Original Article

Social smile reproducibility using 3-D stereophotogrammetry and reverse engineering technology

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ABSTRACT

Objective: To assess the range of social smile reproducibility using 3-D stereophotogrammetry and reverse engineering technology.

Materials and Methods: Social smile images of white adolescents (N = 15, mean age = 15.4 ±1.5 years; range = 14–17 years) were obtained using 3dMDFlex (3dMD, Atlanta, Ga). Each participant was asked to produce 16 social smiles at 3-minute intervals. All images were obtained in natural head position. Alignment of images, segmentation of smile area, and 3-D deviation analysis were carried out using Geomagic Control software (3D Systems Inc, Cary, NC). A single image was taken as a reference, and the remaining 15 images were compared with the reference image to evaluate positive and negative deviations. The differences between the mean deviation limits of participants with the highest and the lowest deviations and the total mean deviations were evaluated using Bland-Altman Plots.

Results: Minimum and maximum deviations of a single image from the reference image were 0.34 and 2.69 mm, respectively. Lowest deviation between two images was within 0.5 mm and 1.54 mm among all participants (mean, 0.96 ± 0.21 mm), and the highest deviation was between 0.41 mm and 2.69 mm (mean, 1.53 ± 0.46 mm). For a single patient, when all alignments were considered together, the mean deviation was between 0.32 ± 0.10 mm and 0.59 ± 0.24 mm. Mean deviation for one image was between 0.14 and 1.21 mm.

Conclusions: The range of reproducibility of the social smile presented individual variability, but this variation was not clinically significant or detectable under routine clinical observation. (*Angle Orthod.* 2016;86:448–455.)

KEY WORDS: Social smile; Reproducibility; Reverse engineering

INTRODUCTION

One of the most important factors compelling patients to seek orthodontic treatment is surely the improvement of smile esthetics, given the significance of its effect on the individual's social life. An esthetic smile has been shown to enhance perception and self-esteem during social interactions.[1] With the advent of the soft tissue paradigm and smile esthetics in diagnosis and treatment planning, clinical inspection has evolved into a thorough evaluation of static and dynamic soft tissues alongside function, structure, and biology.[2,3] However, the reproducible function of dynamic structures is crucial to assess soft tissue–hard tissue relations to determine treatment goals and to evaluate outcomes.

There are several different aspects in connection with evaluating smile esthetics such as the social smile vs the spontaneous smile. A social smile is a voluntary smile that is used by a person in social situations or when posing for a photograph. The spontaneous smile is an involuntary, natural smile representing the emotion you are experiencing at that moment.[4] According to Sarver and Ackerman,[3] when treating occlusal discrepancies, an orthodontist must have repeatable positions of the soft tissues and tooth and

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jaw relationships to use as reference points. In treating the smile, the social smile generally represents a repeatable smile[5]; however, it has been stated that the consistency may change over time in some patients. It has been emphasized that the spontaneous smile can be used as a guide while assessing the association between lip and teeth via dynamic records.[6] Ackerman et al.[7] proposed that an orthodontist should view the dynamics of anterior tooth display as a continuum, delineated by the time points of rest, speech, social smile, and enjoyment smile.

A variety of techniques have been used to assess smile esthetics, such as conventional photography, video recording, laser scanning, and stereophotogrammetry, with photography and videography being the most common methods.[8–10] It has been claimed that the ideal, or so-called reference image, could be found much easier among the many images provided by a video, while on the other hand, Schabel et al.[11] have found a high positive correlation between measurements made with images drawn from standard digital photography and video recording methods. Recently, three-dimensional (3-D) stereophotogrammetry has been introduced, which allows the acquisition of 3-D images by combining photographs captured from various angles using synchronous digital cameras. This method offers significant advantages, such as minimizing motion artifacts, high-color resolution, and obtaining repeated images at short intervals without harming the patient.[12] Although only linear measurements can be performed on these images, reverse engineering software facilitates actual 3-D assessment. Essentially, reverse engineering is a process that analyzes how an object works to enhance or duplicate it.[13] Integration of the software commonly used in engineering into orthodontics makes it possible to obtain more detailed information from these images. Therefore, the present study aimed to assess the range of social smile reproducibility using 3-D stereophotogrammetric imaging and reverse engineering technology.

