AJO-DO

Three-dimensional evaluation of changes in lip position from before to after orthodontic appliance removal

Lindsey Eidson,[a] Lucia H. S. Cevidanes,[b] Leonardo Koerich de Paula,[c] H. Garland Hershey,[d] Gregory Welch,[e] and P. Emile Rossouw[f]
Charlotte and Chapel Hill, NC, and Rio de Janeiro, Brazil

Introduction: Our objectives were to develop a reproducible method of superimposing 3-dimensional images for measuring soft-tissue changes over time and to use this method to document changes in lip position after the removal of orthodontic appliances. **Methods:** Three-dimensional photographs of 50 subjects were made in repose and maximum intercuspation before and after orthodontic appliance removal with a stereo camera. For reliability assessment, 2 photographs were repeated for 15 patients. The images were registered on stable areas, and surface-to-surface measurements were made for defined landmarks. **Results:** Mean changes were below the level of clinical significance (set at 1.5 mm). However, 51% and 18% of the subjects experienced changes greater than 1.5 mm at the commissures and lower lips, respectively. **Conclusions:** The use of serial 3-dimensional photographs is a reliable method of documenting soft-tissue changes. Soft-tissue changes after appliance removal are not clinically significant; however, there is great individual variability. (Am J Orthod Dentofacial Orthop 2012;142:410-8)

Orthodontic tooth or orthopedic bone movement in the face can affect soft-tissue drape; moreover, it is speculated that most fixed orthodontic appliances have a role to play in the soft-tissue drape. Orthodontic treatment decisions with regard to the need for extraction of teeth are often made in midtreatment based on soft-tissue positions. It is important to gain a better understanding of how or whether orthodontic appliances affect the appearance of the soft tissues, particularly the position of the lips.

[a]Private practice, Charlotte, NC.
[b]Associate professor, Department of Orthodontics, University of North Carolina, Chapel Hill.
[c]Postgraduate student, Department of Orthodontics, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.
[d]Professor, Department of Orthodontics, University of North Carolina, Chapel Hill.
[e]Research professor, Department of Computer Sciences, University of North Carolina, Chapel Hill.
[f]Professor and chair, Department of Orthodontics, University of North Carolina, Chapel Hill.
The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.
Supported by the American Association for Orthodontists Foundation and the Southern Association of Orthodontists.
Reprint requests to: Lindsey Eidson, 7820 Ballantyne Commons Parkway, Suite 200, Charlotte, NC 28277; e-mail, lindseyeidsondds@gmail.com.
Submitted, July 2011; revised and accepted, January 2012.
0889-5406/$36.00

doi:10.1016/j.ajodo.2012.01.018

To date, the only study on the role of orthodontic appliances on changes in soft-tissue contours used 2-dimensional photographs for evaluation.[1] Advances in 3-dimensional imaging now make it possible to capture and superimpose digital images and measure changes in soft-tissue positions from 3-dimensional photographs taken at several time points. Such advances in facial imaging allow a more thorough investigation of changes in 3 dimensions and prevent the inherent loss of information that results from 2-dimensional imaging.[2-4]

Cone-beam computed tomography, laser scanners, and structured light-stereo photogrammetry are the current prevailing technologies in 3-dimensional soft-tissue imaging.[5] Although cone-beam computed tomography devices can produce high-quality soft-tissue images, exposure to radiation and noise in the skin surface at the periphery of the cone beam limit their role for soft-tissue assessment alone. In addition, motion artifacts are significantly diminished with the latter devices because the capture time is much shorter.[6] The use of stereo cameras with short shutter speeds such as the 3dMDface stereo camera system (3dMD, Atlanta, Ga) is convenient for clinicians and patients for capturing soft-tissue records.

As 3-dimensional imaging devices and software designed for manipulating digital 3-dimensional files continue to improve, the orthodontic community must assess the effectiveness and reliability of these tools in both research and clinical settings. Previous work has

