Original Article

Soft Tissue Images from Cephalograms Compared With Those from a 3D Surface Acquisition System

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ABSTRACT

Objective: To assess whether 2D cephalometrics is comparable with 3D imaging devices and whether 3D technology could replace traditional 2D image capture in posttreatment evaluation.

Materials and Methods: The study is a prospective evaluation of superimposition techniques obtained from a cohort of 40 patients who underwent orthognathic surgery in a private practice environment. Surgical records were obtained from lateral cephalometric radiographs taken by a Kodak 8000C machine, and the 3D images were obtained from the 3dMD stereo photogrammetric camera capture system. Pre- and postlateral cephalometric records were superimposed on the cranial base (SN line) while pre- and post-3D surgical records were superimposed on the regional best-fit method. A mathematical algorithm, or best-fit calculation, was carried out on the selected surfaces. Each set of superimposed records was analyzed, and five soft tissue landmarks were plotted. The differences between the five surface points were analyzed for each set of records.

Results: The final sample consisted of 34 subjects with full records. A total of 680 surface landmarks were plotted and analyzed. The mean differences of the soft tissue landmarks were analyzed for each pair of data sets and were found to range between 1.06 and 8.07 mm and 1.26 and 7.34 mm for lateral cephalometric and 3D readings, respectively. Paired *t*-tests were carried out using the SPSS 15.0 software, and they showed that the results were not statistically significant between the superimposition techniques on the image capture systems ($P > .05$).

Conclusions: The types of superimposition techniques used in the imaging modalities studied were comparable with one another. (*Angle Orthod.* 2010;80:58–64.)

KEY WORDS: 3D imaging; Soft tissue imaging; Comparison; Cephalograms

INTRODUCTION

In the past, clinicians have used two-dimensional (2D) images such as facial and intraoral photographs, and frontal or lateral cephalometric radiographs to evaluate the face and its profile. With the advent of three-dimensional (3D) imaging, orthodontists can now visualize the face and its changes through topography, surface area, and volume.[1] Technology has allowed for mapping and quantifying facial characteristics from the Broadbent-Bolton cephalometer to present-day 3D-imaging systems.[2,3]

The lateral cephalometric radiograph has been used to monitor the changes of treatment in orthodontic patients; however, only a linear, vertical, and anteroposterior progression of facial change is seen.[1,4,5] In addition, conventional cephalometrics is limited in its ability to describe three-dimensional characteristics of the face. With its lateral projection of the patient's profile, no depth or specific orientation of landmarks can be revealed.[3]

Within the past two decades, computer hardware and software tools have allowed for improvements in 3D hard and soft tissue imaging devices, making them easy to use without causing radiation exposure.[6–11]

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This type of imaging plays a significant role in determining how the face changes in all three planes of space from orthodontic treatment. The literature has shown that three-dimensional surface imaging techniques have been utilized in a variety of orthodontic applications.[3]

Methods of superimposition have been discussed in the past, and the earliest studies of the face entailed measurements of the skull at different ages.[12] Initial human studies used humans with implants placed in the jaws,[13] after which studies showing the stability of the anterior cranial base led to the use of stable structures within this region.[14] Some of these structures include the SN line and portions of the cranium. Soft tissue superimpositions are more complex, but they have been described in some detail. Some authors have suggested the use of the iterative closest-point algorithm in growth studies[15] and modified area-based, regional-fit methods for superimposing soft tissue surfaces. These methods use complex algorithms to achieve the superimposition of surfaces.

To date, there have been no reported studies comparing soft tissue changes between 3D facial images and lateral cephalometric radiographs. The aim of this study was to determine if there is a difference in soft tissue landmarks seen on traditional 2D lateral cephalometric radiographs and 3D surface-image capture on pre- and postorthodontic treatment records.