MATERIALS AND METHODS

Participants

The present study was conducted with the approval of the Ethics Committee of Gülhane Military Medical Academy, and all the participants provided consent forms. The study was conducted on 15 white individuals aged between 14 and 17 years (7 females; 8 males), with a mean age of 15.4 ± 1.5 years. The study included individuals with no facial defects, evident facial asymmetry, muscular disorders, history of facial surgery or trauma, or asymmetric smile evident in clinical assessment.

Figure 1. Alignment of images with the reference image. (A) Reference 3-D stereophotogrammetric image and the corresponding mask. (B–D) 3-D deviation analysis of three randomly selected images obtained from the same participant. Necessary steps for the final image (from left to right): image to be tested, masks of reference and test images, registration at forehead, presentation of deviation between the images using colormap, obtaining the smile image.

3-D Soft-Tissue Image Acquisition

3-D surface images of each participant were acquired by a trained technician using a five-point, 3-D stereophotogrammetric camera setup, the 3dMD Flex System (3dMD, Atlanta, Ga). The device was calibrated before each acquisition. None of the participants was informed that possible reproducibility of their smile was being evaluated and no other information that may bias their responses was shared. During acquisition of the 3-D images, the subjects were seated in a back-supported and vertically adjustable chair. The participants were asked to adjust their head positions via reference lines on the mirror in front of them, and the images were acquired in the natural head position.

During acquisition of the social smiles, the researcher gave the instruction, "I want a big, nice smile in which I can see your teeth," to the participants, immediately after which the photographic technician acquired the image. Verbal repetition of the instruction was made before each acquisition. To ensure that no problems caused by the adaptation procedure would influence the study, the first three acquisitions were considered test shots, without informing the participants, with the fourth image taken as the reference image (Figure 1A). Immediately after the reference image was taken, 15 more images were acquired. 3-D stereophotogrammetric images were acquired on the same day and in three different sessions (five images per session) in order to avoid tiredness. One hour elapsed between sessions. During each session, the images were acquired at 3-minute intervals, and the procedure was repeated by repositioning the participant after each acquisition.

Data Organization and Processing

The 3-D stereophotogrammetric images were converted into standard triangulation language using 3dMD patient software and then imported by reverse engineering software (Geomagic Control, 3D Systems Inc, Cary, NC). Negative and positive deviations from other images of this reference image were evaluated.

Polygon meshes were created, and two different planes were drawn over the meshes to remove the hair, ears, and below-neck region. The first plane passed through the right and left tragus and trichion, while the second plane passed through the right and left tragus and soft tissue menton. For the facial images acquired, the testing image was aligned with the reference image using the best-fit method, and the initial alignment phase was implemented. The process was completed by implementing another alignment on the forehead. The root mean square (RMS) values obtained after final alignment in the forehead region were noted to ensure measuring sensitivity (Figure 1B–D).

A plane was created that combined subnasale and the right and left tragus on the aligned meshes, passing through right and left exocanthion, then a second plane was created perpendicular to the first. The mouth region meshes, as shown in Figure 1B–D, were obtained by removing the regions outside the intersecting planes.

The calculated parameters included the RMS error value of the alignment in the forehead region, the percentage of meshes evaluated within the segmented mouth area, the highest deviation limits in the negative and positive directions, and the means of deviations in the negative and positive directions that occurred as a result of 3-D comparison analysis. Additionally, the mean total deviations were calculated by evaluating the absolute values of negative deviations together with the positive deviations (Figure 2A–C).

Statistical Analysis

A power analysis was made of the two samples using a Satterthwaite t test. Based on a 1:1 ratio between measurements, a sample size of five was found to reveal more than 90% power at a $P < .05$ significance level, with SD1 as 0.26, SD2 as 0.11, and a true difference of means as 0.5 mm.