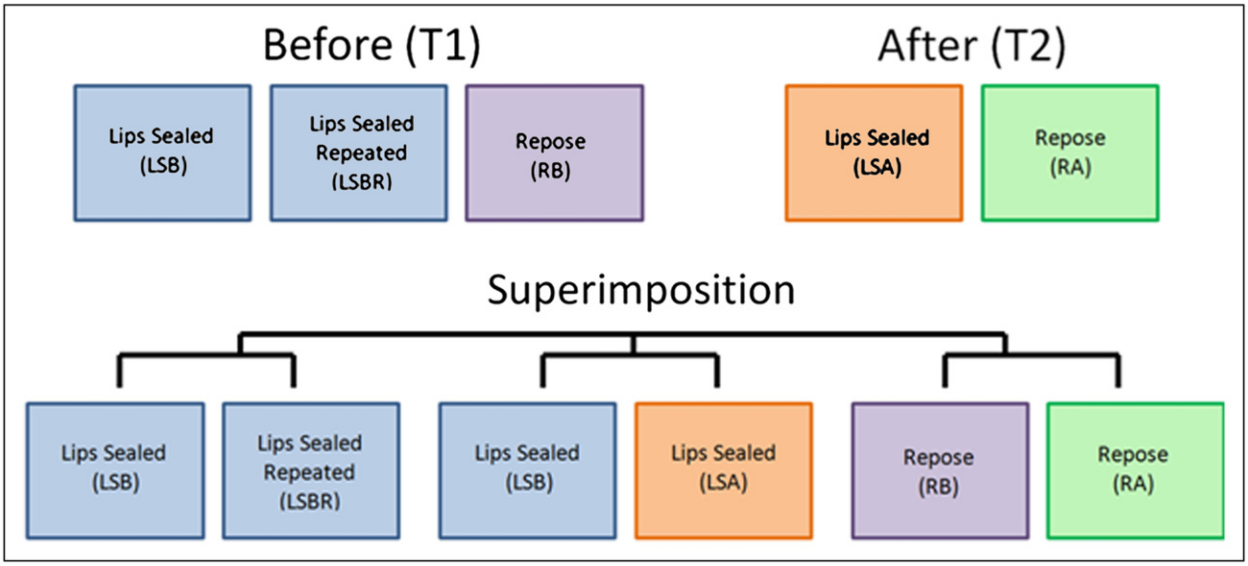

Fig 1. Study design: repeatability of photograph capture and lip-position changes after appliance removal. Before the appliances were removed (*T1*), 3 photographs were captured: "lips sealed before" (*LSB*), "lips sealed before repeated" (*LSBR*), and "repose before" (*RB*). After the appliances were removed (*T2*), "lips sealed after" (*LSA*) and "repose after" (*RA*) were captured. The images were superimposed as described by the chart: LSB to LSBR, LSB to LSA, and RB to RA.

shown the precision and accuracy of images obtained by stereo camera systems clinically compared with direct anthropometric measurements with phantom models.[7,8] The intraobserver and interobserver repeatabilities of 3-dimensional landmark identification have also previously been established.[8,9] However, the repeatability of images captured at different time points still must be established.

In this study, we aimed to (1) introduce a method of reliably measuring soft-tissue change between 2 time points using the 3dMDface stereo camera system and (2) use this methodology to evaluate the effect of orthodontic appliance removal on lip positions in 3 dimensions.

MATERIAL AND METHODS

The sample included 50 subjects recruited from the patient population of the Department of Orthodontics at the University of North Carolina who had completed their orthodontic care, had a Class I occlusion, and were willing to participate. Patients with lip incompetence and major facial asymmetries were excluded from the study. No efforts were made to select a sample based on age, sex, ethnicity, or race. This study was approved by the institutional review board of the University of North Carolina.

The 3dMDface stereo camera system was used for 3-dimensional photograph capture. The camera consists of 2 sets of 3 cameras (2 monochrome, 1 color) positioned with known angulations and distances from each other. The stereo pair was synchronized to photograph the patient in 1.5 ms to generate 1 continuous point cloud system. The software provided, 3dMDpatient, includes algorithms that use the known location of each camera and information from the calibration process to build the 3-dimensional geometry after capture. The color information is then applied to the geometry to create a photo-realistic 3-dimensional picture.

To prevent displacement of the cameras between acquisitions, they were located in a separate consultation room, and their setup was kept constant. Additionally, daily calibration of the 3-dimensional camera was performed following the procedures recommended by the manufacturer.

Five 3-dimensional photographs were captured for each patient at the debonding appointment (Fig 1). For all patients, 2 photographs were captured immediately before debonding and consisted of "lips sealed before" with the patient in maximum intercuspation occlusion with lips together and "repose before" with the patient in wax-record supported rest position. The wax record was obtained by placing a layer of wax between the posterior teeth and having the patient bite on 3 tongue depressors (height, 3 mm) between the maxillary and mandibular central incisors. The record was subsequently trimmed so that no wax extended beyond the facial surfaces of any teeth. A third predebond 3-dimensional

