Reliability and Validity of Measurements of Facial Swelling With a Stereophotogrammetry Optical Three-Dimensional Scanner

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Abstract

**Aim:** Volume changes in facial morphology can be assessed using the 3dMD DSP400 stereo-optical 3-dimensional scanner, which uses visible light and has a short scanning time. Its reliability and validity have not to our knowledge been investigated for the assessment of facial swelling. Our aim therefore was to assess them for measuring changes in facial contour, *in vivo* and *in vitro*.

**Materials and Methods:** Twenty-four healthy volunteers with and without an artificial swelling of the cheek were scanned, twice in the morning and twice in the afternoon (in vivo measurements). A mannequin head was scanned 4 times with and without various externally applied artificial swellings (in vitro measurements). The changes in facial contour caused by the artificial swelling were measured as the change in volume of the cheek (with and without artificial swelling in place) using 3dMD Vultus® software.

**Results:** *In vivo* and *in vitro* reliability expressed in intraclass correlations were 0.89 and 0.99, respectively. In vivo and in vitro repeatability coefficients were 5.9 and 1.3 ml, respectively. The scanner underestimated the volume by 1.2 ml (95% CI -0.9 to 3.4) *in vivo* and 0.2 ml (95% CI 0.02 to 0.4) *in vitro*.

**Conclusion:** The 3dMD stereophotogrammetry scanner is a valid and reliable tool to measure volumetric changes in facial contour of more than 5.9 ml and for the assessment of facial swelling.
Introduction
Changes in facial contour may occur as a result of craniofacial surgery, orthognatic surgery, inflammation, trauma or ablative surgery, for example. Several methods have been used during the past 60 years to measure the various types of facial deformity, mainly contact methods.\textsuperscript{1} Later, non-contact technology increasingly replaced them, although these newer methods often required complicated equipment for measurement to allow for standard orientation of the head for photography and radiography.\textsuperscript{2} Mathematical methods were then applied to describe the changes in facial morphology.\textsuperscript{3} Others used early (non-digital) stereophotogrammetry to make linear measurements on landmark-based points.\textsuperscript{4,5} With the availability of 3-dimensional scanning technology, these scanners have evolved to become the first choice in research on measurements of volume and their comparison. Among other things, these scanners have been used to assess volumetric changes in acute oedema of burns,\textsuperscript{6} breast symmetry,\textsuperscript{7} and post-operative facial swelling.\textsuperscript{8-11} The most commonly used optical 3-dimensional scanners are the laser scanner, the structured light scanner and the stereophoto scanner.

The reliability and validity of the 3dMD DSP400 system have been assessed in landmark measurements on an animal skull,\textsuperscript{12} a phantom head,\textsuperscript{13,14} a human face,\textsuperscript{15,16} the human torso,\textsuperscript{17} and breast.\textsuperscript{18} They have proved to be more than sufficient for clinical needs and better than direct anthropometry or 2-dimensional photography.\textsuperscript{13} It is often hard to compare studies, as only a few authors actually define the properties that they have assessed.\textsuperscript{12,13,15,19,20} The 3dMD DSP400\textsuperscript{®} stereo-optical 3-dimensional scanner (Atlanta, GA 30339, USA) has not to our knowledge been used to measure postoperative swelling, but could be an alternative to laser scanners, as stereo-optical 3-dimensional scanners are usually less expensive, easy to use, and have a recording time of milliseconds. The latter is a great aid in the prevention of motion artefacts, which may easily happen in the head and neck region. The aim of the current study was to assess the reliability and validity of the 3dMD DSP400\textsuperscript{®} stereo-optical 3-dimensional scanner of volumetric changes in facial morphology by making repeated analyses of the volume of the cheeks when an artificial swelling was in place at 4 separate moments during the day, and analysing repeatedly the volume of an artificial swelling attached to the head of a mannequin. In this study “reliability” was defined as the degree to which the measurement is free from measurement error, and “validity” was defined as the degree to which an instrument truly measures the construct it purports to measure.\textsuperscript{21}
Materials and methods

Subjects
To assess in vivo reliability we enrolled 24 healthy volunteers (12 women and 12 men), who were coworkers at the department of orthodontics in the University Medical Centre, Groningen. Their mean (range) age was 29 (19–63) years. Informed consent was obtained from each volunteer before the study.