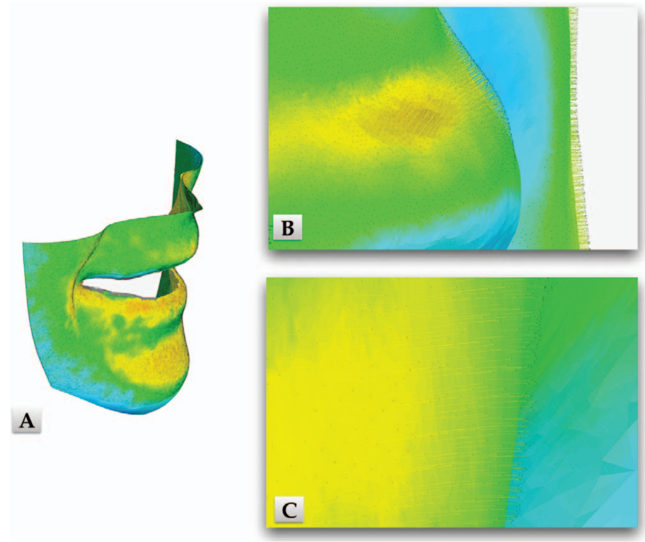

Figure 2. 3-D comparison of two different images. (A) Deviation between two images, shown as a colormap. (B, C) Magnified image of colormap and deviations, shown as a point cloud.

The alignment process was repeated on 20 images, selected randomly from among a total of 225 aligned images from 15 individuals, then the deviations were reanalyzed. Intraexaminer reliability was evaluated using an intraclass correlation coefficient, and correlations between the two sets of measurements were found to be high, between 0.948 and 0.994. A significance level of .05 was used for all statistical analyses. Descriptive statistics of the parameters were analyzed using the Statistical Package for Social Sciences software, version 20 (SPSS Inc, Chicago, Ill).

The participant with the highest deviation limit and the highest total mean deviation and the sample with the lowest deviation limit and the lowest total mean deviation were compared using Bland-Altman Plots, and agreement between the two was expressed in terms of mean $\pm$ 1.96 SD.

RESULTS

Descriptive statistics of the parameters for all 15 participants are presented in Tables 1 and 2. Of the alignments in the forehead region, the RMS error was 0.02 mm at its lowest value and 0.09 mm at its highest among the 15 individuals. The mean deviation varied between 0.04 $\pm$ 0.01 mm (the mean lowest value) and 0.07 $\pm$ 0.02 mm (the mean highest value). The lowest ratio of meshes evaluated was 93.4% and the mean lowest mesh ratio was 96.2 $\pm$ 0.98%. The highest mesh ratio was 99.9% and the mean highest mesh ratio was 98.7 $\pm$ 0.67%.

In the step following, the negative and positive deviation limits were calculated individually, and the

Table 1. Descriptive Statistics of Root Mean Square (RMS) Error (mm), Percentage of Meshes Evaluated, Deviation Limits (mm) in Negative and Positive Directions of All Participants

