The role of computerized video imaging in predicting adult extraction treatment outcomes

Thuan N. Le; Glenn T. Sameshima, DDS, PhD; John E. Grubb, DDS, MSD; Peter M. Sinclair, DDS, MSD

Over the past decade, there has been a dramatic increase in the use of computers as tools in many aspects of orthodontic practice. At first, computers were primarily used for practice management and for cephalometric analysis. Recently there has been an upsurge of interest in the use of computerized video image predictions in orthognathic treatment, where the speed and flexibility of the computer make it an ideal tool for assisting with diagnosis and treatment planning.[1-5] Clinicians have also become more adept in using computers for case presentations and in developing techniques to communicate probable treatment outcomes to their patients. With 70% of prospective orthognathic surgery patients citing esthetics as their principal motivation for seeking treatment, video imaging has become an important means of improving patient communication and education in orthognathic treatment.[6-9]

However, as the esthetic awareness of patients, especially adults, has increased, orthodontists are also being forced to address patients' concerns regarding the potential facial outcomes of the treatment alternatives presented to them. Therefore, not only those patients considering orthognathic surgery, but also those comtemplating extraction treatment may benefit from video imaging that helps them visualize how the profile might be affected by the proposed treatment alternatives.[4,10,11]

Despite considerable research, the effects of incisor retraction on the overlying soft tissue profile remain inconclusive.[12-14] Past studies have shown that there is often a wide range of responses due to factors such as lip tonicity, lip thickness, and lip strain. Current literature suggests that the upper lip retracts approximately 40% to 60% of the distance the upper incisor is retracted, while the lower lip's retraction is close

Abstract

The purpose of this study was to evaluate the accuracy of computerized video imaging in predicting the soft tissue outcome of extracting four premolars in adults. The pretreatment and posttreatment cephalometric and facial photographic records of 31 previously treated, nongrowing patients were digitized and computer-generated cephalometric VTOs and video images were compared with the known outcomes. The results showed that both the VTOs and video images were accurate enough to be used for patient education and communication, as well as for diagnosis and treatment planning. While lay people found that the predicted video images adequately resembled the actual outcomes, orthodontists were more critical, particularly of the lower lip area where variable soft tissue responses to treatment were noted.

Key Words

Video image prediction • Adult extraction treatment

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to 100% of the amount of lower incisor retraction.[15-18]

Several methods are available to visualize the probable hard and soft tissue treatment outcomes of orthodontic treatment, with the most commonly used being cephalometric prediction tracings.[19-21] Because they are essential for planning surgical treatment, prediction tracings are often used for orthognathic cases. However, prediction tracings have their weaknesses, such as variability in lip thickness, the degree of lip eversion and lip tonicity rarely being considered. Also the final artistic rendition of a predicted tracing may differ from one clinician to another. Therefore, these tracings are often helpful only to the clinician and not the patient, since the resulting soft tissue changes do not truly represent the patient's final facial esthetic outcome.[3,20-23]

Computerized video imaging can simplify the prediction process. Several commercially available software systems are capable of generating digitized cephalometric tracings, capturing pretreatment profile photographs, and morphing the photograph to the predicted line drawing, thereby producing a simulated video image of the posttreatment outcome. Operator time and effort are significantly reduced, as the computer can perform many of the necessary movements rapidly and consistently. Changes in specific hard tissues (dental movements, skeletal movements, etc.) can be accurately measured to tenths of a millimeter and less than a degree, providing improved accuracy.[1,3-5,23]

Currently, the most significant benefit of using these systems is their ability to produce video image representations of the patient's facial appearance. This greatly facilitates treatment planning and communication between different dental specialties. It also provides a means by which to demonstrate to patients a projection of their possible surgical or nonsurgical treatment outcomes.[1-5] While over the last few years several studies have evaluated the accuracy of computerized cephalometric VTOs,[22-26] only recently has attention been paid to the accuracy of computerized video imaging.[7,10,27-29] All these studies, however, have concentrated on orthognathic surgical treatment, but to date there has been no study evaluating the accuracy of computerized video imaging in predicting the soft tissue outcomes of extraction treatment in nongrowing adult patients. Therefore, the purpose of this study was to evaluate the technical accuracy and the clinical acceptability of video imaging in predicting the soft tissue outcome of adults treated with the extraction of four premolars. The specific questions addressed were:

Can computerized video imaging accurately predict the soft tissue changes of the upper and lower lips in four-premolar-extraction treatment involving a minimum of 4 mm of incisor retraction measured at the incisal edge?