The artificial swelling
For each volunteer an artificial swelling was made by mixing a similar amount of base paste and catalyst paste of an impression material (Provil Novo Putty®, Heraeus Kulzer GmbH, Hanau, Germany), by forming it into a small bolus. The volunteers were asked to keep their teeth gently occluded. The artificial swelling (bolus) was then placed in the molar region of the subject’s mouth on the buccal side of the teeth and pressed gently against the teeth, which made small impressions in the artificial swelling. These impressions enabled reinsertion of the artificial swelling in the same position again for further measurements later in the day. After the material had set it was removed. It was disinfected with alcohol, as the impression material is not affected by short term disinfection. Each artificial swelling was stored in a marked bag.

To assess the in vitro reliability and validity of the scanner, 6 artificial swellings were made with the same impression material to cover the full volume range of the artificial swellings that were used in vivo. These artificial swellings were placed on the exterior surface of a Styrofoam mannequin head, which was measured 4 times with the stereo-optical scanner, with and without each artificial swelling in place.

Measurement of the volume of the artificial swelling
Each artificial swelling was weighed on a high-precision scale (MettlesPJ360, Mettler- Toledo GmbH, Griefensee, Switzerland). The density of the impression material was taken from the Material Safety Data Sheet of the material (Provil Novo Putty®, Material Safety Data Sheet, Heraeus Kulzer GmbH, Hanau, Germany). The volume of each of these constructed swellings was calculated by dividing the weight of the artificial swelling by its density (1.60g/cm3).
The scanner
Three-dimensional scans were made with the 3dMD DSP400® stereo-optical 3-dimensional scanner by one observer who was proficient with the scanner. The 3dMD system uses a synchronised digital multicamera configuration, with 3 cameras on each side (1 colour, 2 infrared) that capture photorealistic quality pictures. The system can capture full facial images from ear to ear and under the chin in 2ms at the highest resolution. The geometrical accuracy of the facial system used in the study as claimed by the manufacturer is <0.2mm.

Data capture technique
A custom-built studio was used with standardized lighting conditions. The natural head position was used, as it is clinically reproducible. The subjects sat on a self-adjustable chair and were asked to level their eyes horizontally, and the mid-line of the face was aligned towards the camera. Adjustments to seating heights were made to assist the subjects in achieving natural head posture. In order to create a standard head and jaw position, the subjects were instructed to swallow and to keep their jaws in a relaxed position while occluding gently during scanning. The total scan time was approximately 2 milliseconds. Scans with and without the artificial swelling were taken on two occasions; in the morning and in the afternoon. After the subjects had been scanned with the artificial swelling in place they were asked to remove the artificial swelling, to stand up and walk around for half a minute, and then to sit down again for a 3-dimensional scan without the artificial swelling (first session). The procedure was then followed immediately by a second measurement session. The afternoon session was identical to the morning one. The mannequin head was placed on a tripod to stabilise it during the scans. The head was scanned 4 times, with and without the artificial swelling in place, for each of the 6 artificial swellings.

Data processing
To calculate the changes in contour that were caused by the artificial swelling, the corresponding 3-dimensional models of each session (with or without the artificial swelling in place) of each patient were loaded in the 3dMD software (3dMD Vultus® software version 2.2.0.18, 3dMD, Atlanta, GA 30339, USA). In the software, the two corresponding 3-dimensional models (with and without the artificial swelling both for the mannequin head and the 20 test subjects) were aligned
and recorded on the basis of the forehead and bridge of the nose as suggested by the manufacturer. These areas were used because they are assumed to be 3-dimensionally stable. After the two corresponding models had been recorded, the volumetric change in facial contour exerted by the artificial swelling was calculated by selecting the area of the swelling and subtracting the two surface models (with and without artificial swelling) (figure 1).

