercially available diagnostic and planning software package (Quick Ceph Image, Orthodontic Processing).

MATERIAL AND METHODS

Cephalometric data from 40 white patients who had completed treatment that involved orthodontics, one-piece LeFort I osteotomy, and mandibular advancement through bilateral sagittal split osteotomy (BSSO) with or without genioplasty were included in this study. Also, patients who had V-Y closure of the LeFort I incision

Table II. Quick Ceph Image's default soft to hard tissue ratios[18]

Definitions	*Ratios in %*		
	x-axis	*y-axis*	*Rotation*
Orthodontic Ratios			
Upper incisor to upper lip in Class I or II dental relationships	66	—	—
Lower incisor to lower lip in Class III dental relationships	66	—	—
Upper incisor to lower lip in Class I or II dental relationships	44	—	—
Lower incisor to upper lip in Class III dental relationships	44	—	—
Upper incisor to upper lip in Class III dental relationships	22	—	—
Lower incisor to lower lip in Class I or II dental relationships	22	—	—
Orthopedic Ratios			
Maxillary hard tissue A-point to soft tissue A-point	66	33	—
Surgical Ratios			
Maxillary osteotomy—movement at anterior nasal spine to tip of nose	33	16	—
Maxillary osteotomy—movement at anterior nasal spine to upper lip	66	33	—
Maxillary rotation—movement at anterior nasal spine to upper profile	—	—	25
Mandibular osteotomy—movement at protuberance menti to lower lip	50	50	—
Mandibular osteotomy—movement at protuberance menti to chin	100	100	—
Genioplasty—movement at hard tissue pogonion to chin	100	100	—

were compared with those who had simple closure of the incision. The sample consisted of 30 female and 10 male nongrowing subjects, with a mean age of 31.3 years (range: 14.3 to 57.8). Patients who had cleft lip and/or cleft palate or any other congenital deformity were omitted from the study. In addition, any patients who had rhinoplasty or liposuction during the time between records were excluded from the sample.

Cephalometric Criteria

Standardized lateral cephalograms taken presurgically and after treatment were used in the study. All cephalograms were taken with the patient in natural head position, teeth together, and lips in repose. The description of the radiographic intervals are as follows:

1. The presurgical radiographs (T_1) were taken at a mean time of 27.7 days (range: 1 to 99 days) before surgery.
2. The posttreatment radiographs (T_2) were taken at a mean time of 11.5 months (range: 5 to 28 months) after surgery.
3. The mean elapsed time between T_1 and T_2 radiographs was 12.4 months (range: 5 to 29 months).

Computer System Description

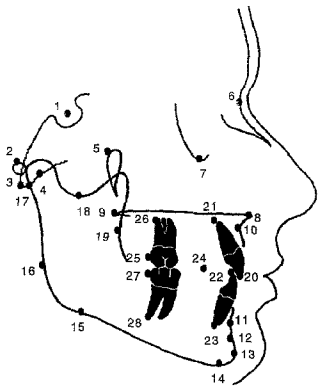
Quick Ceph Image, a computerized diagnostic and treatment planning software system designed for the MacIntosh (Apple Computer, Inc.) computer environment, was used in this study. The complete system, used in this study, consists of a Sony CCD color video camera, a MacIntosh Quadra 700 computer (Apple Computer, Inc.), an Apple 13" High Resolution RGB color monitor (Apple Computer, Inc.), a Hewlett-Packard Deskwriter 550C color printer (Hewlett-Packard Co.), and version 4.3 of the Quick Ceph Image software.

The Quick Ceph Image program generates a soft tissue line drawing or image, based on preprogrammed or user-defined soft to hard tissue ratios. The preprogrammed default ratios, provided by the vendor, are based on retrospective studies of stability and soft tissue changes occurring with various skeletal and dental movements.[15-17] For the purpose of this study, the default ratios preprogrammed for orthodontic and surgical movements by Quick Ceph Image were used. The default hard to soft tissue ratios used by Quick Ceph Image can be seen in Table II.