Do orthodontists and lay people feel that the video image of the simulated treatment profile sufficiently resembles the actual posttreatment profile to be usable clinically for patient information and education?

What are the horizontal and vertical hard-to-soft-tissue ratios in this adult Caucasian sample in response to the extraction of four premolars and incisor retraction?

Materials and methods

The sample used in this study consisted of 31 patients taken from the private offices of three American Board of Orthodontics-certified clinicians. Selection of patients was based on the following criteria:

- All patients were nongrowing Caucasian adults, at least 16 years old for females and 18 years for males;
- No patients had genetic syndromes or other congenital deformities; and
- All patients had four premolars extracted and full fixed edgewise orthodontic treatment with at least 4 mm of maxillary incisor retraction, as measured at the incisal edge.

Additionally, all patients had:

- Less than 1 mm of maxillary and mandibular incisor extrusion or intrusion;
- Less than 1 degree change in mandibular plane angle; and
- Complete diagnostic records, including pre- and posttreatment lateral cephalometric films and profile photographs taken in natural head position with the teeth in centric relation.

The pretreatment cephalograms were manually traced onto acetate paper by the principal author to locate sella, nasion, porion, and orbitale. From the tracing, an x-y coordinate system was established, with its origin at sella and the x-axis established by rotating sella-nasion 7° clockwise. The y-axis was constructed perpendicular to the x-axis line through sella. The pretreatment tracing was superimposed over the posttreatment cephalogram using the best fit methodology for cranial base structures to ensure that the four landmarks mentioned above were digitized consistently. Both pre- and posttreatment cephalograms, with the acetate tracing taped on, were captured into Quick Ceph Imaging Version 6.9 (Orthodontic Processing, Chula Vista, Calif) on a Power Macintosh 7100/66av (Apple Computer, Inc, Cupertino, Calif) using a Sony CCD black and white video camera (Sony Corp, Japan) and Kaiser viewbox (Kaiser, Germany). The patient's profile photograph was captured with a color CCD camcorder (Sony Corp, Japan). A total of 28 cephalometric landmarks were digitized and the soft tissue profile was entered using the stream mode. A total of 34 cephalometric parameters (30 linear and 4 angular) were measured from the digitized landmarks.

After the pretreatment and posttreatment cephalograms were entered and digitized, a pre-to-posttreatment sella-nasion at sella superimposition was performed. The actual amount of treatment change that occurred in each patient was measured using the x-y coordinate system for the following five parameters: (1) upper incisor tip, (2) lower incisor tip, (3) upper incisor angulation to x-axis, (4) lower incisor angulation to mandibular plane, and (5) Frankfort to mandibular plane angle. Using these known treatment changes, a hard tissue treatment simulation (VTO) based on the initial headfilm was performed for each patient. Subsequently, a soft tissue line drawing prediction was generated based on this hard tissue treatment simulation. When the computer-predicted soft tissue line drawing and actual posttreatment tracings were superimposed, it was possible to compare and analyze the accuracy of the computer-generated soft tissue predictions. From this superimposition, the horizontal and vertical differences between the actual posttreatment tracing and the computer-generated soft tissue line drawing were measured at the following nine points: (1) nose, (2) subnasale, (3) superior sulcus, (4) upper lip, (5) upper stomion, (6) lower stomion, (7) lower lip, (8) inferior sulcus, and (9) chin. All movements of the hard and soft tissue landmarks in an anterior or inferior direction were assigned a positive value, while those in a posterior or superior direction were assigned a negative value.

In this study, reported for the first time in the literature, the difference between the patients' actual profile photographs and the computer-generated video images were quantifiably and objectively measured. This was achieved by digitizing both the actual and the computer-generated predicted final video image facial profiles on-screen using the stream mode. These profiles were then substituted for the VTOs and these new line drawings, which now truly represented the video image profiles, were then quantitatively compared, using 18 cephalometric parameters.

