An evaluation of two VTO methods

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Prediction has always been a part of science. The ability to predict allows certain laws or theories to be applied in specific situations. Baumrind[1] suggested that the ability to predict assists the orthodontist psychologically in the treatment planning process by removing some of the art and adding a little more science. The ability to predict is important in most other areas of science and medicine, and it is important in the treatment of orthodontic patients. But the prediction of treatment outcomes has been difficult in orthodontic patients due to variations in growth, development, and treatment.

In 1960, Ricketts[2] stated that all treatment planning constituted some type of prediction. He suggested estimating the amount of change that should occur by predicting the possibilities of tooth movement and facial change. He called his method of prediction a "dynamic synthesis" in which craniofacial growth and tooth movement were predicted. Ricketts[3] had previously developed a similar method using cephalometric radiography in which craniofacial growth and orthodontic treatment effects were predicted. Ricketts' treatment prediction also allowed for a forecast of the integumental profile, which was based on the reaction of the skeletal elements and the teeth to orthodontic treatment.

Bench[4] supported the use of cephalometric prediction, stating that the visualized treatment objective (VTO) allowed for selection of the most applicable treatment plan based on the individual's growth pattern. Important in the application of the VTO was the attainment of ideal dental and soft tissue relationships. Other skeletally based VTOs[5,6] determine the positions

Abstract

A sample of 34 growing Class II patients was used to assess the reliability of manual and computer-generated visual treatment objectives (VTOs) when compared with the actual treatment results. Skeletal, dental, and soft tissue measurements were performed on the VTO and on the posttreatment tracings. Using paired *t*-tests and Pearson correlation coefficients, comparisons were made between the VTO and posttreatment tracings. Both the manual and computer VTO methods were accurate when predicting skeletal changes that occurred during treatment. However, both methods were only moderately successful in forecasting dental and soft tissue alterations during treatment. Only slight differences were seen between the manual and computer VTO methods, with the computer being slightly more accurate with the soft tissue prediction. However, the differences between the two methods were not judged to be clinically significant. Overall, the prediction tracings were accurate to only a moderate degree, with marked individual variation evident throughout the sample.

Key Words

Visualized Treatment Objective • Prediction tracing • Cephalometrics • Growth forecast • Correlation coefficient

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of the teeth, namely the mandibular incisor, with reference to a skeletal line such as A-point–pogonion or nasion–B-point of Steiner's analysis.[7]

Holdaway took a different approach to cephalometric prediction, which has been described by Jacobson and Sadowsky.[8] The goal of this "dynamic" cephalometric analysis and prediction was to establish a balanced facial profile with pleasing facial esthetics and to evaluate the orthodontic correction necessary to obtain the latter goals. The main difference between Holdaway's VTO and other types was that Holdaway predicted the soft tissue profile first, then the positions of the maxillary incisors. Holdaway[9,10] re-emphasized the importance of soft tissue analysis as he quantified certain soft tissue relationships in harmonious faces. In contrast to Ricketts, Holdaway believed that the mandibular incisor could not be rigidly fixed to any anatomical landmark such as the A-point–pogonion line. Instead, the mandibular incisors should be placed relative to the maxillary incisors where adequate lip support had been established.

Several authors[5,8,11-14] have discussed the advantages of VTOs, and these can be summarized as: (1) establishment of specific treatment goals, (2) formulation of a specific treatment plan to reach treatment goals, (3) assistance in determining if the ideal treatment result is attainable orthodontically or surgically, (4) assistance in making midtreatment corrections, (5) enhancing communication between patients and clinicians, (6) allowing quantification of proposed movements to reduce the difficulties in planning facial response to different movements, and (7) allowing rapid comparisons of different treatment options before arriving at a final treatment plan.

Despite the listed advantages of VTOs, limitations exist in their implementation. Several authors[2,8,10,12,15] describe inadequacies of VTOs, including: the use of average growth increments in growth prediction, the use of existing morphological traits to predict future growth events, and the fallibility of presenting VTO analysis as an exact representation of the treatment outcome. The experience of the clinician also plays a large role in the accuracy of the VTO prediction.