Cephalometric Data Analysis

Before cephalometric digitization, acetate paper was attached to each radiograph, onto which small points were marked identifying each landmark. Outlines of the maxilla, mandible, and cranial base were drawn to aid in proper superimpositioning of the presurgical (T_1) and posttreatment (T_2) radiographs. In addition, the maxillary outline on the T_1 radiographs was used as a guide to outline the maxilla on the T_2 radiographs. This was done to assure that the T_1 and T_2 maxillary outlines were similar in contour so that proper superimposition at the time of surgical simulation could be achieved. Points corresponding to landmarks Sella, Nasion, Porion, Orbitale, Basion, and Pterygomaxillary Fissure were marked on the T_2 radiograph by superimposing the T_1 and T_2 radiographs on the cranial base. This was done to assure that these landmarks corresponded on both radiographs and that the anatomic landmarks (Porion and Orbitale), landmarks the computer uses to superimpose the cephalograms, were coincident.

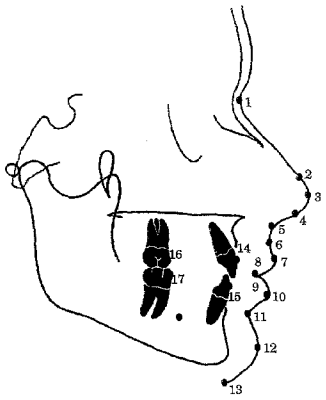
The camera and monitor were calibrated, according to the Quick Ceph Image manual.[18] All radiographs were then digitized using the "on-screen" digitization option included in the Quick Ceph Image program. Forty-five lateral cephalometric landmarks were digitized. Locations



STANDARD LANDMARKS

1. Sella
2. Porion
3. Basion
4. Hinge Axis
5. Pterygoid
6. Nasion
7. Orbitale
8. Anterior Nasal Spine
9. Posterior Nasal Spine
10. A-point
11. B-point
12. Protuberance Menti
13. Pogonion
14. Menton
15. Corpus Left
16. Ramus Down
17. Articulare
18. R3
19. R1
20. Maxillary 1 Crown
21. Maxillary 1 Root
22. Mandibular 1 Crown
23. Mandibular 1 Root
24. Occlusal Plane
25. Maxillary 6 Distal
26. Maxillary 6 Root
27. Mandibular 6 Distal
28. Mandibular 6 Root

Fig. 1. Quick Ceph Image's standard lateral landmarks.



ADDITIONAL LANDMARKS

SOFT TISSUE
1. Nasion
2. Supratip Depression
3. Pronasale
4. Columella
5. Subnasale
6. Superior Labial Sulcus
7. Upper Lip Anterior
8. Stomion Superior
9. Stomion Inferior
10. Lower Lip Anterior
11. Inferior Labial Sulcus
12. Pogonion
13. Menton

HARD TISSUE
14. Upper Incisor Anterior
15. Lower Incisor Anterior
16. Maxillary 6 Crown Tip
17. Mandibular 6 Crown Tip

Fig. 2. Additional landmarks for study's customized analysis.

of the landmarks can be seen in Figs. 1 and 2, respectively. Outlines of the maxilla, mandible and soft tissue profile were also digitized with the stream digitization function of the program.

A customized soft tissue analysis was developed and used to evaluated the cephalometric data. The analysis included 24 linear measurements and 4 angular measurements. Of the 24 linear measurements, 17 were based on measurements from a vertical and horizontal reference line to a digitized landmark. The SN+7° plane was used as the horizontal reference line and a perpendicular to this line passing through hard tissue nasion was used as the vertical reference line. The remaining 7 linear measurements were between 2 digitized landmarks.

Method of Prediction

The following protocol was used to generate a soft tissue profile prediction for each patient in the study. Each patient's previously digitized T_1 radiograph was recalled from the patient's file to appear on the monitor screen. A treatment window was opened, which contained a copy of the T_1 radiograph and tracing. The T_2 radiograph was then recalled and superimposed on the T_1 radiograph in the treatment window. The T_1 hard tissue outline tracings of the maxilla, mandible, and maxillary and mandibular incisors were repositioned, using the click and drag function, to superimpose on the corresponding structures of the T_2 tracing. For patients who had undergone a genioplasty procedure with advancement of the mandible, the T_1 outline of the mandible was moved to correspond with point B and the lower border of the mandible. The genioplasty function of the program was then used to reposition the chin so that hard tissue points Pogonion and Menton corresponded with the same points on the T_2 tracing. Quantification of the direction and magnitude of movement for each hard tissue component was registered

and stored by the computer. Quick Ceph Image uses the x, y, and rotational coordinates of points Anterior Nasal Spine (ANS), point A (A-pt.), maxillary incisor tip, Posterior Nasal Spine (PNS), and the crown of the maxillary first molar to quantify maxillary movements. Movements of the mandible are quantified by movements seen at Protuberance menti (Pm), or Suprapogonion, and mandibular incisor tip. Chin movements are quantified by movements of Pogonion (Pg).