In order to subjectively assess whether the predicted video images were accurate and representative enough to display to patients, color slides of each patient's initial, actual final, and computer-predicted final images were projected simultaneously onto a screen side by side. A panel of evaluators—two orthodontists and two lay people—then subjectively compared the images. Using the Visual Analog Scale (VAS) with gradations ranging from poor to excellent on a 100 mm scale, each evaluator was asked to mark a point on the line denoting his or her perception of the prediction's accuracy compared with the actual result. The evaluators were given common instructions on the use of the scale before actual scoring took place. Assessments were made at the following areas: nose, nasolabial angle, upper lip, interlabial gap, lower lip, labiomental fold, chin, and overall profile.

The following numerical values on the VAS were rated as follows:

0—Poor; little agreement between predicted and actual image

33.3—Fair; prediction acceptable but there were noticeable differences from the actual image

66.6—Good; prediction clinically accurate with only minor differences from the actual image

100—Excellent; prediction indistinguishable from the actual image

These measures of clinical acceptability followed accepted standards used in other video imaging and esthetic-oriented studies.[7-11]

VAS scores were measured to the nearest millimeter and entered into a spreadsheet for data analysis. A reproducibility study was done to check intraexaminer error. Ten cases were randomly chosen and rescored by all evaluators. The scores were measured and compared using the paired *t*-test.

Analysis of the accuracy of the line drawings and predicted video imaging was done using paired *t*-tests at each horizontal and vertical measurement. VAS comparisons were made with a general linear model ANOVA (nested for individual examiners).

Results

Treatment changes (Tables 1 and 2)

During treatment, the upper incisors were retracted horizontally a mean of 5.5 mm ($p<0.001$), extruded a mean of 0.1 mm (p=N.S.), and uprighted by 9.2 degrees ($p<0.001$, Table 1). The lower incisors were retracted a lesser distance, averaging 3.3 mm horizontally ($p<0.001$), intruded 0.8 mm ($p<0.05$), and flared anteriorly 5.5 degrees ($p<0.001$). Skeletally, while there were

Table 1
Hard-tissue treatment changes

	Prettreatment	Posttreatment	Treatment changes
Incisor position			
Upper incisor, mm (h)	71.2 ± 5.7	65.7 ± 5.3	-5.5 ± 1.7 ***
Upper incisor, mm (v)	70.5 ± 4.6	70.6 ± 4.7	+0.1 ± 1.3
Upper incisor - FH, deg	110.6 ± 9.3	101.4 ± 7.2	-9.2 ± 8.7 ***
Lower incisor, mm (h)	66.4 ± 5.4	63.2 ± 5.1	-3.3 ± 2.0 ***
Lower incisor, mm (v)	67.5 ± 4.5	68.3 ± 4.6	+0.8 ± 2.0 *
IMPA, deg	81.6 ± 8.0	87.1 ± 7.8	+5.5 ± 6.6 ***
Maxillary position			
A-point, mm (h)	67.5 ± 3.5	66.8 ± 4.1	-0.7 ± 1.7 *
A-point, mm (v)	47.6 ± 3.4	47.9 ± 3.2	+0.3 ± 1.4
Mandibular position			
B-point, mm (h)	57.3 ± 5.7	56.4 ± 5.9	-0.9 ± 1.1 ***
B-point, mm (v)	84.0 ± 5.1	84.0 ± 6.0	+0.0 ± 1.6
FMA, deg	30.1 ± 4.1	30.8 ± 4.1	+0.7 ± 1.1 **
Chin position			
Pogonion, mm (h)	56.0 ± 6.3	55.8 ± 6.6	-0.2 ± 1.2 *
Pogonion, mm (v)	100.2 ± 5.8	100.3 ± 6.5	+0.1 ± 1.6