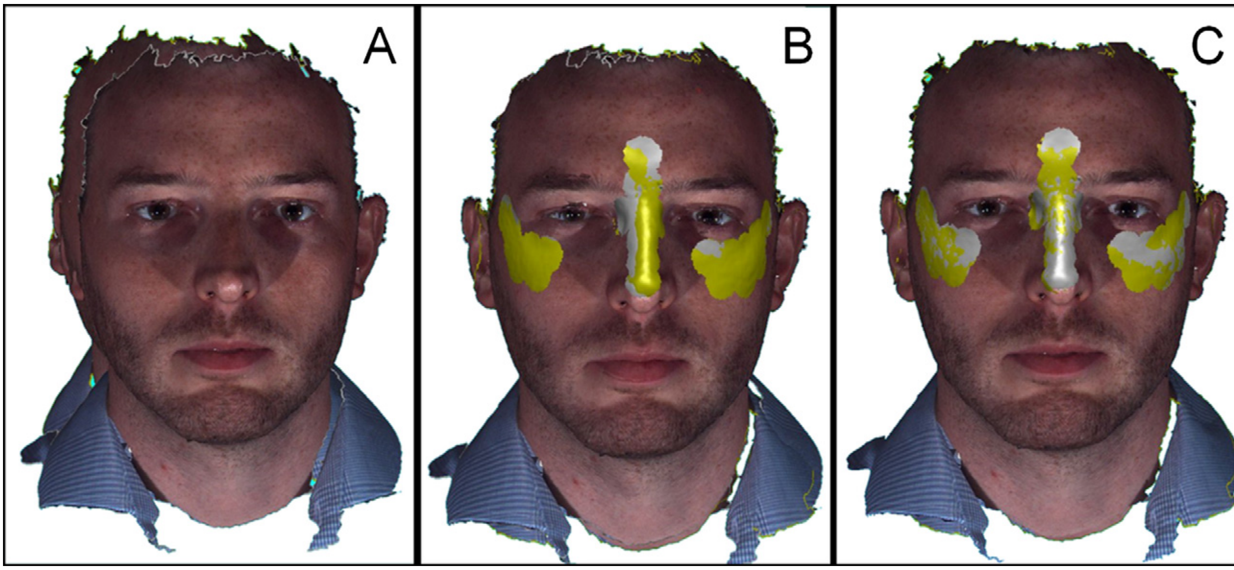

Fig 2. Method of superimposition. **A,** The images are uploaded after capture of "lips sealed before" and "lips sealed before repeated." **B,** After whole-surface superimpositions, areas assumed to be unaltered by the appliances (intercanthal region, dorsum of the nose, temporal region, and upper zygoma) were selected. The images were then superimposed by using only the selected areas. **C,** The superimposed images were subsequently exported from 3dMDpatient.

photograph, "lips sealed before repeated," was taken of 15 patients: this was a repeat of the "lips sealed before" and was captured to determine the reliability of the photographic capture method. For each photograph, the patient was asked to relax his or her facial musculature, swallow, and occlude lightly on the posterior teeth. After the brackets and remaining composite resin were removed, 2 additional photographs were captured. These photographs were "lips sealed after" with the patient in maximum intercuspation occlusion with lips together, as in "lips sealed before," and "repose after" with the patient in wax-record supported rest position, as in "repose before." For these images, the subjects were asked again to relax their facial muscles and occlude lightly on first their posterior teeth (for "lips sealed after") and then the wax record (for "repose after").

Images from before debonding and after removal of the brackets and resin were registered with the 3dMDpatient software. The postdebond 3-dimensional photo was used as a reference ("lips sealed before" to "lips sealed after," and "repose before" to "repose after"). The images of "lips sealed before" and "lips sealed before repeated" were registered in the same manner. The images were first registered by using the whole-surfaces function. After the initial registration, as shown in Figure 2, selections of facial areas on the before and after images were made of the images before debonding and after removal of the brackets and resin of facial areas assumed to be stable between photo acquisitions and unaltered by the orthodontic fixed appliances (intercanthal region, dorsum of the nose, temporal region, and upper zygoma). The program was then used to complete a second best-fit

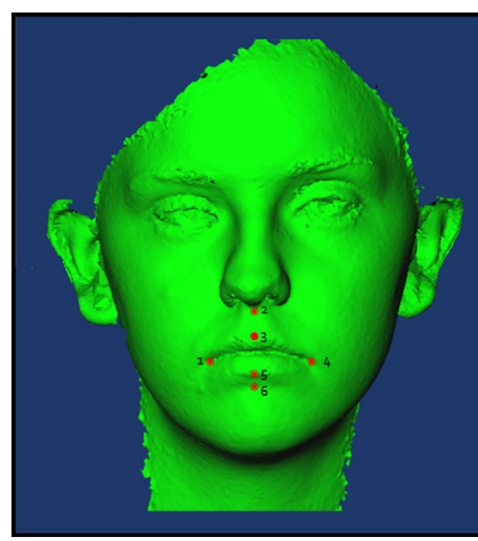

Fig 3. Landmarks of interest: *1*, Right chelion; *2*, subnasale; *3*, midpoint of upper lip vermilion; *4*, left chelion; *5*, lower lip; and *6*, soft-tissue B-point. Landmarks were identified on before and after images, and CMF application generated distances (in mm) from between the 2 images.

