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Three-dimensional intra-rater and inter-rater reliability during a posed smile using a video-based motion analyzing system

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ABSTRACT

Objectives: The purpose of this study was to determine the three-dimensional reproducibility of lip movement during a posed smile using a video-based motion analyzing system.
Materials and methods: In six adult volunteers (4 males and 2 females), the lip motions during a posed smile were recorded six times. Using our recently-developed motion analyzing system, range images were produced across the whole sequence during the posed smile. Virtual grids of 5 × 5 were fitted onto the surfaces, and the three-dimensional coordinates of the intersections of these grids were then computed. The magnitude of the shift of the intersections during smiling was calculated and summed in each area. Intraclass correlation coefficients (ICC), ICC (1,1) for intra-rater reliability and ICC (2,1) for inter-rater reliability were calculated. The number of repeated measurements necessary for an ICC level beyond 0.8 was determined using the formula of Spearman–Brown.
Results: The ICC (1,1) and ICC (2,1) ranged from 0.71 to 0.83 and from 0.77 to 0.99, respectively. The number of repeated measurements necessary for an ICC beyond 0.8 was 2.
Conclusions: From the present study, both the three-dimensional intra-rater and inter-rater reliabilities during a posed smile were considered to be relatively high, and enough reliability could be expected by calculating the average of the values measured two times. However, the sample size was very small, this could not be generalized simplistically.

1. Introduction

The smile is an important factor in determining the goals of orthodontic treatment and maxillofacial surgery. The degree to which an individual can display their teeth and gingiva when smiling is a serious concern (Sarver, 2001) and many studies have reported this. Disturbance or restriction of lip motion due to lip scarring and insufficient muscle reconstruction may also be a cause of concern for patients with cleft lip or with facial palsy respectively (Trotman et al., 2007; Sforza et al., 2012).

Two approaches to evaluating the smile line have been reported: quantitative and qualitative. Quantitative analysis is time consuming and less feasible for regular diagnostic use in clinical practice, whereas qualitative analysis lacks standardization and objective criteria (Van der Geld et al., 2011). The evaluation methods used should be appropriate for the purposes and circumstance of a given study. Many articles have looked at the measurement of lip movements during smiling. These include two-dimensional photographic (Muradin et al., 2007; Riml et al., 2011) and three-dimensional video-based methods (Van der Geld et al., 2007; Sforza et al., 2010). We have previously reported a video based motion analyzing system that can analyze detailed lip movements three-dimensionally (Mishima et al., 2011). The reproducibility of lip movements on smiling has also been investigated for each measuring system. Muradin et al. (2007) reported that there is high reproducibility of a maximum closed mouth smile using two-dimensional photographs. Wu et al. (2005) stated that their video-based measurement had good repeatability in two-dimensional movements of the corners of the mouth. Previously the reproducibility and repeatability of measurements of the smile have been investigated almost exclusively in two-dimensions. Since Gross et al. (1996) stated that two-dimensional amplitudes underestimate the three-dimensional amplitude by as much as 43%, lip movements should be evaluated three-dimensionally. Popat et al. (2010) analyzed facial gestures using a commercially available,

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three-dimensional motion analysis scanner and discussed the reproducibility of the first modes of variation obtained by principal component analysis (PCA). The reproducibility of the principal components was investigated and the actual movements in three-dimensions did not seem to be adequately represented. The purpose of this study was to three-dimensionally determine the reproducibility of lip movements during smiling.

2. Materials and methods

2.1. Subjects

Six adult volunteers (4 males and 2 females) who had no medical history affecting their lip movements were enrolled. Lip movements during a posed smile were analyzed as described below. The subjects were seated with no fixation of their heads. The posed smile was tasked by the phonation of five vowels with maximum mouth opening and was recorded six times each. This research was approved by the Institutional Review Board of Yamaguchi University Hospital.

2.2. Production of range images

Motion images obtained through three infrared digital video cameras (IR camera, Sony XC-E150, Tokyo) and one colour digital video camera (Sony DXC-390, Tokyo) and controlled by a synchronizing signal generator (Imagenics SG-701, Tokyo) were recorded with an infrared pattern projected onto the face at a sampling rate of 30 frames per second. These image sequences were captured directly on a personal computer via IEEE1394. Each frame was digitized at a horizontal and vertical resolution of 720 × 480 pixels. The computer programs described below were based on 3D Video™ software developed by OGIS Research Institute Co. Ltd. (Osaka) but were improved to meet the needs of this specific application. The measurements were processed as follows: calibration of the four cameras followed by the production of a range of images, compensation for head movements and then the production of the virtual grids. The image processing has been described in detail in a previous article (Mishima et al., 2006).

