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Three-Dimensional Stereophotogrammetry Assessment of Facial Asymmetry in Facial Palsy

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Abstract: Three-dimensional stereophotogrammetry is not much used in assessing facial palsy and a comprehensive understanding of sources of variation in these measurements is lacking. The present study assessed intra- and interobserver reliability of a novel three-dimensional stereophotogrammetry measurement of facial asymmetry and examined sources of variation in these outcomes. Three photographs (rest, closed mouth smile, and maximum smile) were made of 60 participants, 30 facial palsy patients and 30 control subjects. All images were analyzed twice by 2 observers independently, to determine intra- and interobserver reliability. Variance component analysis was performed to investigate sources of variation in the outcomes. Intraobserver reliability was good with intraclass correlation coefficients ranging from 0.715 to 0.999. Interobserver reliability ranged from 0.442 to 0.929. Reliability of the smile image measurements was not clearly different from the rest images. Variation in measurement results was largely due to the status of a participant, facial palsy versus control. When splitting the sample, the facial expression was a major source of variation. Acceptable reliability of the proposed 3D facial asymmetry measurement was found, in facial palsy patients and control subjects. Interobserver reliability was marked less compared to intraobserver reliability. For follow-up data only one observer should assess 3D stereophotogrammetry measurements.

Key Words: Facial palsy, facial paralysis, reliability, stereophotogrammetry, three-dimensional

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Facial palsy may cause problems with eye closure, eating, drinking and speaking, and the inability to express emotions. Expert consensus is that a comprehensive evaluation of facial palsy severity consists of a patient-reported outcome measure, clinician grading of facial function, and objective measurement of facial function.[1–3] In facial palsy most objective measurements are based on two-dimensional photographs of standard facial expressions.[4,5] These photographs are inherently imprecise because of the inability to depict and measure the third dimension, which is relevant since facial expressions are done in three dimensions. Additionally, the volume changes of the face which are often a consequence of smile reanimation surgery are also difficult to quantify without the possibility to ascertain the third dimension.[5]

In the last 2 decades, several three-dimensional (3D) motion analysis systems have been described in the assessment of facial palsy.[6–9] However, these systems are highly sophisticated with much equipment and therefore use has not become widespread. 3D stereophotogrammetry systems are becoming more affordable and widely available. In facial palsy, 3D stereophotogrammetry has been used relatively infrequent and a comprehensive understanding of the sources of variation in 3D stereophotogrammetry measurements is lacking.[10,11] In facial palsy one can imagine that landmark and surface area selection based on the facial anatomical landmarks may be difficult due to the altered and asymmetry of the face.

To study spontaneous recovery of facial palsy over time or the results of reanimation procedures longitudinal analysis is performed by comparing "before" and "after" images. However, when implementing new measures "before" images with the new measure may not be present, and in longitudinal studies involving children "before" images may be hard to compare with "after" images because of changes as the result of growth. Recently, 3D stereophotogrammetry was used in facial palsy comparing the affected and unaffected side of the face (mirror-approach).[10] During that study, the investigators placed black markers on the face prior to taking the photo. We believe this method is not practical for implementation in a busy outpatient clinic and it artificially increases reliability because there is no variation in landmark identification within or between observers. Additionally, the authors did not analyze the effect of different facial expressions, while this is relevant for assessing smile reanimation. In a more recent publication, the author did include 3D photographs of patients while smiling, but did not assess the influence of facial expression on the reliability of their assessment.[12] Therefore, the aim of this study was to assess the intra- and interobserver reliability of 3D stereophotogrammetry assessment of facial asymmetry using a mirror-approach in facial palsy patients compared to healthy volunteers – without prior landmark selection and including smile photographs – and to analyze sources of variation in outcomes of the 3D facial asymmetry assessment.

METHODS

Patients

Thirty adult patients visiting our Plastic Surgery or Physiotherapy outpatient clinic with varying degrees of unilateral facial palsy

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MMVV and JHATB contributed equally.