MATERIALS AND METHODS

Subjects

This prospective study consisted of 40 subjects in a private practice for the purpose of combined orthodontics and orthognathic surgery recruited over a 6-month period. Of these, 34 had full records taken and were included in the study. Thirteen patients were skeletal Class I, 16 were skeletal Class II, and 5 were skeletal Class III. Six records were incomplete.

Records were taken pre- and postorthognathic surgery over a 6-month period. A lateral cephalometric radiograph and a 3dMD (3dMD, Atlanta, Ga) image were taken at the same sitting on each subject. Inclusion criteria for the records obtained included pre- and postlateral cephalometric (pre-C and post-C) radiographs taken with the same machine without magnification error, pre- and post-3dMD images in natural head position, and both types of images taken in similar matching facial poses.

Lateral cephalometric radiographs were obtained using a Kodak 8000C Digital Panoramic and Cephalometric System machine (Kodak, Rochester, NY). These were transferred from their proprietary formats and saved as readable files with no known magnification error introduced. These radiographs were obtained with the patient assuming a natural head posture.[16] Hand tracings were drawn from each pre-C and post-C on regular acetate paper, focusing only on the soft tissue. 3D surface images were obtained from a structured light system combined with stereophotogrammetry, the 3dMD face multicamera system.[17] This system uses three cameras positioned on either side of the subject, having a capture time of only 1.5 milliseconds and a reported clinical accuracy of 1.5% of total observed variance.[8] 3dMD images were converted from their proprietary format (*.tsb) and exported as universal readable files (*.obj). These images were imported into commercially available Rapidform 2006 (RF6, Rapidform Inc, Sunnyvale, Calif) computer software, which used an algorithm to superimpose the pre- and postsurgical images.

Superimposition Techniques

Lateral cephalometrics. The digital cephalometric radiographs were printed and traced with the patient's image facing (by convention) to the right.[18] Fiducial markers were used to reorient the lateral cephalograms. The same landmarks were located and traced for each pre-C and post-C radiograph. Hard tissues traced included sella turcica, anterior clinoid process, ethmoidale, basion, and nasion. The soft tissue profile was then drawn in. Pre-C and post-C radiographs were superimposed on SN, the anterior clinoid process, and the spheno-ethmoid plane.[19]

3dMD Images

3dMD images were acquired in natural head posture and exported as an *obj. file and imported into the Rapidform 2006 software. Work activities within the software allowed high-quality polygon meshes, accurate freeform, nonuniform rationale B-spline (NURBS) surfaces, and geometrically perfect solid models to be created.[3] The broadest area of the anterior position of the forehead, including soft tissue glabella, soft tissue nasion, and bridge of nose were incorporated into a regional fit environment. Two images, T^1 and T^2, were superimposed using these methods, the differences between them determined, and landmark points analyzed.

Parameters Measured

Five common soft tissue landmarks were located and analyzed on both the lateral cephalometric radiographs and the 3dMD images[20]:

Soft tissue nasion (STN)—the point of greatest concavity in the midline between the forehead and the nose.

Tip of nose (TN; pronasale)—the most prominent or anterior point of the nose.

Table 1. Landmark Changes Asscociated With the Three Skeletal Types for Both Cephalometrics and 3D Imaging[a]

Subject	Image	STN	TN	UL	LL	STP
B	Ceph	1	1	4.9	6.5	7.5
	3D	0.95	2.9	5.35	5.46	6.7
H	Ceph	1.1	1	5	8.1	15
	3D	0.93	1.9	5.66	6.31	11.044
W	Ceph	0.5	3.5	8.5	4.5	2.5
	3D	0.42	3.69	7.37	4.74	3.1

[a] STN indicates soft tissue nasion; TN, tip of nose; UL, upper lip; LL, lower lip; STP, soft tissue pogonion.

Upper lip (UL; labrale superius)—a point indicating the mucocutaneous border of the upper lip. The most anterior point (usually) of the upper lip.