The purpose of the present study was to compare the accuracy of a skeletally based computerized VTO and a manually constructed soft tissue based VTO through analysis of predicted treatment outcomes and actual treatment outcomes in a sample of cases accepted by the American Board of Orthodontics. The three objectives of the study were to determine: (1) if there is any difference in the accuracy of prediction between a computerized and manual VTO, (2) if there is any difference in the accuracy of prediction between a soft tissue based or skeletally based VTO, and (3) what hard and soft tissue differences, if any, exist between the actual treatment results and the two VTO prediction methods.

Materials and methods

The sample consisted of lateral cephalometric radiographs of 34 patients whose treatment records were submitted for certification by the American Board of Orthodontics. All patients were classified as having Class II malocclusions. Each was treated without the extraction of teeth, and was considered to be growing at the time pretreatment records were made. Mean pretreatment age of the sample was 11.7 years and mean posttreatment age was 14.7 years. Growth of each patient was verified by superimposing the pretreatment and posttreatment radiographs using conventional cephalometric techniques, including: superimposition on the sella-nasion line registering at sella, superimposition of the lingual surfaces of the palate and best fit of the maxillary bony structures, and superimposition of the lingual cortical plate of the mandibular symphysis and inferior border of the mandible.

All pretreatment radiographs were traced on 0.003 inch acetate paper and digitized into a Macintosh™ computer (Power PC 7100AV). Cephalometric software (Quick Ceph Image™ version 6.0, Orthodontic Processing, Chula Vista, Calif) was used to record landmarks and measurements on each radiograph. Landmarks identified in the study are shown in Figure 1. Each measurement was recorded both manually with a protractor and through the use of the computer. The skeletal, dental, and soft tissue measurements performed are shown in Figures 2, 3, and 4, respectively.

For each patient, the computer generated an individualized growth prediction based on the elapsed time between pretreatment and posttreatment radiographs. Following the growth forecast, the final position of the mandibular incisor was predicted based on the new A-point–pogonion line, centered in the alveolar housing of the anterior mandible. The maxillary incisor was then placed in an ideal relationship to the mandibular incisor. The computer generated a soft tissue profile based on the new position of the skeletal structures and the teeth. Holdaway ratios were used to determine the amount of soft tissue-to-hard tissue movement. The soft tissue profile was then edited using the computer's tools until an even contour had been established.