	RMS Error, Forehead (mm)				Percentage of Mesh (%)				Deviation Limits in Negative Direction (mm)				Deviation Limits in Positive Direction (mm)			
Subject	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
1	0.07	0.03	0.050	0.01	98.9	93.4	96.8	1.56	−1.32	−0.50	−0.84	0.34	2.50	0.82	1.28	0.41
2	0.06	0.04	0.046	0.01	98.8	94.5	96.4	1.04	−1.74	−0.49	−1.13	0.35	1.50	0.50	0.98	0.33
3	0.07	0.02	0.038	0.01	99.0	94.1	96.9	1.21	−1.54	−0.52	−0.97	0.27	1.14	0.63	0.96	0.14
4	0.09	0.03	0.053	0.02	99.1	95.0	97.2	1.29	−1.84	−0.71	−1.23	0.34	1.94	0.71	0.99	0.35
5	0.09	0.04	0.066	0.02	99.5	94.3	96.7	1.71	−1.69	−0.50	−1.16	0.29	1.64	0.89	1.25	0.19
6	0.08	0.04	0.057	0.01	98.1	94.7	96.6	1.06	−1.91	−0.34	−1.22	0.43	1.76	0.49	0.99	0.31
7	0.07	0.03	0.036	0.01	98.3	96.0	97.2	0.72	−1.72	−0.73	−0.99	0.25	1.70	0.73	0.99	0.25
8	0.08	0.02	0.049	0.02	98.1	94.1	96.6	1.17	−1.91	−0.34	−1.13	0.43	1.76	0.48	1.11	0.32
9	0.09	0.02	0.051	0.02	98.4	95.1	96.5	0.94	−1.54	−0.50	−0.95	0.33	1.71	0.50	0.99	0.28
10	0.09	0.03	0.045	0.01	97.6	94.5	96.2	0.98	−1.18	−0.53	−0.79	0.23	1.64	0.51	1.00	0.32
11	0.07	0.03	0.045	0.01	98.9	95.7	97.7	0.99	−1.91	−0.41	−1.35	0.41	2.69	1.02	1.73	0.45
12	0.08	0.02	0.037	0.01	99.9	97.3	98.7	0.67	−1.81	−0.77	−1.27	0.32	2.46	0.46	1.12	0.58
13	0.06	0.03	0.048	0.01	99.8	97.4	98.5	0.68	−1.54	−0.53	−0.94	0.25	2.11	0.83	1.51	0.30
14	0.05	0.03	0.045	0.01	99.2	97.8	98.4	0.44	−1.64	−0.53	−0.94	0.28	2.11	0.93	1.54	0.31
15	0.06	0.03	0.048	0.01	99.2	95.1	97.5	1.33	−1.97	−0.50	−1.11	0.43	2.47	0.82	1.26	0.40

absolute values of mean negative deviations of one participant were taken and calculated as the total deviation. The lowest deviation for one image was 0.34 mm among 15 individuals, while the highest deviation was 2.69 mm in the smiles of the same individual. Based on the results of the 15 different alignments from each individual, 15 mean deviations were obtained, which were evaluated in themselves to find the personal amount of mean deviation. When the deviation limits were evaluated together within the same individual, the mean lowest limit was 0.96 ± 0.21 mm (absolute deviation range, 0.5–1.54 mm) and the lowest personal mean deviation was 0.32 ± 0.1 mm (participant No. 3, Figure 1C). The mean highest limit was 1.53 ± 0.46 mm (absolute deviation range, 0.41–2.69 mm) and the highest personal mean deviation was 0.59 ± 0.24 mm (participant No. 11, Figure 1B). Detailed results obtained from the participants with the lowest and highest deviations are presented in Figure 3 A and B, respectively. Agreement between these two participants was evaluated using Bland-Altman Plots, revealing a 95% level of agreement, which were −0.43 mm and +1.58 for deviation limits. The agreements were −0.25 mm and +0.78 mm for the mean total deviation (Figure 4A and B, respectively). When the alignments were considered separately, the mean

Table 2. Descriptive Statistics of Mean Deviations (mm) in Negative and Positive Directions and Absolute Values (mm) of Negative and Positive Deviations

	Mean Deviations in Negative Direction (mm)				Mean Deviations in Positive Direction (mm)				Mean Total Deviations (mm)			
Subject	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
1	−0.79	−0.15	−0.41	0.22	0.84	0.34	0.57	0.14	0.84	0.15	0.49	0.19
2	−0.71	−0.15	−0.46	0.17	0.54	0.16	0.37	0.14	0.71	0.15	0.42	0.16
3	−0.53	−0.19	−0.31	0.10	0.49	0.22	0.33	0.10	0.53	0.19	0.32	0.10
4	−0.86	−0.26	−0.50	0.19	0.70	0.14	0.33	0.17	0.86	0.14	0.41	0.20
5	−0.80	−0.17	−0.39	0.17	0.84	0.22	0.41	0.16	0.84	0.17	0.40	0.16
6	−0.87	−0.20	−0.53	0.22	0.89	0.24	0.45	0.18	0.89	0.20	0.49	0.20
7	−0.60	−0.21	−0.34	0.11	0.76	0.22	0.35	0.14	0.76	0.21	0.34	0.12
8	−0.87	−0.19	−0.45	0.23	0.89	0.22	0.40	0.20	0.89	0.19	0.42	0.21
9	−0.71	−0.15	−0.35	0.15	0.76	0.17	0.39	0.17	0.76	0.15	0.37	0.16
10	−0.39	−0.15	−0.24	0.07	0.58	0.17	0.35	0.14	0.58	0.15	0.38	0.12
11	−1.34	−0.18	−0.55	0.27	1.21	0.33	0.68	0.27	1.21	0.18	0.59	0.24
12	−0.70	−0.18	−0.41	0.16	1.21	0.15	0.41	0.29	1.21	0.15	0.41	0.23
13	−0.57	−0.19	−0.33	0.13	0.80	0.23	0.60	0.16	0.80	0.19	0.47	0.20
14	−0.77	−0.22	−0.42	0.15	0.97	0.43	0.68	0.16	0.97	0.22	0.55	0.19
15	−0.85	−0.15	−0.52	0.20	0.94	0.41	0.59	0.14	0.94	0.15	0.55	0.17