Camera calibration: The intrinsic and extrinsic parameters for four cameras were obtained using a known object. This was a cube with dimensions of 150 mm per side in which a 15 mm checkerboard was printed.

Production of range images: An infrared pattern was projected and the images were recorded through three IR cameras. The images captured by the three IR cameras were changed into 8-bit grayscales for processing. Two different techniques were applied to find a match: a multiple baseline stereo technique (Okutomi and Kanade, 1991) and a template matching technique (Tamura, 2002). The disparity was then calculated and a range image produced across the image sequences.

Compensation for head movements: A sunvisor with a printed checkerboard pattern was worn. The intersections of the checkerboard pattern were manually designated with a mouse and were then automatically tracked across image sequences by applying the Lucas–Kanade algorithm (Lucas and Kanade, 1981). The head position was compensated for as follows: the distances between designated immobile points from one frame to the next would be minimized using a least squares method within the constraints of the orthogonal matrix.

2.3. Analyses of lip motion

The lip was divided into eight areas, consisting of four areas on the upper white lip and four areas on the upper and lower vermilions. These areas were determined by ten landmarks. The following virtual grids were generated in these eight areas (Fig. 1). A three-dimensional curved line on the range image was divided into several segments. The divided points were projected in two dimensions (XY planes) and intersections between these gridlines were produced. The intersections were projected perspectively onto the curved surfaces of the range images and the three-dimensional coordinates of these intersections were computed. In the present study 5 × 5 grids were applied to all areas. The magnitude of shift of the intersections during smiling was then calculated and summed for each area.

2.4. Statistical analysis

The intra-rater and inter-rater reliabilities were examined. The first author (K.M.) measured the sum of shift of the virtual grid intersections for each area using the range images produced from six video sessions, and the fourth author (R.S.) measured the same variables in the same way from the last video session. The intraclass correlation coefficients (ICC), ICC (1,1) for intra-rater reliability and ICC (2,1) for inter-rater reliability were then calculated using a statistical package (IBM SPSS, ver. 19) (Shrout and Fleiss, 1979). According to the Landis and Koch criteria (Landis and Koch, 1977)

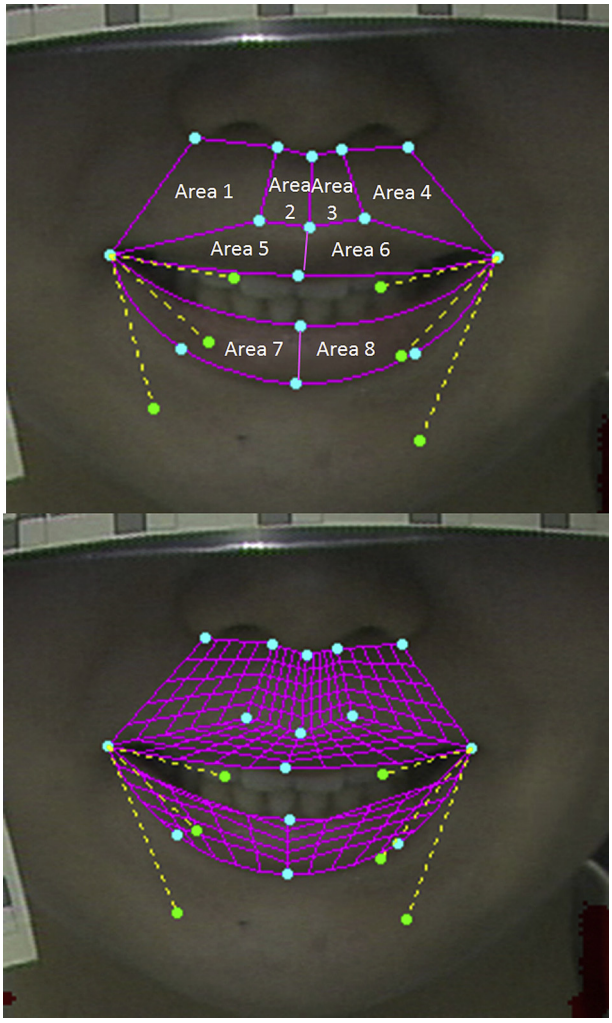

Fig. 1. Eight areas and virtual grids applied to the lip. 5 × 5 grids were applied to eight areas as determined by ten landmarks. The magnitude of the shift of the intersections during smiling was calculated and summed in each area.