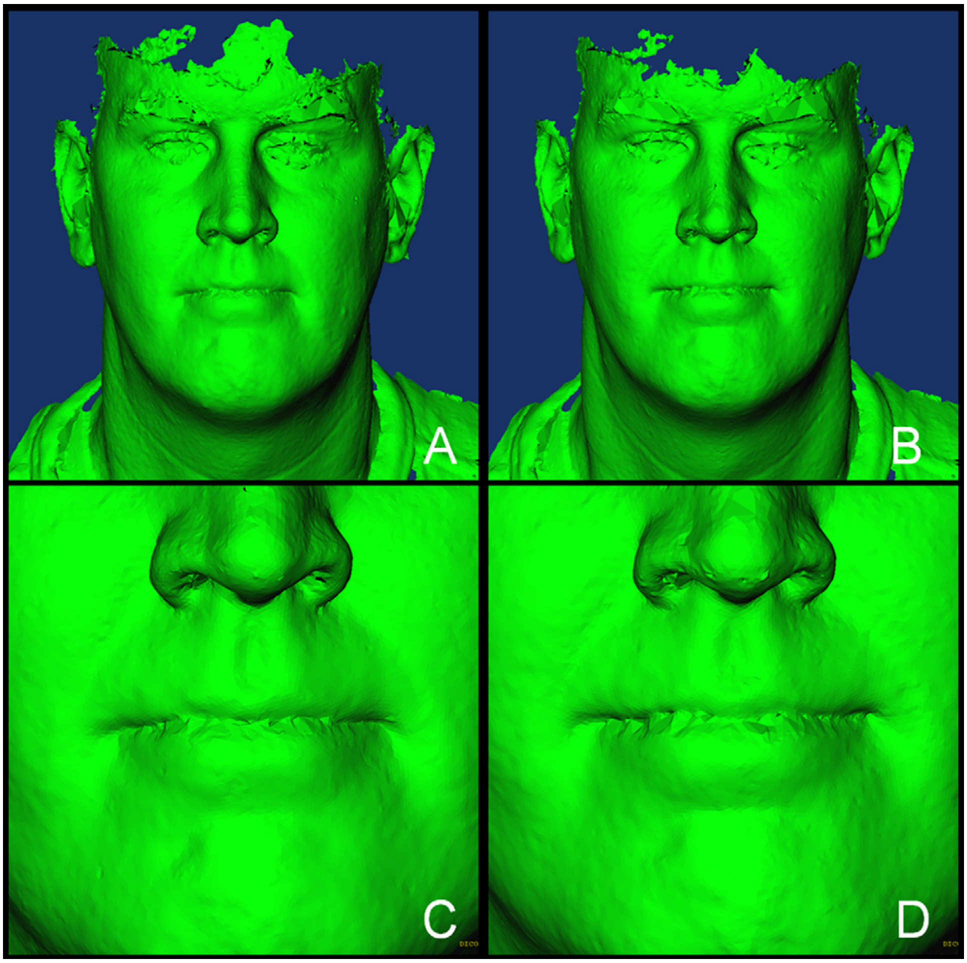

Fig 4. Quality assessment in photograph capture. Small differences in facial expression would cause errors in evaluating landmark differences from the first photograph to the second photograph. **A,** First photograph capture; **B,** second photograph capture showing a slight smile; **C,** close-up of *A*; **D,** close-up of *B*. These subjects were excluded from the study.

registration based on those selected regions by using iterative closest-point algorithms. Registration error is given by the program as the root mean square of the mean differences between images (mean value, 0.14 mm; SD, 0.05 mm).

The registered files were exported as open format, binary .STL files, and subsequently converted to open inventor .IV files by using .STL to .SGI open inventor (version 2.0, utility beta; Reuben Reyes, School of Geosciences, University of Texas, Austin). The images were then imported into CranioMaxilloFacial (CMF) application (developed at the M. E. Müller Institute for Surgical Technology and Biomechanics, University of Bern, Switzerland, under the funding of the Co-Me network [http://co-me.ch/]) for 3-dimensional evaluation.[10] To assess changes in anteroposterior lip position after appliance removal, landmarks of interest (right chelion, left chelion, upper lip, lower lip, subnasale, and soft-tissue B-point) were identified on the "lips sealed before" and "lips sealed after" images. The landmarks are shown in Figure 3. After acquisition and before proceeding to image analysis, a careful quality-control assessment was performed to verify differences in head posture or facial expression that could bias the measurements in this study. The images of 11 subjects showing changes in facial expression from a slight smile or pursing of lips (Fig 4) were discarded, leaving a final sample of 39 subjects in the study. Distance measurements at each landmark were computed by CMF application and reported in millimeters. Directional change was described as either anterior movement after appliance removal (positive value) or posterior movement (negative value).