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were included in the study. Additionally, 30 healthy volunteers of different ages were recruited in our medical center, including medical students, medical and non-medical staff. We chose for 2 times 30 participants because a sample size of at least 50 participants is advised in a reliability analysis.[13] Exclusion criteria for controls were any other disorder of the face or prior surgery to the face. Additionally, male patients and controls with a beard or moustache were excluded from the study since the software cannot adequately capture facial hair. Written consent was obtained from all participants. Of all participants sex and age was recorded. A Sunnybrook Facial Grading System assessment was performed by the first author to obtain a conventional measurement of the degree of facial palsy. We chose not to match participants on sex and age but instead investigate the influence of these factors on the measurement of facial asymmetry, by correcting for them in the analysis.

Procedures

All photographs of participants were made using the Vectra M3 system (Canfield Scientific Inc., Fairfield, NJ), which consists of 6 individual cameras in a calibrated position ensuring good capture of the face from different angles. Participants were asked to wear a headband because hair cannot be captured properly since it reflects the light of the camera too diffusely. Three photographs were made in one session: one with the face at rest (neutral facial expression), one with a closed mouth smile, and one photo with maximum smile. We chose smile expressions because of their relevance for smile reanimation surgery in facial palsy and the impact a smile has in everyday social interaction.[14,15] All photos were analyzed independently by 2 observers (MMvV and JHAtB) on the same monitor. Both observers analyzed all three photographs of all 60 participants in a computer randomized order and twice in 2 sessions, resulting in 720 analyses. Prior to the analyses an analysis protocol was set up and a calibration session was performed by the observers using photographs ($n = 5$) not included in this study.

Symmetry Assessments

The assessment protocol for facial asymmetry was surface-based. On the photographs, first the whole face of a participant was selected, ranging from the forehead to the ventral side of the ears down to the chin. That surface was used by the software to automatically calculate the plane of maximum symmetry and correctly place the face in a reference frame. This image was saved as the 'original' image. Next, the whole face was mirrored in the sagittal plane to create a 'mirror' image. Sixteen landmarks on the mirror image were used to select the left side of the face (Fig. 1), based on a previous study protocol.[10] The software program allowed rotating the face and viewing it from all sides. Neck and ears were not included in the selected surface, since the 3D stereophotogrammetry system is not able to reliably capture those areas.

The 'original' and 'mirror' images were then superimposed on each other using the reference frame of the software. The root mean square deviation (RMSD) between the selected left facial surface on the 'mirror' image to the surface of the 'original' image was calculated as a measure of asymmetry. The RMSD reflects the mean distance between two surfaces, neglecting the negative and positive distances. The RMSD has been proven to be a reliable way to measure facial asymmetry in surface stereophotogrammetry.[16] A color-coded surface map is displayed representing the distances between the 2 surfaces (Fig. 2).

This whole procedure – surface selection, mirroring, superimposition and RMSD calculation – was performed twice by each investigator independently for each photograph.

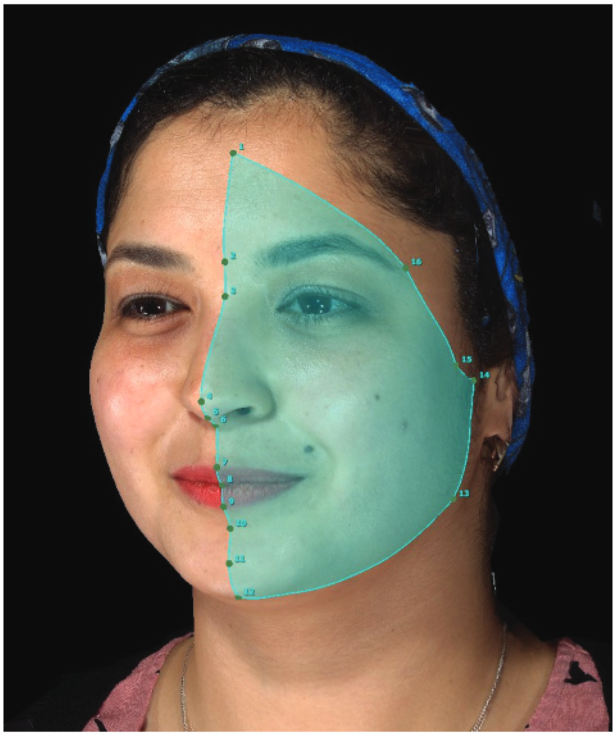

FIGURE 1. Selected area for asymmetry evaluation. A three-quarter profile is shown for easy viewing of the lateral landmark position.