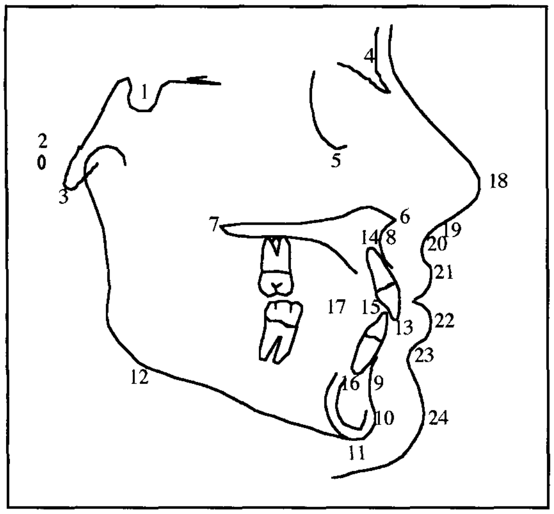

Figure 1

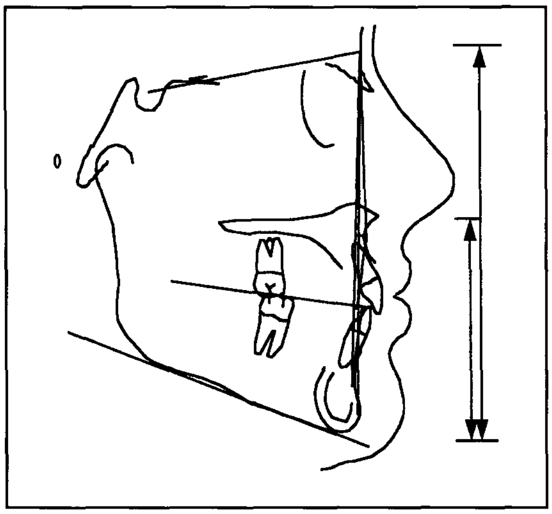

Figure 2

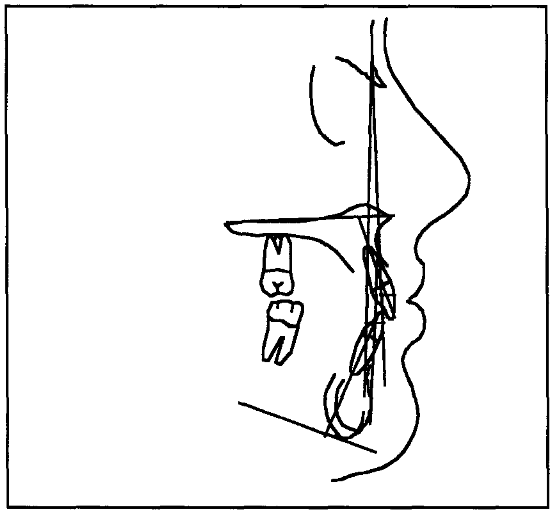

Figure 3

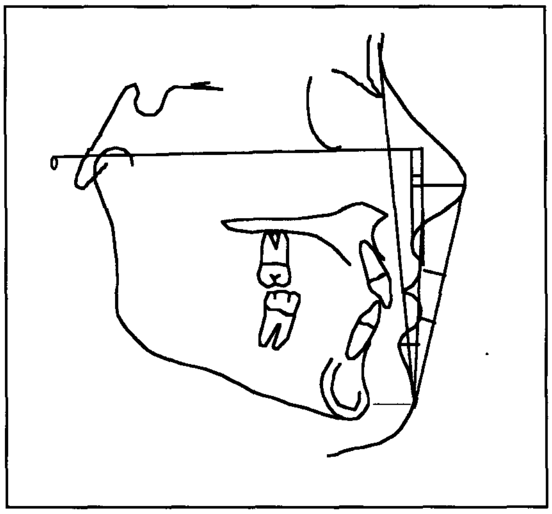

Figure 4

Figure 1
Landmarks used in this study: 1. Sella; 2. Porion; 3. Basion; 4. Nasion; 5. Orbitale; 6. ANS; 7. PNS; 8. A-point; 9. B-point; 10. Pogonion; 11. Menton; 12. Corpus left; 13. Maxillary incisor crown; 14. Maxillary incisor root; 15. Mandibular incisor crown; 16. Mandibular incisor root; 17. Functional occlusal plane; 18. Nasal tip; 19. Subnasale; 20. Superior labial sulcus; 21. Labrale superius; 22. Labrale inferius; 23. Inferior labial sulcus; 24. Soft tissue pogonion.

Figure 2
Skeletal measurements used in this investigation.
SNA
SNB
ANB
Wits appraisal
Convexity at A-point
Occl. plane - SN
Mand. plane - SN
Total facial height
Lower facial height
Lower facial height %

Figure 3
Dental measurements used in this investigation.
U1 - NA (mm)
U1 - NA (deg)
U1 - Palatal plane
L1 - NB (mm)
L1 - NB (deg)
L1 - Mand. plane
L1 - A-pog
Interincisal angle

Figure 4
Soft tissue measurements used in this investigation
Soft tissue facial angle
H angle
Upper lip - E plane
Lower lip - E plane
Lower lip - H line
Subnasale - H line
Inferior sulcus - H line
Superior sulcus depth
Nasal prominence

Angular and linear measurements were carried out for the landmarks in the predicted positions.