* p<.05; ** $p < .01$; *** p < .001
h = horizontal; v = vertical

Table 2
Soft-tissue treatment changes

	Pretreatment	Posttreatment	Treatment changes
Nose area			
Nose, mm (h)	94.6 ± 3.9	94.8 ± 4.1	+0.2 ± 0.6
Nose, mm (v)	36.7 ± 4.3	36.5 ± 4.3	-0.2 ± 1.1
Subnasale, mm (h)	82.2 ± 4.2	80.8 ± 4.8	-1.4 ± 1.5 ***
Subnasale, mm (v)	45.7 ± 4.1	46.4 ± 4.1	+0.7 ± 1.4 *
Superior sulcus, mm (h)	79.4 ± 4.4	77.1 ± 4.6	-2.3 ± 1.1 ***
Superior sulcus, mm (v)	51.9 ± 5.4	55.3 ± 5.9	+3.4 ± 3.6 ***
Upper lip area			
Upper lip, mm (h)	80.6 ± 5.1	77.4 ± 5.2	-3.2 ± 1.2 ***
Upper lip, mm (v)	63.5 ± 4.7	63.4 ± 4.9	-0.1 ± 1.7
Upper stomion, mm (h)	75.2 ± 5.4	71.2 ± 5.1	-4.0 ± 2.4 ***
Upper stomion, mm (v)	68.0 ± 4.5	67.9 ± 4.8	-0.1 ± 1.1
Lower lip area			
Lower stomion, mm (h)	74.2 ± 5.5	70.0 ± 5.2	-4.2 ± 1.5 ***
Lower stomion, mm (v)	68.9 ± 4.5	68.8 ± 4.8	-0.1 ± 1.0
Lower lip, mm (h)	78.6 ± 5.5	74.7 ± 5.4	-3.9 ± 1.5 ***
Lower lip, mm (v)	72.8 ± 4.7	73.1 ± 4.9	+0.3 ± 1.9
Chin area			
Inferior sulcus, mm (h)	69.8 ± 6.2	67.8 ± 6.1	-2.0 ± 1.6 ***
Inferior sulcus. mm (v)	84.4 ± 5.0	84.8 ± 5.4	+0.4 ± 2.1
Chin, mm (h)	66.7 ± 7.4	66.2 ± 6.8	-0.5 ± 1.7
Chin, mm (v)	101.0 ± 5.9	102.9 ± 6.1	+1.9 ± 2.8

* $p < .05$; ** $p < .01$; *** $p < .001$
h = horizontal; v = vertical

statistically significant treatment changes at A-point horizontal, B-point horizontal, and FMA, these differences were all less than 0.9 mm, 0.7 degrees, and 0.7 degrees, respectively, and were deemed to be clinically insignificant.

With this four-premolar-extraction treatment, there were also significant soft tissue changes, particularly for the upper and lower lips (Table 2). On average, the upper lip was retracted 3.2 mm horizontally (p<0.001), while the lower lip was retracted an even greater amount, averaging 3.9 mm (p<0.001). Vertically, the changes in the upper and lower lips were neither statistically nor clinically significant. In this sample of patients, the upper lip was retracted 58% of the distance that the upper incisors were retracted, while the lower lip was retracted 120% of the distance that the lower incisors were retracted. Vertically, the upper lip moved down 50% of the upper incisor's treatment change, while the lower lip moved up 38% of the lower incisor's treatment change.

Accuracy of hard tissue treatment simulations (Table 3)

Before starting the video imaging process, the actual posttreatment and computer-simulated posttreatment cephalometric tracings were compared to check that the hard tissue treatment movements were performed accurately. The results showed minimal errors occurring in only three parameters, with A- and B-points (horizontal) and FMA showing statistically significant (p<0.05) variations that were, however, deemed to be clinically insignificant, being only 0.7 mm, 0.6 mm, and 0.3 degrees, respectively.

Actual vs. predicted cephalometric line drawings (Table 4)

The overall accuracy of the predicted soft tissue line drawings for the nasal area was high; however, subnasale horizontal was predicted to be on average 0.7 mm more anterior (p<0.01) than its actual posttreatment position. The vertical position of superior sulcus was also predicted to be 1.7 mm lower than its actual position (p<0.01). The upper lip predictions were also quite accurate, with only the upper stomion prediction being too far anterior by 0.8 mm (p<0.05).

However, predictions for the lower lip area were less accurate, with three out of the four parameters evaluated showing significant errors. The computer predicted the lower lip to be significantly more forward (i.e., a fuller lower lip) than the actual posttreatment soft tissue line. Lower stomion horizontal (p<0.001) and lower lip horizontal (p<0.001) were both too far anterior by more than 1 mm, while lower stomion vertical was predicted too far inferiorly by 0.6 mm ($p<0.050$). In the chin area, the computer also erred by positioning the horizontal position of inferior sulcus 1.5 mm too far anteriorly ($p<0.001$) and the chin's vertical position 1 mm superiorly to its actual position ($p<0.05$).