Lower lip (LL; labrale inferius)—the median point on the lower margin of the lower membranous lip.

Soft tissue pogonion (STP)—the most prominent or anterior point on the chin in the midsagittal plane.

After each set of pre- and post-cephalometric radiographs and 3dMD images were superimposed, measurements were made between the allocated landmarks to assess linear changes in the soft tissue profile. Lateral cephalometric points were measured with calipers, and the 3dMD images were analyzed using the Rapidform 2006 software. All measurements were done in millimeters. These five landmark points were analyzed using paired *t*-tests and carried out using the SPSS 15.0 software (SPSS, Chicago, Ill) ($P < .5$).

RESULTS

Parameters

Results for each individual tracing and 3D-measurement type are included in the following section. Reliability studies carried out on inter- and intraoperator reliability for both the lateral cephalometric tracing and RF6 were not statistically significant. The readings fell within a 0.5-mm limit. The data sets were tested for normality and found to be normally distributed (Table 1).

Soft Tissue Nasion (STN)

The mean difference for the cephalometric superimposition method was 1.07 mm, with an SD of 0.56. The superimposition method using the regional method for the 3D images had a mean of 1.26 mm and SD of 0.64. The difference between mean values was approximately 0.19 mm; the distribution is shown in Figure 1. *T*-tests performed on the two data sets were not statistically significant ($P > .05$).

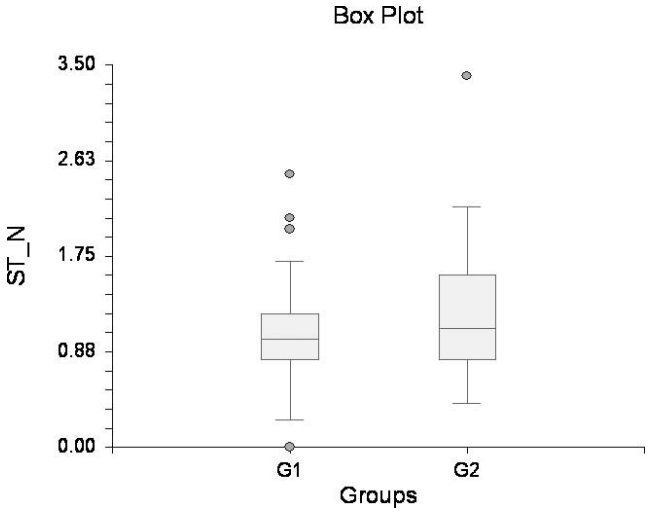

Figure 1. Box plots showing mean values for treatment changes associated with STN; G1, cephalometric radiograph; G2, 3D.

Tip of Nose (TN)

The mean difference for the cephalometric superimposition method was 2.09 mm with an SD of 1.44. The superimposition method using the regional method for the 3D images had a mean of 2.65 mm and SD of 1.48. The difference between mean values was approximately 0.56 mm; the distribution can be found in Figure 2. *T*-tests performed on the two data sets were not statistically significant ($P > .05$).

Upper Lip (UL)

The mean difference for the cephalometric superimposition method was 5.39 mm, with an SD of 3.13. The superimposition method using the regional method for the 3D images had a mean of 5.59 mm and SD

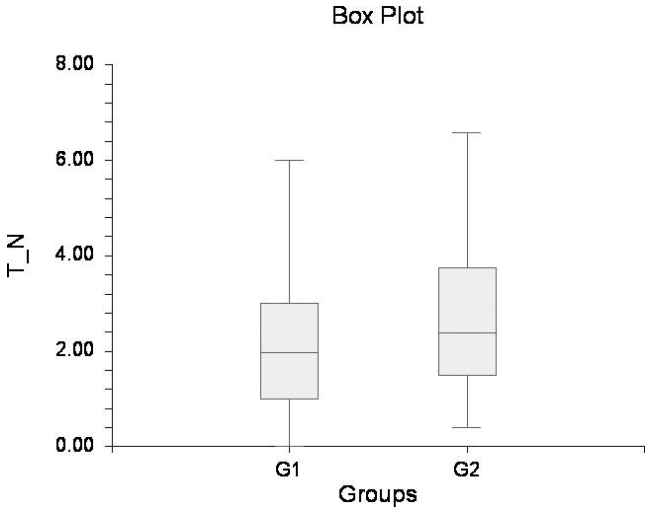

Figure 2. Box plots showing mean values for treatment changes associated with TN; G1, cephalometric radiograph; G2, 3D.