As hard tissue components of the T_1 radiographs were moved to superimpose on the corresponding structures of the T_2 radiographs, the computer generated a profile outline using the preprogrammed default soft to hard tissue ratios. Each altered T_1 tracing was saved as the computer predicted tracing (PT) for each patient and then printed. Landmarks, as in the T_1 and T_2 radiographs, were marked on the PT printout and subsequently digitized in the same manner as the T_1 and T_2 radiographs. Measurements from the T_2 and PT analyses were then printed for statistical comparison.

Method Error

Errors associated with digitization and methods of measurement were assessed by digitizing 10 randomly selected cephalograms, printing the digitized tracings, and then redigitizing the printed tracings.

When comparing the measurements of the digitized printouts with the measurements of the actual cephalometric tracings, the tracings from which the printout were made, the linear measurement's mean differences were within 0.62 mm. The mean differences of the angular measurement were within 0.90°. The only statistically significant differences between the digitized printout and the T_2 tracing were in the vertical positions of subnasale, stomion inferior, soft tissue pogonion, and soft tissue menton. However, the mean differences of these landmarks were within 0.60 mm with a standard error of the mean of less than 0.16 mm.

Statistical Analysis

The data were analyzed for the entire sample and also for separate groups, which significantly differed in the amount and direction of maxillary movement resulting from surgery. Groupings were based on more than a 2 mm maxillary movement along the x- or y-axes. Two other groups, patients who had genioplasty with mandibular advancement and patients who had V-Y closure of the maxillary LeFort I incision, were compared with those who had not had these procedures to detect whether significant differences were present.

Means, differences of the means, standard error of the means, the two tailed t test, and p-values were calculated for the measurements between the PT and T_2 tracing soft tissue analyses for the total sample. Mean differences, differences of the mean differences, standard error of the mean differences, the two tailed t test, and p-values were calculated for the measurements between the non-V-Y and V-Y closure groups and also between the nongenioplasty and genioplasty groups. The difference of the means, standard error of the mean differences, and the F test p-values were calculated for the measurements between the PT and T_2 soft tissue analyses for the maxillary movement groups. Means, standard deviations, and ranges for the computer-generated surgical movements were also calculated. Statistical significance was defined as $p < 0.01$.

RESULTS

For the total sample, the PT landmarks and the immediate T_2 radiograph landmarks locations showed statistically significant differences in several of the vertical and horizontal measurements (Table III).

Vertical: The PT and T_2 tracing vertical positions of Inferior Labial Sulcus (ILS) and the vertical distances from Stomion Inferior (Stom Inf) to ILS were significantly different at the $p < 0.01$ level. Differences between the PT and T_2 vertical positions of Subnasale (Sn), Stom Inf, Lower Lip Anterior (LLA), soft tissue Pogonion (Pg′) and the vertical distance from Sn to Stom Sup showed the greatest variability and were significantly different at the $p < 0.001$ level. Quick Ceph Image (QCI) tended to place the predicted vertical positions of Sn, Stom Inf, ILS, and Pg′ more inferiorly than their posttreatment positions. Vertical distances from Sn to Stom Sup and from Stom Inf to ILS were shorter when compared with the distances on the T_2 tracings, indicating that the distances between these landmarks were predicted to be closer together.

Horizontal: The degree of variability between the PT and T_2 tracing horizontal landmark positions was less than in the vertical landmark positions. The mean difference of superior labial sulcus (SLS) was statistically significant at the $p < 0.01$ level and the mean differences of Lower Lip Anterior (LLA), The LLA to E-plane and Lower Incisor Anterior (LIA) to LLA were significantly different at the $p < 0.001$ level. The QCI tended to overestimate the horizontal position of LLA and the horizontal distances between LLA to E-plane and LIA to LLA. The positions of LLA on the PTs were more anterior than their positions on the T_2 tracings and the distances between LLA to E-plane and LIA to LLA on the PTs were more than the distances on the T_2 tracings.