Objective accuracy of video imaging (Table5)

Following the restreaming of the video profiles, the computerized video images were found to be less accurate than the original VTO predictions upon which they were based (Table 5). Six of the 18 soft tissue landmarks showed significant errors of greater than 1 mm ($p<0.001$). Of those six landmarks, three had errors greater than 2 mm. Of significance in the nose and upper lip areas were upper stomion horizontal, which was predicted to be 2.9 mm forward ($p<0.001$), and superior sulcus vertical, which was predicted to be 2.6 mm farther inferior than the actual profile ($p<0.01$). In the lower lip area, the video image predictions placed the soft tissue forward of the actual profile, putting the lower stomion horizontal, lower lip horizontal, and inferior sulcus horizontal more anterior (fuller lower lip) on average by 1.2 mm, 1.0 mm, and 2.1 mm, respectively ($p<0.001$). Vertically, the lower lip was predicted to be too far inferior by 1.1 mm ($p<0.01$) and the chin was predicted to be more superior by a mean of 1.6 mm ($p<0.001$).

Subjective accuracy of video imaging (Table 6)

Overall, the orthodontists rated the video image predictions as being only fair to good (mean 47.9), while lay people rated them significantly better ($p<0.001$), in the good-to-excellent range (mean 71.0). This was true for all areas except nasiolabial angle.

Both panels consistently scored the nose and nasiolabial angle predictions the highest (70 to 89), but they disagreed on the accuracy of the other areas. Orthodontists scored in the fair-to-good categories, their scores being anywhere from 11 to 19 points lower ($p<0.001$) than the lay people, who scored these areas in the good-to-excellent range.

Discussion

In general, the cephalometric VTO and video image predictions in this study were found to be accurate in simulating the soft tissue outcomes of adult four-premolar-extraction treatment. Both the predicted line drawing VTOs and the objective quantified video images were found to be accurate enough for use in diagnosis and treatment planning (Figure 1).

The average discrepancy between the actual

Table 3
Accuracy of hard-tissue treatment simulations

	Actual posttreatment	Prediction	Prediction - actual
Incisor position			
Upper incisor, mm (h)	65.7 ± 5.3	65.6 ± 5.4	-0.1 ± 0.5
Upper incisor, mm (v)	70.6 ± 4.7	70.9 ± 4.6	+0.3 ± 1.1
Upper incisor - FH, deg	101.4 ± 7.2	101.2 ± 6.2	-0.2 ± 1.9
Lower incisor, mm (h)	63.2 ± 5.1	63.3 ± 5.1	+0.1 ± 0.6
Lower incisor, mm (v)	68.3 ± 4.7	68.1 ± 4.7	-0.2 ± 0.6
IMPA, deg	87.1 ± 7.8	86.6 ± 7.4	-0.5± 2.2
Maxillary position			
A-point, mm (h)	66.8 ± 4.1	67.5 ± 3.7	+0.7 ± 1.7 *
A-point, mm (v)	47.8 ± 3.2	47.5 ± 3.4	-0.3 ± 1.4
Mandibular position			
B-point, mm (h)	56.3 ± 5.9	56.9 ± 5.9	+0.6 ± 1.4 *
B-point, mm (v)	84.0 ± 6.0	84.5 ± 5.5	+0.5 ± 1.4
FMA, deg	30.8 ± 4.1	30.5 ± 4.1	-0.3 ± 0.9 *
Chin position			
Pogonion, mm (h)	55.8 ± 6.6	55.5 ± 6.4	-0.3 ± 1.2
Pogonion, mm (v)	100.3 ± 6.5	100.6 ± 6.2	+0.3 ± 1.2