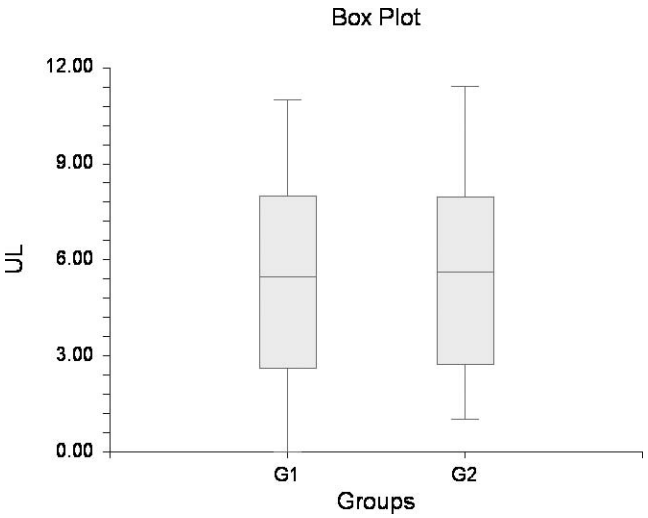

Figure 3. Box plots showing mean values for treatment changes associated with UL; G1, cephalometric radiograph; G2, 3D.

of 3.06. The difference between mean values was approximately 0.02 mm; the distribution can be found in Figure 3. *T*-tests performed on the two data sets were not statistically significant ($P > .05$).

Lower Lip (LL)

The mean difference for the cephalometric superimposition method was 5.93 mm, with an SD of 2.96. The superimposition method using the regional method for the 3D images had a mean of 5.87 mm and SD of 2.83. The difference between mean values was approximately 0.06 mm; the distribution can be found in Figure 4. *T*-tests performed on the two data sets were not statistically significant ($P > .05$).

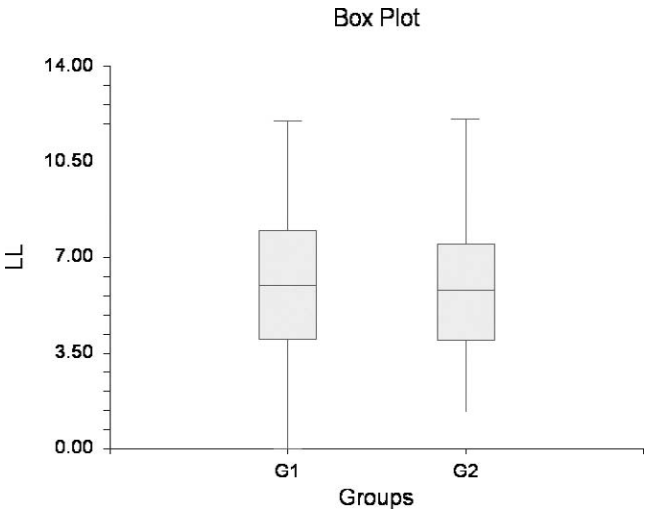

Figure 4. Box plots showing mean values for treatment changes associated with LL; G1, cephalometric radiograph; G2, 3D.