A growth forecast for each patient was also drawn manually according to the method described by Jacobson and Sadowsky[8] and Holdaway.[10] Following completion of the growth forecast, an individualized soft tissue profile was constructed to reflect desired changes during treatment. Next, the maxillary incisor was placed to accommodate the new position of the lips (i.e., to eliminate lip strain) while being centered in the alveolar housing of the anterior maxilla. The mandibular incisor was then placed in an ideal relationship to the maxillary incisor. Angular and linear measurements were calculated manually for the predicted landmarks.

Following construction of the VTOs, posttreatment radiographs were traced and digitized both manually and with the computer software. Angular and linear measurements were carried out to the selected landmarks.

Means and standard deviations were calculated for each variable. Statistical analysis included paired *t*-tests to determine the statistical differences between the means of the VTO tracings and the actual posttreatment tracings. Statistical significance was predetermined at the $p < 0.05$ level of confidence. In addition, Pearson correlation coefficients were used to validate differences between VTO tracings, computer posttreatment tracings, and manual posttreatment tracings. Tracing error was assessed by randomly retracing 10 radiographs with the manual and computer tracing methods.

Results

Method error analysis revealed high correlation between the two tracing trials for both the manual and computer tracings, with no correlation coefficient being less than 0.90. Further analysis revealed that there was no more than 0.5 mm or 0.5° difference between any of the first and second trial measurements for either the manual or computer methods. In addition, cor-

Table 1
Means, standard deviations, and *p*-values for the skeletal variables of the manual posttreatment and VTO tracings

Variable	Posttreatment mean	S.D.	VTO mean	S.D.	*p*-value
SNA	81.01	3.01	82.08	2.88	0.0001*
SNB	77.08	2.94	77.56	2.88	0.0646
ANB	3.98	1.66	4.52	1.8	0.0154*
Conv. at A	2.26	2.22	3.73	2.19	0.0001*
Wits	0.29	2.02	-0.29	2.26	0.0731
TFH	120.85	7.22	119.81	7.05	0.0565
LFH	67.82	5.20	66.91	4.96	0.0365*
LFH%	55.78	2.1	55.88	1.88	0.7358
SN-OP	18.54	4.67	19.79	4.28	0.0116*
SN-MP	31.06	5.38	31.37	4.85	0.5204

Table 2
Means, standard deviations, and *p*-values for the skeletal variables of the computer posttreatment and VTO tracings

Variable	Posttreatment mean	S.D.	VTO mean	S.D.	*p*-value
SNA	80.84	2.94	81.66	3.4	0.0119*
SNB	77.06	2.98	77.54	2.92	0.0769
ANB	3.78	1.62	4.13	1.73	0.2158
Conv. at A	2.44	2.28	3.16	2.33	0.0292*
Wits	0.21	2.24	-0.05	2.2	0.4976
TFH	122.93	7.73	120.00	7.59	0.0001*
LFH	68.82	5.41	67.92	5.44	0.0462*
LFH%	55.95	1.94	56.55	2.01	0.0118*
SN-OP	18.51	4.27	18.62	3.87	0.8111
SN-MP	31.26	5.02	30.75	4.76	0.1374

Table 3
Means, standard deviations, and *p*-values for the dental variables of the manual posttreatment and VTO tracings

Variable	Posttreatment mean	S.D.	VTO mean	S.D.	*p*-value
U1-NA(mm)	4.12	1.49	2.66	0.99	0.0001*
U1-NA(deg)	21.37	5.47	16.81	4.14	0.0001*
U1-PP	110.38	5.27	106.69	4.46	0.0008*
L1-NB(mm)	5.63	1.89	5.47	1.65	0.4991
L1-NB(deg)	29.41	6.23	29.72	3.6	0.7833
L1-MP	100.74	7.36	100.56	4.79	0.8805
L1-APo	1.06	1.72	1.20	1.17	0.6025
Interinc. <	125.60	8.65	129.53	4.14	0.0251*

relation analysis showed high correlation when the manual and computer tracing methods were compared, indicating that the manual measurements and the computer measurements were very similar.