Angular: No angular measurement differences between the PT and T_2 tracings were statistically significantly different. However, variability between the PT and T_2 landmarks did exist.

Table III. Total sample: Means, mean differences, standard error of the means, *t* value for mean = 0, and *p* value for the vertical, horizontal and angular positions of the computer predicted (PT) and actual (T_2) soft tissue landmarks

Landmark	Computer predicted (PT)	Actual (T_2)	Difference (PT-T_2)	SE of Mean	t value for mean = 0	p-value
Vertical (mm)						
Pronasale	47.34	46.81	0.53	0.26	2.05	0.05
Subnasale	60.21	59.40	0.81	0.21	3.89	0.00**
Superior Labial Sulcus	65.88	65.71	0.17	0.25	0.69	0.50
Upper Lip Anterior (ULA)	75.80	75.56	0.24	0.23	1.03	0.31
Stomion Superior (Stom Sup)	81.48	81.64	−0.16	0.23	−0.68	0.50
Stomion Inferior (Stom Inf)	85.08	82.96	2.12	0.40	5.27	0.00**
Lower Lip Anterior (LLA)	91.11	88.92	2.19	0.41	5.39	0.00**
Inferior Labial Sulcus (ILS)	102.00	101.01	0.99	0.32	3.05	0.00*
Pogonion	118.95	116.80	2.16	0.38	5.74	0.00**
Menton	133.49	132.91	0.58	0.24	2.35	0.02
Subnasale to Stom Sup	21.27	22.24	−0.98	0.21	−4.57	0.00**
Stom Inf to ILS	16.91	18.03	−1.12	0.32	−3.43	0.00*
ILS to Menton	31.49	31.90	−0.41	0.39	−1.05	0.30
Horizontal (mm)						
Pronasale	31.73	32.07	−0.34	0.18	−1.85	0.07
Subnasale	15.21	15.52	−0.31	0.22	−1.38	0.18
Superior Labial Sulcus	12.75	13.35	−0.60	0.20	−2.90	0.00*
Upper Lip Anterior (ULA)	15.94	15.73	0.21	0.23	0.88	0.39
Lower Lip Anterior (LLA)	14.31	12.69	1.62	0.37	4.41	0.00**
Inferior Labial Sulcus	5.23	4.89	0.34	0.28	1.21	0.23
Pogonion	7.75	7.78	−0.03	0.26	−0.12	0.90
ULA to E-plane	−5.86	−6.00	0.14	0.21	0.66	0.51
LLA to E-plane	−2.63	−4.49	1.86	0.34	5.49	0.00**
Upper Incisor Anterior to ULA	12.11	11.81	0.30	0.22	1.35	0.18
Lower Incisor Anterior to LLA	14.27	12.35	1.93	0.35	5.38	0.00**
Angular (degrees)						
Subnasale-Upper Lip to Horizontal Reference	92.82	90.92	1.91	0.74	2.58	0.01
Nasiolabial Angle	107.81	108.75	−0.94	1.14	−0.82	0.42
Nasal Dorsum Angle	26.96	28.06	−1.10	0.42	−2.61	0.01
Labiomental Fold	132.64	137.82	−5.18	2.12	−2.44	0.02

$n = 40$; $*p < 0.01$; $**p < 0.001$.

Analysis of the amount and direction of maxillary movements for each patient resulted in six separate groups that differed in directional movements of at least 2 mm. Group I (maxillary impaction group) consisted of 18 patients; group II (maxillary impaction and advancement group) consisted of 10 patients; group III (maxillary impaction and setback group) consisted of 3 patients; group IV (maxillary downgraft group) consisted of 6 patients; group V (maxillary advancement group) consisted of 2 patients; and group VI (maxillary setback group) consisted of 1 patient. Analysis of mean differences between the PT and T_2 tracing vertical, horizontal, and angular measurements among the groups revealed no statistically significant differences (Table IV).