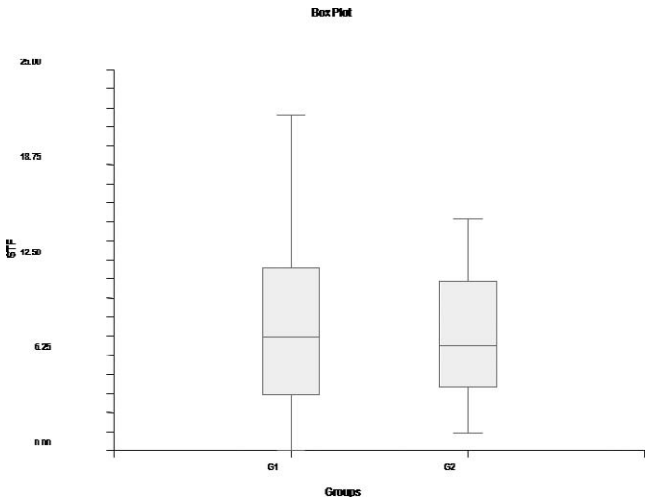

Figure 5. Box plots showing mean values for treatment changes associated with STP; G1, cephalometric radiograph; G2, 3D.

Soft Tissue Pogonion (STP)

The mean difference for the cephalometric superimposition method was 8.07 mm, with an SD of 5.16. The superimposition method using the regional method for the 3D images had a mean of 7.34 mm and SD of 3.94. The difference between mean values was approximately 0.73 mm; the distribution can be found in Figure 5. *T*-tests performed on the two data sets were not statistically significant ($P > .05$).

DISCUSSION

Traditionally, treatment changes have been measured in two dimensions. However, during lateral cephalometric radiographic capture, patients are subjected to radiation dosage, and images are prone to magnification errors.[16] Therefore, conventional methods are limited in their ability to illustrate three-dimensional characteristics of the face since there is no representation of proper orientation and depth.[3] In this study, two important outcomes were noted and will be discussed under the headings of superimposition techniques and advantages of 3D imaging.

Superimposition Techniques

In assessing the superimposition techniques, no significant differences were noted between the five soft tissue landmarks chosen between the 34 subjects' pre- and posttreatment evaluations when comparing the 2D and 3D images. The linear differences between the mean changes were minimal among the five landmarks when comparing lateral cephalometric radiographs and 3D facial images. On average, the mean of the differences was 0.312 mm. The point STP showed the greatest difference, but was within 1 mm.

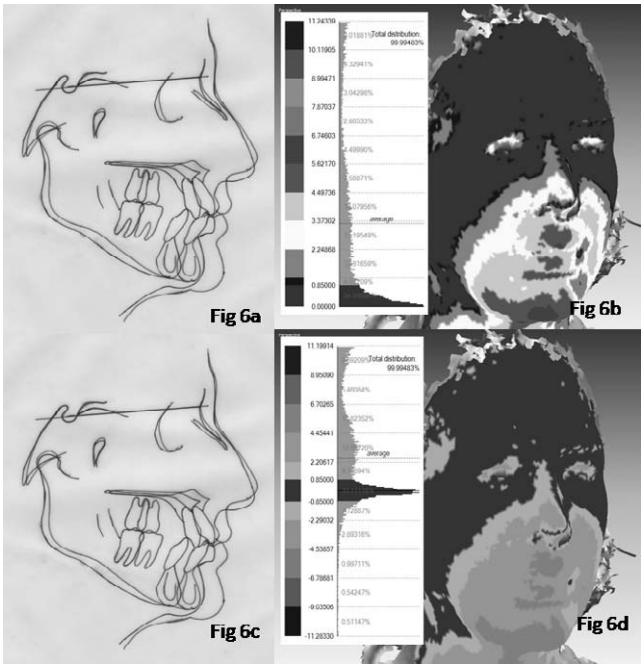

Figure 6. Subject B a) and c) Changes on the lateral cephalometric radiograph showed soft tissue changes. b) and d) The 3D superimposition revealed how the same landmarks moved forward.