To assess changes in vertical lip position after appliance removal, the "repose before" and "repose

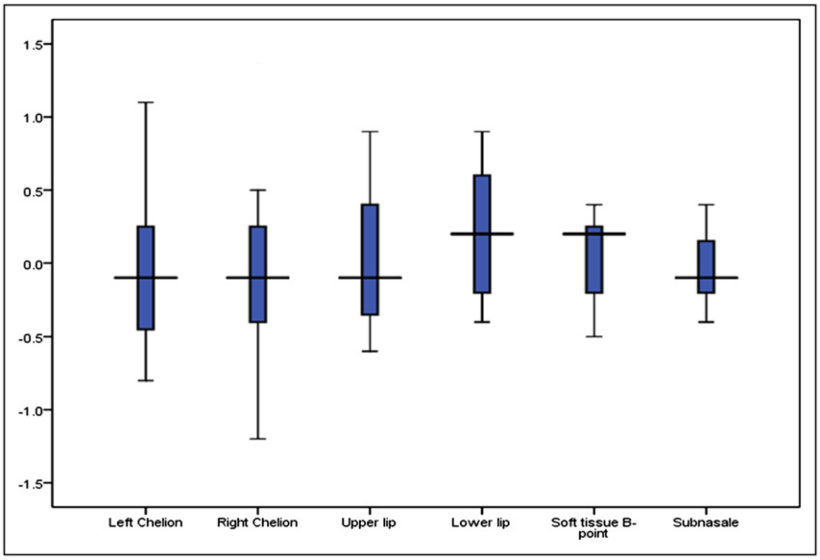

Fig 5. Repeatable photographs: box plot of mean differences. Mean differences for each landmark were not statistically significant from 0 mm (*P* >0.05). Positive values indicate movement anteriorly from photograph 1 to photograph 2.

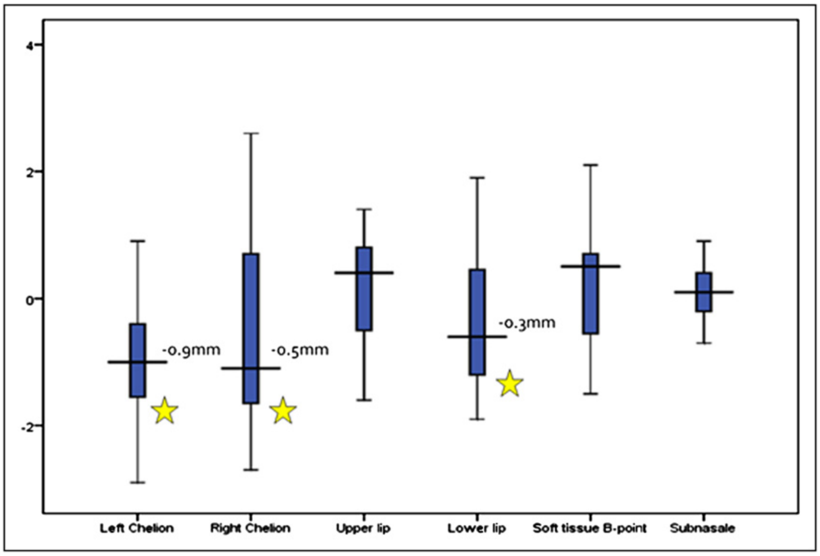

Fig 6. Box plot of the mean differences in landmark position from the 2 photographs. Denoted by *stars*, the mean differences of left chelion, right chelion, and lower lip were statistically significant from 0 mm. The values, however, were smaller than 1.5 mm.

after" images were evaluated. The quality-control assessment for these images showed that 15 subjects had differences in facial expression; therefore, the final sample size for the analysis of vertical lip position was 35 subjects. Lip length was defined as the distance from subnasale to stomion superius. Lip length differences from the 2 time points were recorded, with superior and inferior movements reported as negative and positive values, respectively, so that a positive value would imply an increase in lip length after the appliances were removed.

For the evaluation of systematic bias in landmark location in the 3-dimensional photographs, 3 observers (L.E., L.H.S.C., L.K.P.) independently repeated the landmark identifications at a 1-week interval and recorded the x, y, and z coordinates for each landmark. For the