Analysis of the differences among subjects who had a genioplasty procedure in addition to LeFort I and mandibular advancement with those who had not had an additional genioplasty procedure revealed no statistically significant differences (Table V). However, QCI seemed to overpredict the vertical distances between landmarks ILS and soft tissue Menton in the genioplasty group and to underpredict the vertical distance in the nongenioplasty group.

When the differences of the mean differences of the group of subjects who had V-Y closure of the LeFort I incision with the group who had not had V-Y closure of the incision were compared, no statistically significant differences were detected (Table VI). In the V-Y closure group, QCI tended to predict the vertical positions of these landmarks more superiorly than their T_2 tracing positions.

Also, no statistically significant differences between the PT and the T_2 tracing landmark positions and measurements were evident when the sample was evaluated by sex or age.

DISCUSSION

Results of this study indicated that there was variability among several of the landmark positions

Table IV. Maxillary group comparisons: Mean differences (predicted minus actual), standard error of the mean differences, and the F test *p*-value for the vertical, horizontal and angular positions of the computer predicted and actual (T_2) soft tissue landmarks

	Groups by maxillary movements												
	Impaction (n = 18)		*Impact/Adv (n = 10)*		*Impact/Back (n = 3)*		*Downgraft (n = 6)*		*Advance (n = 2)*		*Setback (n = 1)*		
Landmark	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*F-test p-value*
Vertical (mm)													
Pronasale	0.25	0.36	1.34	0.49	−0.37	0.89	−0.15	0.63	2.65	1.09	0.00	1.55	0.12
Subnasale	0.78	0.31	1.10	0.42	−0.36	0.77	0.88	0.54	1.60	0.94	0.00	1.33	0.57
Superior Labial Sulcus	0.36	0.37	0.47	0.50	−1.17	0.91	−0.32	0.64	1.05	1.11	−1.00	1.58	0.49
Upper Lip Anterior (ULA)	0.18	0.34	0.96	0.46	−0.97	0.85	0.00	0.60	−0.35	1.04	0.70	1.46	0.42
Stomion Superior (Stom Sup)	0.18	0.34	0.49	0.46	−0.87	0.85	−0.57	0.60	−1.55	1.04	1.00	1.47	0.37
Stomion Inferior (Stom Inf)	2.18	0.60	1.45	0.80	2.37	1.47	3.77	1.04	−0.20	1.80	1.70	2.54	0.44
Lower Lip Anterior (LLA)	2.39	0.61	1.86	0.82	1.77	1.49	3.43	1.06	−0.70	1.83	1.4	2.59	0.51
Inferior Labial Sulcus (ILS)	0.97	0.49	0.79	0.66	1.56	1.21	1.92	0.85	−0.30	1.48	−1.40	2.09	0.62
Pogonion	2.84	0.55	1.29	0.74	2.06	1.35	2.70	0.96	0.20	1.65	−0.70	2.34	0.32
Menton	0.74	0.38	0.00	0.51	1.33	0.93	0.37	0.66	1.20	1.13	1.00	1.61	0.77
Subnasale to Stom Sup	−0.97	0.30	−0.64	0.40	−0.47	0.73	−1.38	0.51	−3.20	0.89	1.00	1.26	0.09
Stom Inf to ILS	−1.20	0.50	−0.62	0.67	−0.83	1.22	−1.80	0.87	−0.20	1.50	−3.20	2.12	0.76
ILS to Menton	−0.22	0.60	−0.78	0.79	−0.27	1.44	−1.57	1.02	1.60	1.77	2.40	2.50	0.53
Horizontal (mm)													
Pronasale	0.74	0.27	0.00	0.37	0.20	0.67	0.25	0.47	−0.15	0.82	−1.00	1.16	0.41
Subnasale	−0.48	0.34	−0.34	0.46	0.70	0.85	0.00	0.60	−0.50	1.04	−1.10	1.48	0.82
Superior Labial Sulcus	−0.95	0.28	−0.97	0.37	1.03	0.69	0.10	0.49	−0.85	0.84	1.00	1.19	0.06
Upper Lip Anterior (ULA)	0.00	0.32	−0.54	0.42	2.00	0.77	1.12	0.54	0.00	0.95	1.80	1.34	0.04
Lower Lip Anterior (LLA)	1.25	0.56	1.46	0.76	2.53	1.39	2.15	0.98	1.60	1.70	3.90	2.41	0.83
Inferior Labial Sulcus	0.12	0.44	0.48	0.59	0.60	1.08	0.57	0.76	0.35	1.32	0.70	1.87	0.99
Pogonion	−0.33	0.19	−0.22	0.25	−0.70	0.46	−0.75	0.32	−0.20	0.57	0.00	0.81	0.77
ULA to E-plane	0.00	0.30	−0.35	0.40	1.53	0.73	0.30	0.52	−0.35	0.89	2.20	1.27	0.18
LLA to E-plane	1.58	0.52	1.83	0.70	2.87	1.28	2.06	0.91	1.20	1.57	4.10	2.22	0.82
Upper Incisor Ant to ULA	0.00	0.29	−0.32	0.39	2.00	0.72	1.28	0.51	−0.35	0.88	1.80	1.25	0.03
Lower Incisor Ant to LLA	1.46	0.55	1.89	0.74	3.40	1.34	2.52	0.95	1.55	1.65	3.50	2.33	0.73
Angular (degrees)													
Subnasale-UL to Horizontal Reference	1.67	1.06	−0.58	1.41	4.27	2.58	4.05	1.83	2.60	3.17	9.80	4.48	0.16
Nasiolabial Angle	1.19	1.67	−0.23	2.23	−4.83	4.09	−3.05	2.88	−6.20	5.00	−11.50	7.07	0.29
Nasal Dorsum Angle	−1.32	0.62	−0.37	0.84	0.47	1.53	−1.02	1.08	−3.55	1.87	−4.80	2.65	0.37
Labiomental Fold	−4.99	3.26	−2.75	4.37	0.77	7.98	−11.18	5.65	−4.15	9.78	−16.90	13.83	0.74