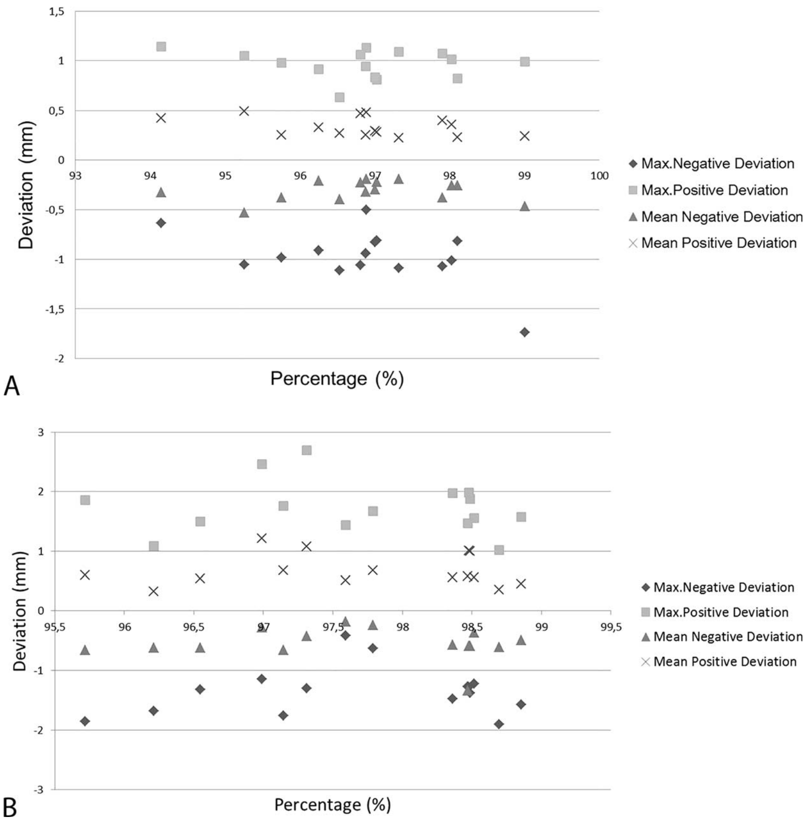

Figure 3. Distribution plot of participants presenting the lowest (A) and highest (B) deviation.

highest deviation was 1.21 mm (participant No. 11) and the mean lowest deviation was 0.14 mm (participant No. 4).

DISCUSSION

The present study aimed to assess the reproducibility of social smile using 3-D stereophotogrammetry and reverse engineering technology. The social smile was observed to deviate between 0.34 and 2.69 mm. Additionally, the mean deviation between images was found to vary between 0.14 and 1.21 mm. The maximum deviation between two images were as much as 2.7 mm, but mean total deviation did not exceed 1.5 mm for all participants. These amounts of deviations were minor and clinically insignificant. It was not possible to detect visual variations in three dimensions that were less than 2 or 3 mm when a patient presented a social smile repeatedly. The maximum limits of deviation did not present a specific localization pattern on the segmented mouth area. Thus, possible effects influencing the clinical decision regarding treatment objectives (eg, gingival exposure during smiling) remained limited.