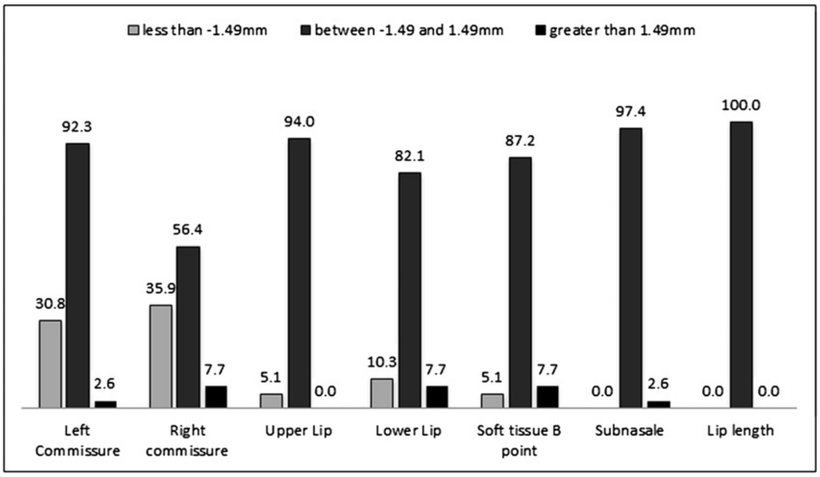

Fig 7. Percentage distributions of patients with and without clinically significant levels of landmark positional changes. Although the mean differences of all subjects were not clinically significant (greater than 1.5 mm in the anterior [positive] or posterior [negative] direction), there was considerable individual variability among the subjects.

evaluation of systematic bias in landmark position changes in the repeated 3-dimensional photographs using the 3dMDface stereo camera system, 1 observer (L.E.) identified landmarks on the registered images, "lips sealed before" and "lips sealed before repeated." The interlandmark distances were recorded and analyzed. The precision and accuracy of landmark identification and intraexaminer and interexaminer reliabilities have also been established in previous studies.[7,8]

Statistical analysis

Systematic bias in intraobserver and interobserver landmark locations was assessed by a mixed-effects analysis of variance model used to estimate the intraclass correlation coefficients (ICCs). The Student t test was used to evaluate the distances between landmarks on 2 separate occasions (1 week apart) for 2 repeated images ("lips sealed before" and "lips sealed before repeated"). Changes in lip position after appliance removal (both in maximum intercuspation with lips sealed, between "lips sealed before" and "lips sealed after"; and in repose, between "repose before" and "reposed after") were also evaluated with the Student t test.

RESULTS

The intraexaminer and interexaminer reliabilities were estimated by ICCs for each landmark's x, y, and z coordinates. Overall, the ICC values indicated excellent reliability for both intraobserver and interobserver assessments (>0.9 for all assessments).

For the repeated photographs and before- and after-appliance-removal portions of the study, the anteroposterior results were recorded and assigned positive or negative values based on anterior or posterior movements, respectively. The vertical results from the repose images were assigned positive or negative values based on inferior or superior movements, respectively.

The mean distances between the landmarks from the 2 repeated photographs are shown in Figure 5. Student t test and probability calculations (that the mean difference was greater than 0.5 mm) were conducted to evaluate the data. There were no statistically significant differences between the 2 repeated photographs.

Summarized in Figure 6 are the data for mean landmark differences from before to after appliance removal. The data were evaluated in the same manner as the repeatable photograph data. Means for left chelion (–.89 mm; SD, ±1.21), right chelion (–.50 mm; SD, ±1.45), and lower lip (–.26 mm; SD, ±1.04) each showed statistically significant differences from 0 mm (with a mean difference in the posterior direction, signed negative) after the braces were removed. Although no statistically significant mean difference was at the level of clinical significance (set at 1.5 mm), there was considerable individual variability. Fifty-one percent and 18% of the subjects had differences less than −1.5 mm or greater than 1.5 mm for the commissures and lower lips, respectively (Fig 7).

DISCUSSION

In this study, we describe a reproducible technique of using 3-dimensional photographs at 2 time points on