*$p < 0.01$.

when comparing the total sample's PT tracings with the immediate T_2 cephalometric tracings. More variability between the PT and T_2 tracings was found in the vertical measurements than in the horizontal or angular measurements.

When the total sample was separated into groups, determined by the amount and direction of maxillary movements, no statistically significant differences between the PT and T_2 tracing mean differences were found. However, the validity of these group comparisons may be questioned because of the small number of subjects in three of the six groups. When the total sample was separated into groups by patients who had genioplasty or had not had genioplasty in conjunction with the maxillary and mandibular surgical procedures and patients who had V-Y closure or non-V-Y closure of the LeFort I incision, no statistically significant differences were found between the PT and T_2 mean differences for either group. Also, no statistically significant differences were found between the PT and T_2 tracings when evaluating the sample by age and sex.

Results of this study show that areas of discrepancies related to anatomic structures between PT and T_2 soft tissue profiles are similar to those in previous investigations of the accuracy of computerized surgical prediction methods.[8,13,14] However, the direction and magnitude of the discrepancies of these anatomic areas vary from study to study. The current study revealed more computer-predicted measurements or landmark positions that were statistically significantly different from the posttreatment radiographic tracings measurements or landmark positions than did the previous validity studies. One reason for the increase in number of signifi-

Table V. Genioplasty and nongenioplasty group comparisons: Mean differences, differences of the mean differences, standard error of the mean differences, *t* value for mean = 0, and *p*-value for the vertical, horizontal, and angular soft tissue landmark positions of the patients who had genioplasty versus those who had not had genioplasty