Paired *t*-tests and Pearson correlation coefficients were used to compare the manual posttreatment tracings with the manual VTO tracings, and the computer posttreatment tracings with the computer VTO tracings. Means, standard deviations, and *p*-values for the selected variables for the manual and computer tracings are shown in Tables 1 through 6 (* denotes *p*-values that are statistically significant). Pearson correlation coefficients for the comparison of the selected variables are shown in Tables 7, 8, and 9.

Paired *t*-test results

When comparing the manual posttreatment tracings with the manual VTO tracings using paired *t*-tests, statistically significant differences were seen between the means for the skeletal variables SNA, ANB, convexity at A-point, LFH, and SN-OP (Table 1). When comparing the computer posttreatment tracings with the computer VTO tracings, statistically significant differences were seen between the means of the variables SNA, convexity at A-point, TFH, LFH, and LFH% (Table 2).

When comparing the manual posttreatment tracings with the manual VTO tracings, statistically significant differences were seen between the means for the dental variables U1 to NA (mm), U1 to NA (degrees), U1 to PP, and the interincisal angle (Table 3). When comparing the computer posttreatment tracings with the computer VTO tracings, statistically significant differences were noted between the means for the variable U1 to NA (mm) only (Table 4).

When comparing the manual posttreatment tracings with the manual VTO tracings, statistically significant differences were noted between the means for the soft tissue variables H-angle, upper lip to E-plane, lower lip to H-line, superior sulcus depth, subnasale to H-line, and nasal prominence (Table 5). When comparing the computer posttreatment tracings with the computer VTO tracings, no statistically significant differences were noted. However, differences between the means approached statistical significance for the variables upper lip to E-plane, lower lip to H-line, and nasal prominence (Table 6).

Correlation results

Correlation analysis showed high agreement (*r* greater than 0.70) for the skeletal variables SNA, SNB, TFH, LFH, SN-OP, and SN-MP when comparing both the manual posttreatment tracings with the manual VTO tracings and the computer posttreatment tracings with the computer VTO tracings. Differences in agreement between the manual computer VTOs were noted for the skeletal variables ANB, convexity at A-point, and the Wits appraisal, with the manual VTO better correlated with the corresponding posttreatment tracings (Table 7).

Correlation analysis indicated generally poor agreement when comparing the dental variables for the manual posttreatment tracings with the manual VTO tracings. Only the L1 to NB (mm) measurement for the manual VTO was shown to be highly correlated with the manual posttreatment tracings. In general, correlation coefficients for the variables describing the maxillary incisor, when comparing the manual posttreatment tracings with the manual VTO tracings, were higher than the corresponding coefficients comparing the computer posttreatment tracings with the computer VTO tracings. However, none of the correlation coefficients was greater than 0.50, indicating poor correlation for all comparisons. Similarly, correlation coefficients for the variables describing the mandibular incisor, when comparing the computer posttreatment tracings with the computer VTO tracings, showed greater correlation than the corresponding correlation coefficients comparing the manual posttreatment tracings with the manual VTO tracings. However, the correlation coefficients for the latter comparisons showed only moderate correlation at best (Table 8).

Correlation analysis comparing the manual posttreatment tracings with the manual VTO tracings showed moderate to high correlation for the variables soft tissue facial angle, H-angle, upper lip to E-plane, lower lip to E-plane, lower lip to H-line, nasal prominence, and chin prominence. The latter results were similar when comparing the computer posttreatment tracings with the computer VTO tracings. Correlation analysis for the variables superior sulcus depth, subnasale to H-line, and inferior sulcus to H-line indicated poor correlation when comparing the manual posttreatment tracings with the manual VTO tracings, and showed only moderate correlation when comparing the computer posttreatment tracings with the computer VTO tracings (Table 9).