Figure 1. Measurement of volumetric changes in facial contour. The two 3-dimensional scans with and without swelling are recorded, and the region of the swelling selected (blue). The difference between the two surfaces is caused by the artificial swelling, and this volume is calculated automatically by the software.
Statistical analysis

To verify whether the variation in the results of measurements was related to the magnitude of the facial swelling, we made a scatter plot of the mean (of 4 sessions) of the facial swelling of each participant against the SD of that participant.
To analyse differences between measurements, a repeated measures ANOVA was calculated on the outcomes of the scanning of the artificial swelling with time of day (morning or afternoon) and session (1st, or 2nd) as factors, for participants and the mannequin’s head. Intraclass correlations (two-way mixed model, absolute agreement) were calculated for the participants and the mannequin’s head. A within subjects ANOVA was used to calculate a repeatability coefficient for participants as well as for the mannequin’s head. In the ANOVA the total variance in the results of measurements is partitioned in variation because of the subjects and a residual variance (measurement error). From this residual variance the repeatability coefficient was calculated, as follows: 1.96 x \sqrt{2} \times \sqrt{\text{residual variance}}. A paired t-test was calculated to assess the significance of differences between the results of the first measurement session and the volume inserted in the mouth of the participants or attached to the head of the mannequin.

Results

We found no significant correlation (r = -0.022, p = 0.91) between the mean (of 4 sessions) of the facial swelling of each participant and the SD of that participant (figure 2).

![Figure 2. Plot of the mean of 4 sessions / participant against the SD of that mean.](image-url)
The mean volume inserted in the mouth of the participants (n=24) was 14.0 ml (sd 2.2, range 8.4 – 19.4) and attached to the mannequin head was 15.1 ml (sd 6.1, range 6.3 – 22.5) (Table 1). Measurements did not differ significantly between morning and afternoon or between session 1 or 2 (Table 1). The intraclass coefficient for the participants was 0.89 and for the mannequin head 0.99. For participants the between-subject variance was 137.79 and the residual variance 4.53.

The results of 1 participant were not used in the repeated measures ANOVA because the measurements for the afternoon sessions were not available.

* p value for differences between morning and afternoon
**p value for differences between session 1 and session 2
95% CI : 95% confidence interval
# p value for differences between volume measured and volume inserted / attached.

For the mannequin head these values were 147.79 and 0.23, respectively. The repeatability coefficient for participants was larger than that for the mannequin (Table 1). The 3dMD DSP400® stereo-optical 3-dimensional scanner underestimated the volume inserted by a mean of 1.2 ml (95% CI -0.9 to 3.4) (p = 0.24) in participants, and in the mannequin head with a mean of 0.2 ml (95% CI 0.02 to 0.4). (p = 0.04).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Participants</th>
<th>P value</th>
<th>Mannequin’s head</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (ml) (95% CI)</td>
<td>14 ( 2.2) (8.4 to 19.4)</td>
<td></td>
<td>15.1 ( 6.1) (6.3 to 22.5)</td>
<td></td>
</tr>
<tr>
<td>Measurements (ml)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Morning, session 1</td>
<td>12.6 (5.6)</td>
<td>0.49 *</td>
<td>14.8 (5.7)</td>
<td>0.57*</td>
</tr>
<tr>
<td>- Morning, session 2</td>
<td>12.0 (5.9)</td>
<td></td>
<td>14.7 (6.1)</td>
<td></td>
</tr>
<tr>
<td>- Afternoon, session 1</td>
<td>12.9 (6.5)</td>
<td>0.053**</td>
<td>15.0 (6.3)</td>
<td>0.54**</td>
</tr>
<tr>
<td>- Afternoon, session 2</td>
<td>12.7 (6.8)</td>
<td></td>
<td>14.8 (6.2)</td>
<td></td>
</tr>
<tr>
<td>Reliability: intraclass coefficient (95% CI)</td>
<td>0.89 (0.81 to 0.95)</td>
<td></td>
<td>0.99 (0.98 to 0.99)</td>
<td></td>
</tr>
<tr>
<td>Reliability: Repeatability coefficient</td>
<td>5.9</td>
<td></td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Validity: Difference (95% CI)</td>
<td>1.2 (-0.9 to 3.4)</td>
<td>0.243#</td>
<td>0.2 (0.02 to 0.4)</td>
<td>0.04#</td>
</tr>
</tbody>
</table>