In order to assess smile esthetics systematically in different patients or at different time points in the same individual, Ackerman et al.[5] suggested the use of a smile index. Measured on 2-D photographs, the smile index was obtained by dividing the intercommissural width by the interlabial gap. Walder et al.[14] evaluated the reproducibility of social smiles on two consecutive days using different stimuli (verbal and visual) and concluded that the smile was reproducible with either stimuli from 2-D assessments. However, a significant difference of 1.51 mm was found in the intercommissural width, as the mean change ranged between 0.1 and 0.9 mm for all other parameters. It was asserted that the subjective reproducibility of a smile was lower and that facial functions were perceived in three dimensions spatially. In other words, changes occur in anterior-posterior, horizontal, and vertical directions. Linear parameters analyzed in previous studies of 2-D photographs and relevant changes in a single plane might have caused some aspects of the area of interest to be overlooked when different types of smiles were considered (commissure, canine, complex).[15] Possible changes that were expected for each individual might be realized at various amounts in vertical, sagittal, and horizontal

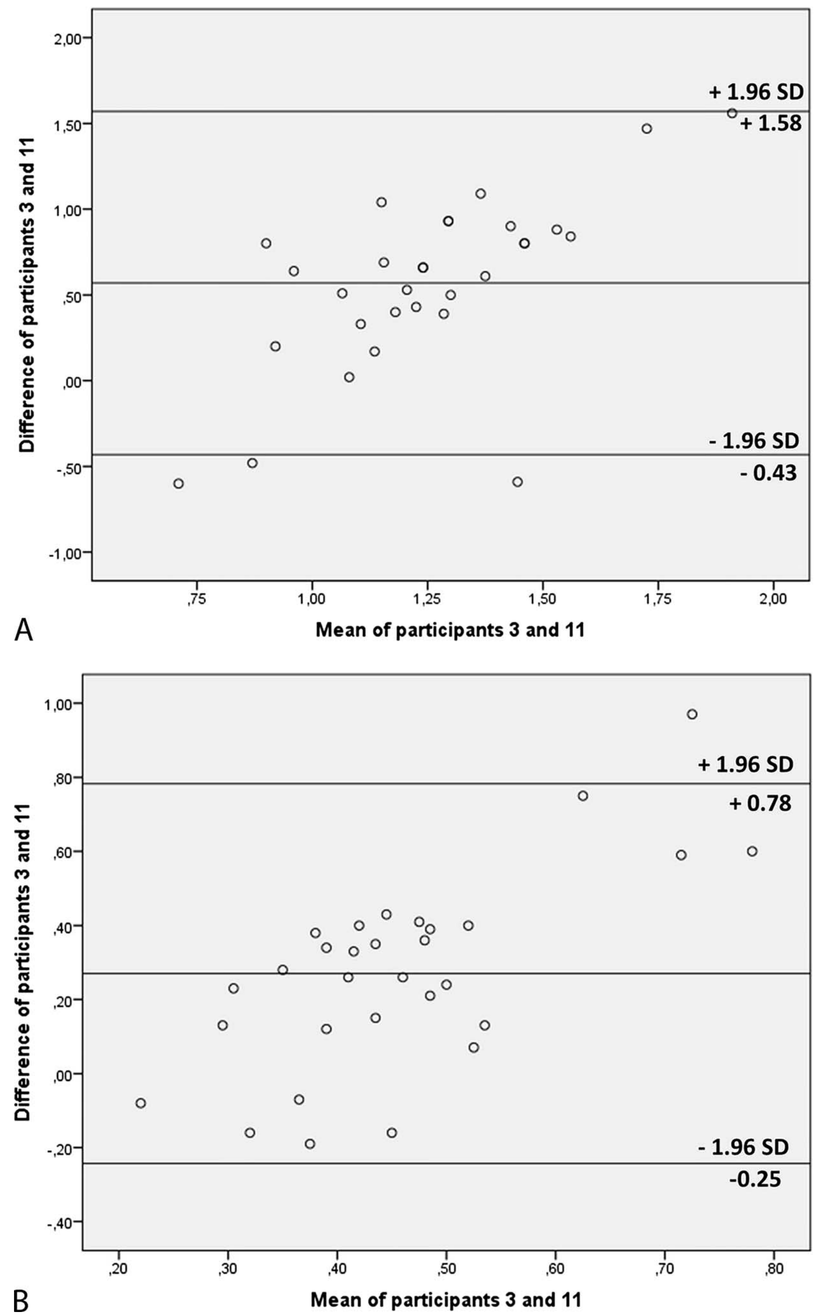

Figure 4. Bland-Altman distribution plots of participants presenting the highest and lowest deviation limits (A); highest and lowest mean total deviations (B).