Table 4
Means, standard deviations, and *p*-values for the dental variables of the computer posttreatment and VTO tracings

Variable	Posttreatment mean	S.D.	VTO mean	S.D.	*p*-value
U1-NA(mm)	3.83	1.83	2.25	1.67	0.0005*
U1-NA(deg)	20.89	5.39	19.53	4.16	0.2122
U1-PP	110.07	5.98	108.35	3.11	0.1091
L1-NB(mm)	5.88	2.01	5.50	1.54	0.1354
L1-NB(deg)	29.74	5.97	28.81	3.50	0.2707
L1-MP	101.44	7.17	100.47	4.81	0.2426
L1-APo	1.19	1.76	1.14	1.25	0.8482
Interinc. <	125.63	8.27	127.54	4.77	0.1902

Table 5
Means, standard deviations, and p-values for the soft tissue variables of the manual posttreatment and VTO tracings

Variable	Posttreatment mean	S.D.	VTO mean	S.D.	*p*-value
Soft tissue fac.<	91.60	2.58	91.85	3.17	0.4518
H angle	13.76	4.10	16.31	2.10	0.0001*
UL - E-plane	-4.09	2.33	-2.34	1.38	0.0001*
LL - E-plane	-1.65	2.53	-1.13	1.13	0.1710
LL - H-line	1.01	1.41	0.47	0.52	0.0139*
Sup. sulcus depth	2.81	1.30	3.32	0.83	0.0301*
Subnas. - H-line	4.19	2.12	5.62	0.99	0.0001*
Inf. sul. - H-line	5.32	1.80	4.91	0.91	0.1987
Nose prom.	16.94	2.12	15.63	1.86	0.0001*
Chin prom.	12.04	1.87	12.26	2.23	0.4329

Table 6
Means, standard deviations, and p-values for the soft tissue variables of the computer posttreatment and VTO tracings

Variable	Posttreatment mean	S.D.	VTO mean	S.D.	*p*-value
Soft tissue fac.<	90.91	2.53	91.05	2.95	0.6812
H angle	14.01	3.62	14.75	2.62	0.1883
UL - E-plane	-4.03	2.39	-3.51	1.81	0.0900
LL - E-plane	-2.32	2.67	-2.50	2.32	0.2901
LL - H-line	0.56	1.44	1.16	0.89	0.0831
Sup. sulcus depth	3.07	1.29	2.97	1.03	0.5741
Subnas. - H-line	4.11	1.4	4.11	2.17	1.0000
Inf. sul. - H-line	5.50	1.83	5.29	1.27	0.4332
Nose prom.	17.11	2.23	16.66	2.01	0.0835
Chin prom.	11.29	2.87	11.57	2.29	0.478

Discussion

The present study attempted to compare a computer-generated versus a manual prediction method, and to discriminate between skeletally

Table 7
Pearson correlations coefficients for skeletal variable comparisons

Variable	Man. VTO vs. man. posttreatment	Comp. VTO vs. comp. posttreatment	Man. posttreatment vs. comp. posttreatment
SNA	0.91	0.85	0.97
SNB	0.88	0.86	0.97
ANB	0.74	0.53	0.96
Conv. at A	0.83	0.68	0.98
Wits	0.63	0.49	0.92
TFH	0.91	0.91	0.96
LFH	0.89	0.89	0.99
LFH%	0.61	0.77	0.93
SN-OP	0.82	0.92	0.94
SN-MP	0.86	0.92	0.94

Table 8
Pearson correlation coefficients for the dental variable comparisons

Variable	Man. VTO vs. man. posttreatment	Comp. VTO vs. comp. posttreatment	Man. posttreatment vs. comp. posttreatment
U1-NA (mm)	0.46	0.06	0.95
U1-NA (deg)	0.24	0.16	0.97
U1-PP	0.33	0.22	0.95
L1-NB (mm)	0.71	0.69	0.98
L1-NB (deg)	0.22	0.59	0.99
L1-MP	0.44	0.75	0.99
L1-APo	0.42	0.66	0.96
Interinc. <	-0.04	0.28	0.99

based and soft tissue-based prediction methods. Results for both the computer and manual prediction methods revealed that the VTOs were fairly accurate for some variables but inaccurate for others.