Table 1 Results of measurements for participants (n = 23) and mannequin head and p values for differences between morning and afternoon and sessions 1 and 2. Data are mean (SD) except where otherwise stated.
Discussion
The reliability of the stereo-optical 3-dimensional scanning system for measuring facial swelling is higher in vitro than in vivo, but both intraclass coefficients were above 0.85, indicating that the system can be used clinically. The 3dMD DSP400® stereo-optical 3-dimensional scanner systematically underestimated the volume, but this underestimation was clinically small (0.2 ml) relative to the volume of the swelling (mean 15.1 ml) for the in vitro experiment. For the in vivo experiment the underestimation was somewhat larger (1.2 ml), but not significantly so. The repeatability coefficient of the in vivo scan was 5.9 ml, which indicated that the system could detect changes in facial volume of 5.9 ml or more between 2 measurement sessions.

The difference in reliability in vivo and in vitro can be explained by the influence of changes in the soft tissues between scans in participants. Another source of error would be changes in the subject’s facial expression. This effect was apparent in our study. One participant smiled during measurements without the artificial swelling in the mouth, and had a neutral facial expression while the artificial swelling was in the mouth. This resulted in the face having a larger volume when the artificial swelling was not in the mouth (figure 2: circle on the left side).

However, as that behavior was consistent, the SD was small (< 2 ml). The lack of correlation between the mean volume measured and the SD of these measurements within participants indicate that the measurement error is not dependent on the size of the swelling.

The difference in validity between the in vivo and in vitro measurements can be explained by the deformation of the soft tissues, as swelling will have its effects both inward and outward in the mouth. Measurements of the external surface will inadvertently lead to underestimation of the true volume, as inward deformation will not be taken into account when volume changes are measured by external surface measurements. In other words, the method is applicable for reliably detecting volumetric changes in the facial contour, but is not applicable for estimating the true increase in tissue volume that underlies the externally visible change in facial contour.

The 3DMD system that we used has been assessed by comparing 3-dimensional landmark measurements on a mannequin head with those taken by calipers. The differences ranged between 0.1 and 0.5 mm and between -0.8 and 0.5 mm. The intraclass coefficients ranged from 0.98 to 1.00.

In a study similar to ours but using a different 3-dimensional scanning system, it was claimed that the system was accurate and reliable for assessing volumes in studies of facial swelling. However, limits of agreement, or repeat-ability coefficients, were not reported.
in that study. In another study that used a handheld laser scanner to assess facial swelling\textsuperscript{26} it was reported that the measurements of swelling on an artificial mannequin head the measurement error was 4%, but when testing the device in volunteers the variation in results was larger, up to 7.6 ml (a value close to our repeatability coefficient of 5.9 ml) as a result of repositioning of the participants. The findings of our study agree with the other studies that have assessed the validity of the 3DMD system\textsuperscript{13,14}

Clinically, the 3DMD system can be used to measure facial swelling and changes in volume in the facial region reliably, and to assess the effects of interventions (such as operation, treatment of oedema, or medication). The changes must, however, be greater than 5.9 ml to indicate a true difference. Changes of less than 5.9 ml cannot be interpreted clinically because they could be the result of measurement error of the 3dMD DSP400\textsuperscript{®} stereo-optical 3-dimensional scanner, alignment errors of the observer, and variations in facial expression or posture of the subjects scanned. The true volume (validity) that underlies a swelling cannot be assessed accurately with this system. For assessing the true change in volume that underlies the swelling, transmissive technology such as magnetic resonance imaging should be used.

**Conclusion**
The 3dMD stereophotogrammetry scanner is a reliable and valid tool for measuring volumetric changes in facial contour larger than 5.9 ml and for the assessments of facial swelling.

**Conflict of interest statement**
The authors have no commercial interest in the products used in the study.

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