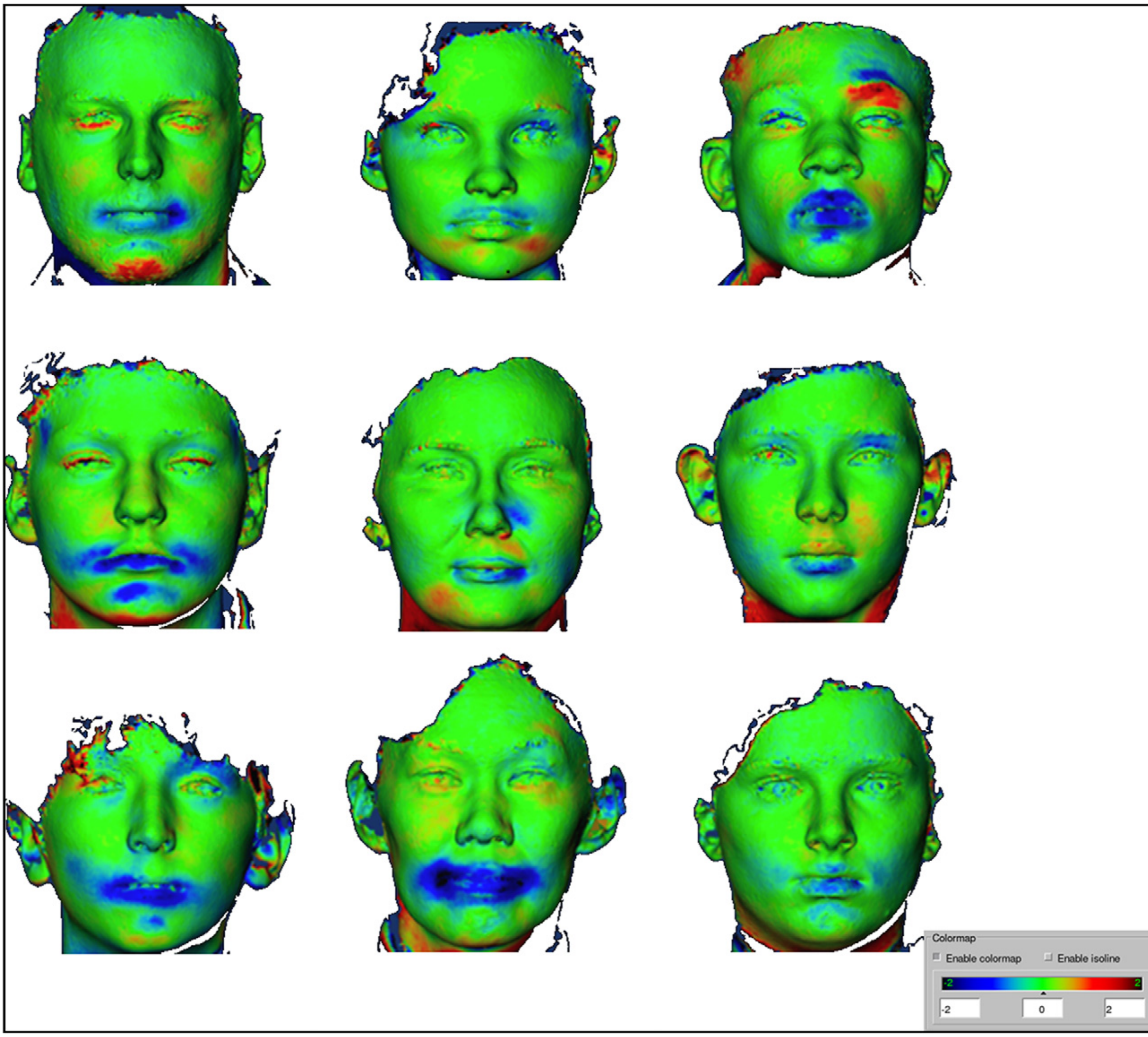

Fig 8. Color map showing the individual variability among the subjects. The range is from –2 to +2 mm of change from before to after removal, with negative change (movement in the posterior direction after removal) represented by *blue* and positive change (movement in the anterior direction after removal) represented by *red*.

the same day to document soft-tissue changes in the perioral area after orthodontic appliance removal.

For the repeated photographs, the mean differences in the 6 landmark positions (right and left chelions, upper and lower lips, subnasale, and soft-tissue B-point) showed no statistically significant differences from 0 mm of change. These findings support the ability of the 3dMDface stereo camera system to capture repeatable photographs with relatively few errors. These photographs were captured on the same day and within 5 minutes of each other, and this most likely improved the chances of keeping a low error rate in the capture of images. Future studies should continue this work by seeking to establish repeatability over longer time intervals.

In this study, 3-dimensional photographs were captured before and immediately after the orthodontic appliances were removed, and the images were superimposed to evaluate changes in the perioral area after orthodontic debonding. There were statistically significant differences in landmark positions in the right and left commissures and the lower lip. For all 3 landmarks, the positional changes were in the posterior direction after the appliances were removed. Although statistically significant, the mean differences for these landmarks were below the level of clinical significance (set at 1.5 mm), and the probability that a measurement for any of the 6 landmarks would be greater than 1.5 mm was low. The results of this study therefore suggest that fixed orthodontic appliances do not significantly alter the perioral soft-tissue positions immediately after their removal. This agrees with the findings of Abed et al,[1] who used angular measurements taken from 2-dimensional photographs in profile view and found no statistically significant differences in lip positions from before to after appliance removal. There were, however, considerable variations in landmark differences among subjects for all landmarks, with some patients having significant changes and some having little or no change from before to after appliance removal (Fig 8). Future studies could provide insight into features that are associated with marked changes from appliance removal.