Skeletal anteroposterior variables were accurately predicted using both the manual and computer methods. Both VTO methods tended to slightly underestimate the amount of skeletal convexity reduction that was achieved during treatment. The means for the parameters SNA and convexity at A-point were statistically significantly different for both the computer and manual VTOs when compared with the computer and manual posttreatment tracings, respectively. The differences between the VTO and posttreatment means of the SNA and SNB measurements were not considered of clinical significance because the differences were less than 1°. Correlation analysis revealed that the skeletal anteroposterior measurements of the VTOs were highly correlated with the posttreatment tracings. The latter results were similar to those of Thames et al.,[16] who showed that a computer prediction was accurate to within 1° for skeletal convexity measurements such as SNA and SNB. Cangialosi[17] et al. found that the computer overestimated changes occurring in the angles SNA and SNB; however, the angle ANB remained within 0.5° of the actual posttreatment result. The high correlation coefficients found in the present investigation indicated a meaningful ability to predict the anteroposterior positions of A-point and B-point with both the computer and manual VTO methods.

Skeletal vertical parameters were also highly predictable according to the results from the correlation data. However, both the computer and manual VTO tracings tended to underestimate the amount of vertical change that occurred with treatment for both the parameters of lower facial height and total facial height. The underestimation of the latter parameters was possibly due to the VTO's inability to account for eruption of the posterior teeth that occurs with orthodontic mechanics as well as underestimation of the vertical growth component of the facial skeleton. Maull[18] showed an increase in lower anterior facial height as a percentage of total anterior facial height in all 42 patients in her sample. Her results also revealed no change in the mandibular plane angle, and this finding was similar to the results obtained with both VTO methods in the present study. The results obtained in the present investigation suggest an ability to forecast both the skeletal anteroposterior and vertical components of the prediction only up to a certain degree. The remaining variability in the prediction of the skeletal parameters remains unexplained.

Statistical evaluation of the dental measurements revealed that a more accurate representation of the mandibular incisor was achieved with the computer VTO than with the manual VTO and showed moderate to high correlation coefficients with each of the parameters studied. Poor correlation was seen with the maxillary incisor when both the computer and manual VTO tracings were compared with their respective posttreatment tracings. On average, both VTO methods showed more retraction of the maxillary incisor than had actually occurred with treatment. This latter finding was expected due to the subjective nature of incisor placement in each of the VTO constructions. Perhaps the mandibular incisor was easier to place with the use of the computer because this tooth was placed before the maxillary incisor in the computer method and the new A-point–pogonion line was easily visualized. The results of the present study are similar to those of past investigations[16,17] and suggest that prediction of the final axial inclination and bodily position of the maxillary and mandibular incisors is difficult, even in situations where the movement of these teeth has been limited through nonextraction treatment procedures.

Several authors[3,19-22] have advocated the position of the mandibular incisor as a critical determinant in facial esthetics. However, Wylie[23] and Holdaway[9,10] recognized that other factors, such as the position of the chin and the axial inclination of both maxillary and mandibular incisors contributed to the overall esthetics of the facial profile. The current study sought to determine whether the soft tissue contour of the lower third of the face could be predicted accurately through the use of two types of VTOs. The manual VTO was as accurate as the computer VTO in predicting posttreatment soft tissue convexity (soft tissue facial angle and H-angle) according to the correlation data, even though only moderate correlation existed. Similarly, the computer and manual VTO tracings showed similar accuracy in predicting the anteroposterior positions of the lips as related to the nose and soft tissue chin. The predictions of the anteroposterior position of the lips to the nose and soft tissue chin were, at best, only moderately correlated with the posttreatment tracings.