* $p<.05$; ** $p<.01$; *** $p<.001$
h = horizontal; v = vertical

Table 4
Accuracy of line drawing (VTO) predictions

	Actual	VTO prediction	VTO - actual
Nose area			
Nose, mm (h)	94.8 ± 4.1	94.6 ± 3.8	-0.2 ± 0.7
Nose, mm (v)	36.5 ± 4.3	36.8 ± 4.3	+0.3 ± 1.4
Subnasale, mm (h)	80.7 ± 4.8	81.4 ± 4.3	+0.7 ± 1.2 **
Subnasale, mm (v)	46.4 ± 4.1	46.3 ± 4.0	-0.1 ± 1.2
Superior sulcus, mm (h)	77.1 ± 4.6	77.5 ± 4.3	+0.4 ± 1.3
Superior sulcus. mm (v)	55.3 ± 5.9	57.0 ± 5.2	+1.7 ± 3.4 **
Upper lip area			
Upper lip, mm (h)	77.4 ± 5.2	77.4 ± 4.7	+0.0 ± 1.3
Upper lip, mm (v)	63.4 ± 4.9	63.5 ± 4.9	+0.1 ± 1.7
Upper stomion, mm (h)	72.2 ± 5.1	73.0 ± 5.0	+0.8 ± 1.8 *
Upper stomion, mm (v)	67.9 ± 4.8	70.0 ± 4.5	+0.1 ± 1.2
Lower lip area			
Lower stomion, mm (h)	70.0 ± 5.2	71.3 ± 5.2	+1.3 ± 1.1 ***
Lower stomion, mm (v)	68.8 ± 4.8	69.4 ± 4.9	+0.6 ± 1.3 *
Lower lip, mm (h)	74.7 ± 5.4	75.7 ± 5.3	+1.0 ± 1.3 ***
Lower lip, mm (v)	73.0 ± 4.9	73.4 ± 5.1	+0.4 ± 2.1
Chin area			
Inferior sulcus, mm (h)	67.8 ± 6.1	69.3 ± 6.3	+1.5 ± 1.78 ***
Inferior sulcus, mm (v)	84.9 ± 5.4	84.5 ± 5.7	-0.4 ± 3.3
Chin, mm (h)	66.1 ± 6.8	66.0 ± 7.3	-0.1 ± 1.8
Chin, mm (v)	102.9 ± 6.1	101.8 ± 6.0	-1.1 ± 2.5 *

* $p<.05$; ** $p<.01$; *** $p<.001$
h = horizontal; v = vertical

Table 5
Objective accuracy of video image predictions

	Actual	Video image	Video image - actual
Nose area			
Nose, mm (h)	94.9 ± 3.9	95.0 ± 3.6	+0.1 ± 1.0
Nose, mm (v)	36.9 ± 4.5	37.1 ± 4.6	+0.2 ± 1.9
Subnasale, mm (h)	80.9 ± 4.7	81.7 ± 3.9	+0.8 ± 1.6 **
Subnasale, mm (v)	45.4 ± 4.2	46.0 ± 3.9	+0.6 ± 1.2 *
Superior sulcus, mm (h)	77.1 ± 4.8	77.9 ± 4.4	+0.8 ± 1.3 **
Superior sulcus, mm (v)	53.3 ± 5.9	55.9 ± 6.0	+2.6 ± 4.6 **
Upper lip area			
Upper lip, mm (h)	77.4 ± 5.3	77.7 ± 4.7	+0.3 ± 1.4
Upper lip, mm (v)	63.0 ± 5.3	63.6 ± 4.6	+0.6 ± 2.7
Upper stomion, mm (h)	69.2 ± 5.2	72.1 ± 5.0	+2.9 ± 3.0 ***
Upper stomion, mm (v)	68.6 ± 4.8	68.5 ± 4.7	-0.1 ± 1.3
Lower lip area			
Lower stomion, mm (h)	69.7 ± 5.3	70.9 ± 5.4	+1.2 ± 1.3 ***
Lower stomion, mm (v)	68.6 ± 4.8	69.1 ± 4.8	+0.5 ± 1.6
Lower lip, mm (h)	74.5 ± 5.6	75.5 ± 5.9	+1.0 ± 1.1 ***
Lower lip, mm (v)	72.6 ± 4.9	73.7 ± 5.2	+1.1 ± 2.3 *
Chin area			
Inferior sulcus, mm (h)	67.2 ± 6.3	69.3 ± 6.7	+2.1 ± 1.9 ***
Inferior sulcus, mm (v)	85.4 ± 5.5	85.1 ± 5.4	-0.3 ± 3.7
Chin, mm (h)	66.0 ± 7.1	66.7 ± 7.1	+0.7 ± 1.9*
Chin, mm (v)	102.9 ± 6.4	101.3 ± 6.0	-1.6 ± 2.8 **