Although the capture of serial 3-dimensional photographs is a promising method of evaluating changes in soft tissues over time, it is not without drawbacks. There can be considerable difficulty in achieving the same lip posture at various time points. As in similar studies, the patients were asked to swallow, put their lips together (or rest on the wax bite record with lips relaxed), and lightly occlude their posterior dentition; however, 11 and 15 subjects' images were discarded for the lips sealed and repose samples, respectively, because of obvious changes in facial expressions at the 2 times (Fig 4).[3,4] These changes in lip posture were usually due to a slight smile or a slight pursing of the lips that was unperceivable by the operator at the time of photograph capture but was detectable when observed in 3dMDpatient and CMF software as side-by-side images. The frequency of this problem in image capture (22% and 30% of the original sample) suggests that the difficulty in reproducing lip posture is a major factor to consider in future projects; thus, it is essential to try to minimize the problem.

In addition, potentially confounding errors were minimized by taking the photographs on the same day. Therefore, we were able to take advantage of the assumption that areas of the face that were not in close proximity to the perioral area would remain stable, and significant areas of the intercanthal region, dorsum of the nose, and lateral zygoma regions could be selected and used for low-error registration of the photographs. If a longer study (eg, evaluation of facial growth over time, changes in postoperative swelling, or effects of orthodontic treatment) were planned, the assumption could not be made that the areas of registration for our study would be stable. Suggestions for other means of registration are found in the literature. Maal et al[11] and others described reference-based registration, in which the right and left exocanthions and the interpupillary point were used to create a horizontal plane. A vertical plane constructed at a right angle to the horizontal plane is then constructed, and the 2 planes are used to register the images. The benefit of this type of registration is that the exocanthions and the distance between the orbits are stable over time, and changes in soft tissues do not affect the registration. One drawback of this type of registration is that errors in landmark identification significantly affect the superimpositions. Maal et al[11] reported mean errors of 1 to 1.25 mm using reference-based registrations, whereas, for surface-based registration, the mean errors were significantly lower: 0.28 to 0.40 mm. Measurements of fine changes in landmark position such as those made in this study could not be completed accurately with registration-based superimposition. Therefore, developing a method of surface-based registration in cases of marked soft-tissue changes would be an important goal for research in this field.

CONCLUSIONS

Superimposition of 3-dimensional photographs is a promising tool for evaluation of soft-tissue changes over time. The photographs are highly accurate, are relatively easy to manipulate in user-friendly software, and eliminate the need for radiation for assessment. Based on this study, the following conclusions can be made.

1. Serial 3-dimensional images with the 3dMDface stereo camera system are repeatable when captured on the same day.
2. Changes in the perioral soft tissues after appliance removal are not clinically significant, but individual variations do exist.

REFERENCES

1. Abed Y, Har-Zion G, Redlich M. Lip posture following debonding of labial appliances based on conventional profile photographs. Angle Orthod 2009;79:235-9.
2. Moyers RE, Bookstein FL. The inappropriateness of conventional cephalometrics. Am J Orthod 1979;75:599-617.
3. Tolleson SR, Kau CH, Lee RP, English JD, Harila V, Pirttiniemi P, et al. 3-D analysis of facial asymmetry in children with hip dysplasia. Angle Orthod 2010;80:519-24.
4. Gor T, Kau CH, English JD, Lee RP, Borbely P. Three-dimensional comparison of facial morphology in white populations in Budapest, Hungary, and Houston, Texas. Am J Orthod Dentofacial Orthop 2010;137:424-32.
5. Kau CH, Richmond S, Incrapera A, English J, Xia JJ. Three-dimensional surface acquisition systems for the study of facial morphology and their application to maxillofacial surgery. Int J Med Robot 2007;3:97-110.
6. Lane C, Harrell W Jr. Completing the 3-dimensional picture. Am J Orthod Dentofacial Orthop 2008;133:612-20.

7. Lubbers HT, Medinger L, Kruse A, Gratz KW, Matthews F. Precision and accuracy of the 3dMD photogrammetric system in craniomaxillofacial application. J Craniofac Surg 2010;21: 763-7.
8. Aynechi N, Larson BE, Leon-Salazar V, Beiraghi S. Accuracy and precision of a 3D anthropometric facial analysis with and without landmark labeling before image acquisition. Angle Orthod 2011; 81:245-52.
9. Plooij JM, Swennen GR, Rangel FA, Maal TJ, Schutyser FA, Bronkhorst EM, et al. Evaluation of reproducibility and reliability of 3D soft tissue analysis using 3D stereophotogrammetry. Int J Oral Maxillofac Surg 2009;38:267-73.
10. Chapuis J, Schramm A, Pappas I, Hallermann W, Schwenzer-Zimmerer K, Langlotz F, et al. A new system for computer-aided preoperative planning and intraoperative navigation during corrective jaw surgery. IEEE Trans Inf Technol Biomed 2007;11: 274-87.
11. Maal TJ, van Loon B, Plooij JM, Rangel F, Ettema AM, Borstlap WA, et al. Registration of 3-dimensional facial photographs for clinical use. J Oral Maxillofac Surg 2010;68:2391-401.