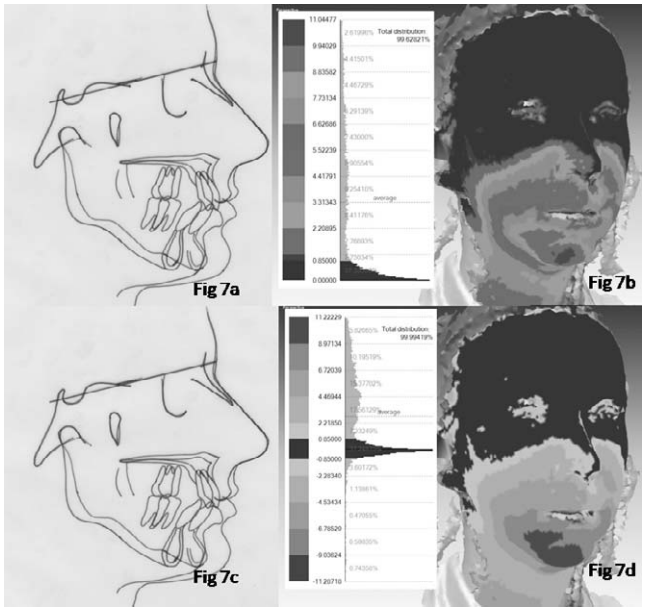

Figure 7. Subject H a) and c) Changes on the lateral cephalometric radiograph showed soft tissue changes. b) and d) The 3D superimposition revealed how the same landmarks moved forward.

This could be due to the fact that this point was at the edge of the 3dMD field of view and was therefore prone to light distortion during image capture.

Advantages of 3D Imaging

Facial 3D image capture allowed for more information to be assessed than did 2D image capture. This is consistent with similar studies.[21] This further strengthens the notion that the human face is a three-dimensional form, and the best way to describe facial changes taking place after orthodontic treatment calls for the use of an imaging system that truly captures facial anatomy. Traditionally, the lateral cephalometric radiograph has been used for assessing orthodontic treatment needs, but it is a two-dimensional image.[22] The following three illustrations (incorporating three different skeletal types) describe the soft tissue facial changes noted in this study that illustrate how more information is seen using a 3D-imaging device. The results of the differences in landmark points occurring between treatment visits for each of the three subjects are shown in Table 1.

Subject B was a Class I skeletal patient who had surgery; the soft tissue changes can be seen in Figure 6. The lateral cephalometric radiograph showed the following soft tissue changes: the forehead remained the same, the tip of the nose moved upward, the upper lip moved forward (6.0 mm), the lower lip moved forward (6.0 mm), and the chin moved forward (8.0 mm). Similarly, the 3D superimposition revealed how the same landmarks moved forward. The tip of the nose moved upward, the upper lip moved forward (5.9 mm), the lower lip moved forward (6.0 mm), and the chin also moved forward (6.0 mm). The 3D image of this patient showed more surface area changes that could not be illustrated on the lateral cephalometric radiograph. The soft tissue areas lateral to the lips revealed a negative volumetric change, as was also seen in the cheek region and inferior border of the mandible. The skin in this area might have become tauter in this region due to the two-jaw advancement procedure that was done. Also, more definition could be noted in the chin-throat angle when viewed laterally, which cannot be assessed on the soft tissue outlines of the lateral cephalometric radiograph.