* $p < .05$; ** $p < .01$; *** $p < .001$
h = horizontal; v = vertical

Table 6
Visual analog scale

	Orthodontists	Lay people	Difference
Nose	89.9 ± 11.6	78.8 ± 8.5	+11.1 ± 12.4 ***
Nasolabial angle	70.0 ± 18.8	71.5 ± 10.7	-1.5 ± 19.2
Upper lip	50.4 ± 20.6	66.9 ± 11.6	-16.5 ± 19.9 ***
Interlabial gap	50.6 ± 22.9	61.7 ± 14.1	-11.1 ± 21.8 **
Lower lip	43.9 ± 16.2	63.0 ± 14.6	-19.2 ± 19.5 ***
Labiomental fold	46.4 ± 13.2	62.1 ± 13.0	-15.7 ± 13.4 ***
Chin	50.5 ± 18.1	66.9 ± 11.0	-16.4 ± 15.1 ***
Overall profile	47.9 ± 15.2	71.0 ± 10.3	-23.1 ± 13.4 ***

* $p < .05$; ** $p < .01$; *** $p < .001$

posttreatment soft tissue outcomes and the predicted line drawing VTOs were small, ranging from 0.4 mm to 1.7 mm (Table 4). Only 5 of the 18 soft tissue landmarks measured had errors greater than 1 mm and none had errors greater than 2 mm. The largest error, that of predicting the vertical position of superior sulcus, could be due to the recontouring of this area as the upper lip protrusion decreased during treatment. In agreement with previous studies, the upper lip's horizontal position in this study was predicted very accurately.[7,24-27] Eales[24] reported that the predicted upper lip soft tissue points demonstrate a mean error, for the most part, of less than 1 mm, while Lew[25] showed that the computer was especially accurate in predicting the horizontal position of the upper lip. It is also very interesting to note the hard-to-soft-tissue ratio for upper lip retraction in this sample was 58%, which concurs with other studies reporting a range of 40 to 60%.[18,30]

In contrast, VTOs for the lower lip area were less accurate. Stomion horizontal, lower lip horizontal, and inferior sulcus horizontal were all placed forward of the actual profile by an amount greater than 1 mm, while in the vertical plane, the lower lip was accurately predicted. More error was expected in the horizontal than in the vertical plane because minimal dental changes had occurred vertically during treatment. These finding are in agreement with Hing's and Upton's studies, which also used Quick Ceph and found predictions for the lower lip area to be the most difficult and error-prone.[22,28]

It should be noted that since many of the standard deviations seen for the treatment changes were larger than the average changes themselves (Table 2), the software will not accurately depict the treatment change for some of the patients in the sample. This variability could be considerably reduced if we had more information about factors such as lip tone or thickness, which are the subjects of investigations currently underway in our laboratory.

Many factors can contribute to the difficulty of predicting lower lip position. These include incisor angulation, tissue thickness, and tissue tonicity. Upper incisor influence on lower lip position has often been cited in the literature: Eales[24] and Jensen[30] stated that changes seen in the lower lip can be explained by its release from the influence of the upper incisor producing a rotation up and back around the inferior labial sulcus. The same factor could apply in this study since the majority of the cases underwent extraction because of maxillary protrusion. There was some degree of pretreatment lip eversion due to the maxillary protrusion. Extraction treatment resulted in normalization of the overjet, which allowed for restoration of the lower lip to a more natural drape. Due to inadequate data on lower lip changes with treatment, the computer cannot compensate for this occurrence and thus cannot make an accurate prediction of the lower lip's position. Also, the absence of reliable hard-to-soft-

Figure 1

Figure 2

Figure 1
Video image prediction records for typical adult four-premolar extraction patient. L to R: initial image, actual final image, and computer-generated prediction of the final outcome, which was representative of the average predictions produced.

Figure 2
Video image prediction records. L to R: initial image, actual final image, and computer-generated prediction of the final outcome demonstrating a slightly jagged soft-tissue outline, which was the most common error noted in the predictions.

tissue ratios for different areas of the lower lip further complicates the prediction process. Most studies report a wide range of horizontal hard-to-soft-tissue ratios for the lower lip, ranging from 70% to 120%, with the exception of Jensen[30] who reported significant correlations with a 72% hard-to-soft-tissue ratio. Considering that the lower lip ratio for this sample was 120%, which is in the upper end of what the literature has reported, the actual errors seen in the lower lip predictions were relatively small.