The computer VTO tracings were better at assessing depth of the upper and lower lips, with moderate correlation existing for the measurements of superior sulcus depth and inferior sulcus to the H-line. Poor correlation existed for the latter variables when the manual VTO tracings were compared with the manual posttreatment tracings. The differences between the computer and manual VTO tracings with respect to the depth of the lips could have been due to the fact that the soft tissue was idealized and drawn first in the manual VTO tracings with individual differences not fully taken into account. Yogosawa[24] stated that facial soft tissue morphology may be as variable as malocclusions, but prediction of the eventual soft tissue configuration can be accomplished when the individual's soft tissue characteristics are taken into account.

The computer and manual VTO tracings were similar in the prediction of nasal and chin prominence. Again, however, only moderate correlation existed with the computer and manual posttreatment tracings, respectively.

Table 9
Pearson correlation coefficients for soft tissue variable comparisons

Variable	Man. VTO vs. man. posttreatment	Comp. VTO vs. comp. posttreatment	Man. posttreatment vs. comp. posttreatment
Soft tissue fac.<	0.79	0.72	0.93
H angle	0.65	0.52	0.96
UL - E-plane	0.69	0.68	0.98
LL - E-plane	0.54	0.73	0.91
LL - H-line	0.53	0.46	0.87
Sup. sulcus depth	0.29	0.61	0.95
Subnas. - H-line	0.53	0.42	0.93
Inf. sul. - H-line	0.24	0.57	0.79
Nose prom.	0.66	0.76	0.91
Chin prom.	0.71	0.64	0.68

Soft tissue prediction in the present study was similar to that of Thames,[16] who showed that the Rocky Mountain Data Systems computer was inaccurate in predicting soft tissue contour in his sample of high-angle Class II malocclusions. The only soft tissue correlation coefficients above 0.70 were those comparing nasal prominence, chin projection, and soft tissue facial angle, which suggests a poor ability to predict soft tissue contour of the labial structures with both manual and computer methods.

According to the mean differences between the VTO and posttreatment tracings, most of the variables in the study were predicted within clinically accepted ranges. However, correlation analysis revealed that individual variation was the dominant theme when prediction of incisor position and soft tissue structures were involved. Reasons for the latter results could involve variation in individual responses to treatment, growth variation with an individual, patient cooperation during treatment, and the experience of the investigator in constructing realistic treatment predictions. Further limitations exist in the study because neither the manual nor computer prediction methods allow for sex differences in growth to be expressed in the VTOs. Due to the latter technological limitation, data for males and females were pooled; therefore, differences between sexes cannot be determined from this study.

No attempt was made in the present study to determine the advantages of each particular type of VTO in the clinical setting. However, one might consider the computerized VTO easier to use due to decreased time needed to display and manipulate images. The computer might also increase patient awareness of the goals of treatment through use of a videoimage that combines photography and cephalometry.[14]

Overall, the computer and manual VTO construction methods yielded similar results in terms of the skeletal variables that were studied. Only slight differences were noted between the computer and manual VTOs with regard to dental and soft tissue variables, with the computer VTO being slightly more accurate. Neither of the VTOs accurately predicted incisor position or soft tissue contour on a routine individual basis. Johnston[15] stated that there was a limit to the accuracy of prediction due to the intrinsic error associated with the cephalometric technique in general. Johnston's study revealed no single morphologic trait or combination of traits that would serve as predictors of future growth events. The results of the present study reveal that prediction of treatment outcomes in growing patients is possible only to a certain extent, and that the variables that affect prediction cannot be fully defined due to the difficulty in forecasting the contributions of each individual anatomical structure to the final overall product.

Conclusions

The findings of the present study revealed that:

1. The computer and manual VTO methods were similar in their prediction of skeletal, dental, and soft tissue anatomical structures, with no clinically significant differences between methods.
2. The skeletal parameters investigated were well correlated when both the manual and computer VTO methods were compared with the posttreatment tracings.
3. The dental and soft tissue parameters investigated were, for the most part, poorly correlated when both the manual and computer VTO methods were compared with the posttreatment tracings.

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