Landmark	*Genioplasty mean difference PT-T_2 (A) (n = 23)*	*Nongenioplasty mean differences PT-T_2 (B) (n = 17)*	*Difference of differences (A-B)*	*SE of mean difference*	*t value for mean = 0*	*p-value*
Vertical (mm)						
Pronasale	0.13	1.00	−0.82	0.51	−1.60	0.12
Subnasale	0.54	1.17	−0.63	0.41	−1.51	0.14
Superior Labial Sulcus	−0.10	0.53	−0.63	0.50	−1.28	0.21
Upper Lip Anterior (ULA)	−3.48E-02	0.61	−0.65	0.46	−1.39	0.17
Stomion Superior (Stom Sup)	−0.38	0.13	−0.51	0.47	−1.09	0.28
Stomion Inferior (Stom Inf)	1.87	2.46	−0.59	0.81	−0.72	0.47
Lower Lip Anterior (LLA)	1.86	2.64	−0.78	0.82	−0.95	0.35
Inferior Labial Sulcus (ILS)	0.69	1.39	−0.70	0.65	−1.07	0.29
Pogonion	2.22	2.07	0.15	0.77	0.19	0.85
Menton	0.89	0.16	0.73	0.49	1.49	0.14
Subnasale to Stom Sup	−0.93	−1.04	0.11	0.44	0.26	0.79
Stom Inf to ILS	−1.16	−1.05	−0.11	0.67	−0.17	0.87
ILS to Menton	0.20	−1.24	1.44	0.76	1.89	0.07
Horizontal (mm)						
Pronasale	−0.12	−0.65	0.54	0.37	1.48	0.14
Subnasale	2.17E-02	−0.76	0.78	0.44	1.76	0.09
Superior Labial Sulcus	−0.36	−0.90	0.54	0.41	1.31	0.20
Upper Lip Anterior (ULA)	0.47	−0.16	0.63	0.47	1.35	0.18
Lower Lip Anterior (LLA)	2.03	1.06	0.96	0.73	1.31	0.20
Inferior Labial Sulcus	0.29	0.40	−0.12	0.57	−0.21	0.83
Pogonion	0.11	−0.22	0.33	0.54	0.61	0.54
ULA to E-plane	0.20	5.29E-02	0.15	0.43	0.34	0.73
LLA to E-plane	2.03	1.62	0.41	0.69	0.59	0.56
Upper Incisor Anterior to ULA	0.41	0.14	0.27	0.45	0.60	0.55
Lower Incisor Anterior to LLA	2.20	1.56	0.64	0.72	0.88	0.38
Angular (degrees)						
Subnasale-Upper Lip to Horizontal Reference	1.76	2.10	−0.33	1.51	−0.22	0.83
Nasiolabial Angle	−0.41	−1.65	1.24	2.33	0.53	0.60
Nasal Dorsum Angle	−0.52	−1.88	1.36	0.84	1.63	0.11
Labiomental Fold	−7.83	−1.59	−6.24	4.23	−1.47	0.15

*$p < 0.01$.

cantly different measurements and landmarks may be due to the fact that this study's sample consisted of patients who had undergone a two-jaw surgical procedure with or without genioplasty and the other studies' samples had undergone only single-jaw surgical procedures. Other reasons may result from preprogrammed soft to hard tissue ratios differing from computer system to computer system, different methods of investigation, variability in the amount and direction of hard tissue movements, differing sample sizes, and different methods of statistical evaluation.

Methods of manually predicting soft tissue outcomes after orthognathic surgery have also been shown to have inherent inaccuracies and their variations may be even more than variations shown with computer-aided predictions.

It appears that both manual methods of surgical prediction, as well as computerized methods of surgical prediction, have associated inaccuracies when predicting postsurgical soft tissue outcomes. Probably the most significant reason for the inaccuracies is the variability in soft to hard tissue ratios the computer software uses to predict the soft tissue outcomes. This study used the default soft to hard tissue ratios of QCI, which are those published by Wolford et al.[16] and Epker and Fish.[17]

SUMMARY AND CONCLUSIONS

The following conclusions can be drawn from the results of the study:

1. The amount and direction of soft tissue changes differed between the Quick Ceph Image prediction

Table VI. Non-V-Y and V-Y closure group comparisons: Mean differences, differences of the mean differences, standard error of the mean differences, *t* value for mean = 0, and *p*-value for the vertical, horizontal and angular landmark positions of the patients who had non-V-Y closure versus V-Y closure of the LeFort I incision