Previously, due to software limitations, it was not possible to directly measure the accuracy of video image predictions, and they were assumed to be the same as for the VTOs.[7] In this study, the software allowed the operator to directly and objectively measure the video image's accuracy. It became clear that the video image predictions were often not congruent with the underlying line drawing predictions. The errors in the video image predictions were at similar locations and were fairly consistent in nature with the errors seen in the predicted VTOs (Tables 4 and 5); however, they were of greater magnitude, with 3 of 18 landmarks showing errors of >2 mm. With the video image predictions having similarly located but larger errors than the VTOs, it may be deduced that the algorithm ratio used to morph the initial photographs to produce video images may not use the same ratios as those used to produce the predicted VTOs. Another possible reason for the inaccurate video image prediction could be the technical limitation of the program. Occasionally, Quick Ceph produces a video image that has a jagged tissue outline. This forces the operator to measure the soft tissue outline at its outermost edge and may account for the larger magnitude of error detected. This discrepancy may also be due in part to limitations in capturing the original pretreatment print photographs. The soft tissue outline on the photographs was not sharp on some images, so it is possible that the program's algorithms could not predict the soft tissue outline accurately in this situation. Although this did not interfere with their clinical acceptability, the video imaging predictions might become more accurate with the live image-capturing technique recommended by Quick Ceph (Figure 2).

When the accuracy of the video image prediction was tested subjectively using the Visual Analog Scale, the orthodontists scored the overall profile of the prediction in the fair-to-good range of the scale, grading the lower lip more critically than the upper lip. When the video image error exceeded 2 mm, the orthodontists were clearly able to recognize this difference. Surprisingly, the lay people still judged the video image predictions to be in the good-to-excellent range. Except for the nose, the lay people consistently graded all areas of the video image prediction higher than the orthodontists. Other studies have shown the same pattern,[27,29] suggesting either that lay people are more forgiving in grading the images or they cannot differentiate the subtle differences between the video images and the actual outcomes. In fact, it has been shown that changes of 2 to 4 mm in soft tissue profiles are often not recognizable by either the lay person or the clinician.[26]

It should be noted that this was a retrospective study of previously treated patients with known hard tissue outcomes. Most orthodontists use video imaging as a pretreatment planning and consultation tool and do not know how well their video predictions will eventually match the actual treatment results. There is, therefore, a need for prospective studies to evaluate this question as well as whether patients prefer their actual results over the video image predictions of their probable treatment outcomes.

Conclusions

The computer-generated cephalometric VTO predictions were found to be accurate in simulating the outcomes of adult extraction treatment. Although the lower lip was consistently predicted to be 1 mm anterior to its actual posttreatment position, these errors were still small enough to allow for accurate treatment planning.

While the video image predictions were found to be less accurate than the VTOs for 3 of 18 parameters showing errors greater than 2 mm, the video images were still acceptable for use in patient education and communication as well as for treatment planning.

Lay people thought that the video images were representative of the actual posttreatment outcomes and rated them good to excellent, while orthodontists were more critical and judged the predicted images as being fair to good.

The upper lip showed a relatively consistent 58% hard-to-soft-tissue retraction ratio, similar to other studies, while the lower lip's variable retraction ratio averaged 120% of the underlying hard tissue change.

Author Address

Peter M. Sinclair
University of Southern California
School of Dentistry
Orthodontics Department
Los Angeles, CA 90089-0641
E-mail: Sinclair@hsc.usc.edu

Submitted by Dr. Le in partial fulfillment for the degree of Master of Science in Craniofacial Biology, University of Southern California.

Thuan N. Le, former resident, Orthodontic Department, University of Southern California. Currently in private practice in Los Angeles, California.

Glenn T. Sameshima, assistant professor, Orthodontic Department, University of Southern California.

John E. Grubb, clinical associate professor, Orthodontic Department, University of Southern California, and private practice, Chula Vista, California.

Peter M. Sinclair, professor and chairman, Orthodontic Department, University of Southern California.

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