directions. In this regard, it could be anticipated that to assess smiles in 3-D independently of the smiling character of the individual, it might be more favorable in the present day. Using 3-D stereophotogrammetric imaging in combination with reverse engineering software paves the way for an actual 3-D assessment.

Rigsbee et al.[8] claimed that spontaneous smiles were more likely to be reproduced than social smiles in photographic assessments. On the other hand, Burstone[16] stated that features of a social smile could present great variability, thus it might not be an appropriate guide in treatment planning. Similarly, Zachrisson[17] stated that a social smile is difficult to reproduce, and so would be an unsuitable reference. Furthermore, Ekman[18] mentioned that one of the disadvantages of the social smile is the influence of social skills and emotional background over the individual, which results in an unnatural smile.

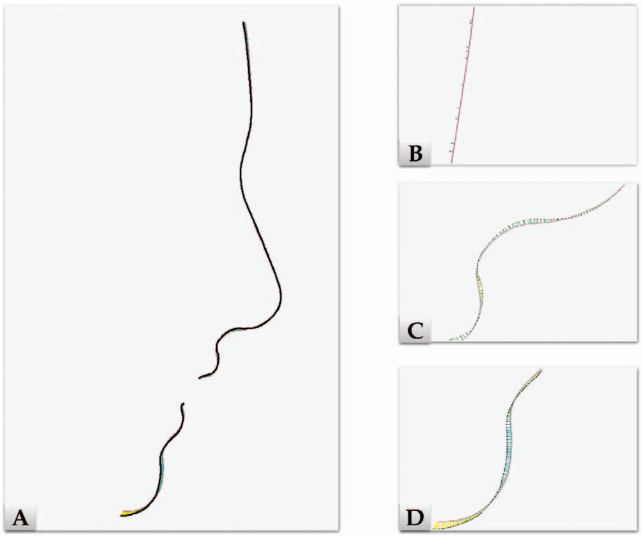

Figure 5. (A) Two-dimensional cross-section of final alignment on forehead. Sliced image of the deviation at (B) forehead, (C) upper lip, and (D) lower lip-chin.

Ackerman[5] reported that the reproducibility of a social smile is uncertain in children, but that there might be a maturational development process for a reproducible smile. He stated further that a social smile may vary over time in adolescence. Accordingly, the present study confirmed the variability of measurement points located in the smile area.

In medical imaging, the matching of two different surfaces is referred to as registration.[19] This process is crucial, as the data should not result from errors during alignment in relevant evaluations. Registrations should be carried out in areas that experience no change, and the regions for which the change is being evaluated should not be included.[20] The most reliable regions were suggested as the forehead and the nose for the alignment of different surfaces with a surface-based registration method.[21] The smile area, determined as shown in Figure 3, was segmented to permit analysis of the changes only at this site (Figure 5A–D).

Reliability and system errors of stereophotogrammetry have been thoroughly investigated. Registration errors reported ranged between 0.1 and 0.2 mm.[22,23] Similarly, the error of the system in rest position ranged between 0.39 and 0.52 mm for images obtained at 1-minute and 3-week intervals, respectively.[19] In particular, 3dMD was reported to present a 0.35 ± 0.32 mm registration error.[24] In the present study, acquisition of multiple images at frequent intervals through 3-D stereophotogrammetry made it possible to assess the reproducibility of the social smile by evaluating all points in the designated area in 3-D with considerably high reliability. Moreover, the integration of reverse engineering technology facilitated the actual 3-D evaluation rather than 2-D sectional images obtained through 3-D images.

CONCLUSION

- The range of reproducibility of the social smile presented individual variability, but this variation was neither clinically significant nor detectable under routine clinical observation.

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