Landmark	*Non V-Y mean difference ($PT\text{-}T_2$) (n = 28)*	*V-Y mean difference ($PT\text{-}T_2$) (n = 12)*	*Difference of differences (non VY-VY)*	*SE of mean difference*	*t value for mean = 0*	*p-value*
Verical (mm)						
Pronasale	0.49	0.62	−0.12	0.57	−0.22	0.83
Subnasale	0.90	0.60	0.30	0.46	0.66	0.52
Superior Labial Sulcus	0.43	−0.44	0.87	0.53	1.65	0.11
Upper Lip Anterior (ULA)	0.52	−0.41	0.93	0.49	1.89	0.07
Stomion Superior (Stom Sup)	0.13	−0.83	0.96	0.49	1.95	0.06
Stomion Inferior (Stom Inf)	1.94	2.53	−0.59	0.88	−0.67	0.51
Lower Lip Anterior (LLA)	2.07	2.47	−0.41	0.89	−0.45	0.65
Inferior Labial Sulcus (ILS)	1.05	0.85	0.20	0.71	0.28	0.78
Pogonion	2.09	2.30	−0.22	0.83	−0.26	0.79
Menton	0.63	0.44	0.19	0.54	0.36	0.72
Subnasale to Stom Sup	−0.78	−1.42	0.63	0.46	1.37	0.18
Stom Inf to ILS	−0.88	−1.66	0.77	0.71	1.09	0.28
ILS to Menton	−0.41	−0.40	−1.43E-02	0.86	−1.65E-02	0.99
Horizontal (mm)						
Pronasale	−0.40	−0.19	−0.21	0.40	−0.52	0.60
Subnasale	−0.28	−0.37	9.28E-02	0.50	0.19	0.85
Superior Labial Sulcus	−0.49	−0.84	0.35	0.45	0.78	0.44
Upper Lip Anterior (ULA)	0.13	0.38	−0.25	0.51	−0.49	0.62
Lower Lip Anterior (LLA)	1.35	2.22	−0.87	0.80	−1.09	0.28
Inferior Labial Sulcus	0.14	0.79	−0.65	0.61	−1.07	0.29
Pogonion	−0.40	0.82	−1.21	0.55	−2.19	0.03
ULA to E-plane	0.32	−0.30	0.62	0.45	1.39	0.17
LLA to E-plane	1.82	1.95	−0.13	0.74	−0.18	0.86
Upper Incisor Anterior to ULA	0.28	0.32	−3.92E-02	0.49	−8.05E-02	0.94
Lower Incisor Anterior to LLA	1.67	2.52	−0.84	0.78	−1.08	0.29
Angular (degrees)						
Subnasale-Upper Lip to Horizontal Reference	1.44	3.00	−1.56	1.61	−0.97	0.34
Nasiolabial Angle	0.18	−3.54	3.72	2.45	1.52	0.14
Nasal Dorsum Angle	−1.32	−0.58	−0.74	0.92	−0.80	0.43
Labiomental Fold	−3.62	−8.83	5.21	4.61	1.13	0.26

*$p < 0.01$.

profile tracings and the posttreatment profile tracings in patients who had undergone combined maxillary and mandibular surgery with and without genioplasty.

2. The most statistically significant differences between the Quick Ceph Image predicted profile tracings and the posttreatment radiographic profile tracings were in the horizontal and vertical landmarks associated with the lower lip. Quick Ceph Image tended to predict the position of the lower lip more inferior, shorter, and more protrusive than the lip on the posttreatment radiographic tracings.
3. Statistically significant differences were found between the predicted and posttreatment radiographic positions and measurements of Sn, SLS and Sn to Stom Sup. Quick Ceph Image tended to predict the upper lip to be shorter and the point correlating to SLS more posterior than those on the posttreatment radiographic tracings.
4. The vertical positions of Pg′ on the predicted tracings were statistically significantly different from the positions on the posttreatment radiographic tracings. Quick Ceph Image predicted Pg′ to be more inferior than Pg′ on the posttreatment radiographic tracings.
5. No statistically significant differences were found between the Quick Ceph Image predicted and posttreatment radiographic landmark positions on the basis of gender, age, or for subjects in the maxillary movement group, genioplasty group, or the V-Y closure group.

Although statistical differences were noted between the samples' computer-predicted profile tracings and the posttreatment radiographic profile tracings, the mean differences between landmarks and measurements of the two tracings were relatively small and possibly clinically insignificant. It must be reemphasized that there are many difficulties in accurately predicting soft tissue changes, not only in response to orthognathic

surgery but also in normal growth and development and in patients undergoing routine orthodontic mechanotherapy.

Further research is encouraged in the area of soft tissue response to combined maxillary and mandibular orthognathic surgery not only in the lateral view, but in the frontal view as well. These studies should include large samples with specific criteria for patient age, sex, type of surgery, as well as direction and amount of the surgical procedures performed. Also, more studies investigating the value and validity of current computerized diagnostic and treatment planning systems are needed.

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