In the skeletal Class II division I patient H, who underwent a mandibular advancement, similar differences were noted in the soft tissue outlines between the lateral cephalometric radiograph and the 3D image. These changes can be seen in Figure 7. Both images showed how the forehead region remained the same while the tip of the nose moved upward and forward. In the cephalometric superimpostion, the lips and chin moved forward: upper lip, 5.0 mm; lower lip, 12.0 mm; and chin, 13.0 mm. In the 3D images, all the same landmarks moved forward: the upper lip, 6.0 mm; the lower lip, 11.0 mm; the chin, 11.5 mm. The chin point difference between the lateral cephalometric radiograph and the 3D image for this case showed the greatest difference, which was a consistent finding in

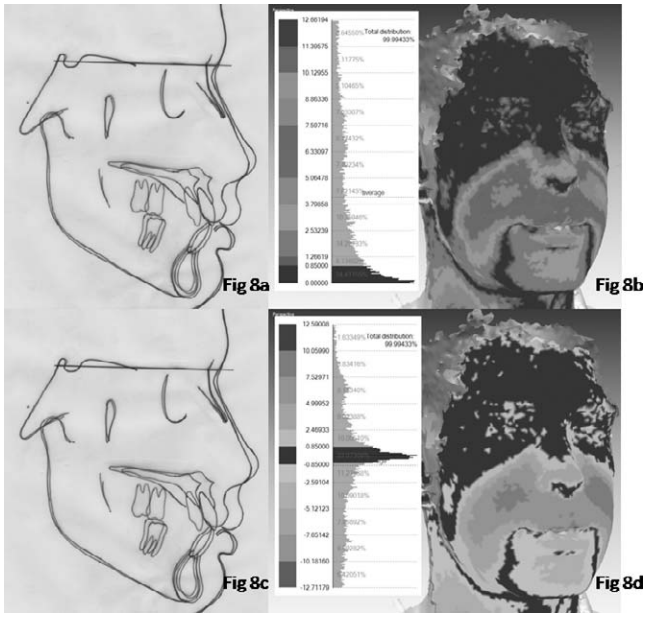

Figure 8. Subject W a) and c) Changes on the lateral cephalometric radiograph showed soft tissue changes. b) and d) The 3D superimposition revealed how the same landmarks moved forward.

this study. Therefore, in the Class II example, all soft tissue changes seen in the 2D radiograph were noted in the 3D images, along with more findings. The forehead and soft tissue nasion areas remained the same as on the lateral cephalometric radiograph, but the 3D superimposition revealed positive volumetric changes in the malar and lateral cheek areas. The chin throat angle changed more after orthognathic surgery, which is clearly illustrated in the 3D superimpositions.

The last case was that of a Class III skeletal patient, W, who underwent orthognathic surgery; changes can be seen in Figure 8. In both the lateral cephalometric and 3D facial image superimpositions, the tip of the nose moved forward and slightly upward, and the forehead regions remained the same after surgery. Shown by the lateral cephalometric superimposition, the upper lip moved forward 8.0 mm, the lower lip moved backward 4.0 mm, and the chin point moved backward 3.0 mm. Similar changes were noted with the 3D image superimpositions. The upper lip moved forward 7.0 mm, the lower lip moved backward 4.6 mm, and the chin moved backward 3.2 mm. In the 3D superimposition, a positive surface area change occurred in the alar base of the nose, a small region beneath the alar base (which corresponded to the upper lip moving forward), and the region inferior to the malar areas. The lateral cheek areas demonstrated positive volumetric change, which is undetectable on the patient's lateral cephalometric radiograph when looking at the 3D image from a lateral view. The soft tissue overlying the inferior border of the mandible revealed a slight positive surface-area change. The lower lip and chin followed the same backward movement as shown by the lateral cephalometric radiograph illustrated by a negative surface area change on the color map.

Limitations of Study

One limitation was based on the assumption that all patients were positioned properly during both types of image capture. Second, it was assumed that there was no magnification error in the lateral cephalometric radiographs. Finally, an overall limitation was the fact that the 3dMD images only address soft tissue surface changes and not hard tissue structure changes. Studies on the exact correlation between hard and soft tissue structures still need to be conducted, especially in 3D.

CONCLUSIONS

- This study demonstrated that the types of superimposition techniques used in the imaging modalities were comparable with one another.
- Future midtreatment soft tissue evaluations can be carried out using a noninvasive imaging device (3dMD capture system).

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