Statistical Analysis

Descriptive statistics were presented as number of patients (%) or medians and interquartile ranges (IQR). To describe the sample the mean of all four RMSD values (2 observers × 2 sessions) were used. Sex of the patients and controls was compared using a Chi-squared test. Age of the patients and controls was compared by Mann Whitney *U* test. Intraobserver reliability was assessed by comparing the RMSD values from the first and second session of each observer. Interobserver reliability was assessed by comparing the RMSD values from both sessions between the observers. Intra- and interobserver reliability was calculated using intraclass correlation coefficients (ICC; two-way random effects model, single measures, absolute agreement). We considered an ICC of at least 0.70 to be acceptable.[17] Bland-Altman plots were made for graphic representation and interpretation of intra- and interobserver agreement.[18]

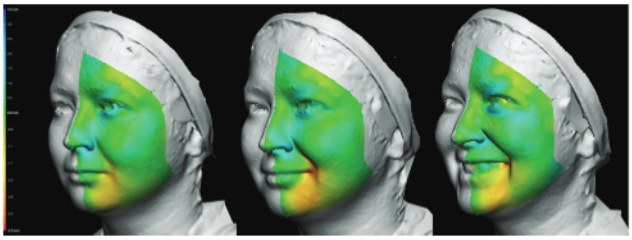

FIGURE 2. Color-coded surface map displaying the distances between the 'mirror' and 'original' images. Green areas represent no distance between the 2 surfaces; blue areas represent a positive distance, red areas a negative distance between the two surfaces. Presented are a rest (*left*), closed mouth smile (*middle*), and maximum smile (*right*) photo. A three-quarter profile is shown for easy viewing of the lateral area selected.

Variance components (restricted maximum likelihood estimation) analyses were conducted with 'participant,' 'observer,' 'session,' 'participant status' (patient vs control) and 'facial expression' (rest, closed mouth smile, and maximum smile) as random factors. Also two-way interactions were analyzed. Error variation was calculated as the sum of all sources of variation minus participant variation. The contribution of factors to the total variation and the error variation was expressed as a percentage. Redundant or negative variance components were set to zero. Linear mixed models were used to analyze the effect of age (centralized around the mean), sex, patient or control status, and the photo (rest, closed mouth smile, and maximum smile) on RMSD values, while incorporating a random effect for 'participant,' 'observer' and 'session.' Residuals were visually inspected to check for a normal distribution. Statistical analysis was performed using the Statistical Package for Social Sciences version 23 (IBM, NY). An alpha level of 0.05 was used for statistical significance in all analyses.

RESULTS

The images of one control subject were not of adequate quality (incorrect expression and facial position) to be included in this study, resulting in an ultimate study population of 30 patients with facial palsy and 29 controls. Twenty-one patients (70.0%) were male compared to 9 (31.0%) controls ($P = 0.009$, Chi-squared test). Median (IQR) age of the patients was 66.3 (54.3; 73.3) years compared to 33.2 (25.0; 58.1) years in the control group ($P < 0.001$, Mann Whitney *U* test) (Supplemental Digital Content, Table 1, http://links.lww.com/SCS/B104). Median (IQR) Sunnybrook values were 29 (21; 37). Median (IQR) RMSD values were 1.87 (1.31; 2.58) for patients compared to 0.79 (0.65; 1.10) for controls ($P < 0.001$, Mann Whitney *U* test). Median RMSD values were smallest for rest measurements, and largest for the maximum smile measurements (Supplemental Digital Content, Table 1, http://links.lww.com/SCS/B104). ICCs as a measure for intraobserver reliability were all above 0.700 ranging from 0.715 to 0.999. ICCs for interobserver reliability ranged from 0.442 to 0.929, with 13 out of 24 ICCs above the threshold of 0.700. Bland-Altman plots showed a better intraobserver agreement compared to interobserver agreement (Figs. 3 and 4). No clear difference in ICC values for intra- or interobserver reliability between facial palsy patients and control subjects was found (Supplemental Digital Content, Table 2, http://links.lww.com/SCS/B104). A slight systematic difference in interobserver agreement can be seen for increasing RMSD values with higher RMSD values for observer 1 compared to observer 2. Cases outside the limits of agreement were reviewed, but no data entry mistakes or other clear reason for these differences could be found. Most outlying cases were facial palsy patients.

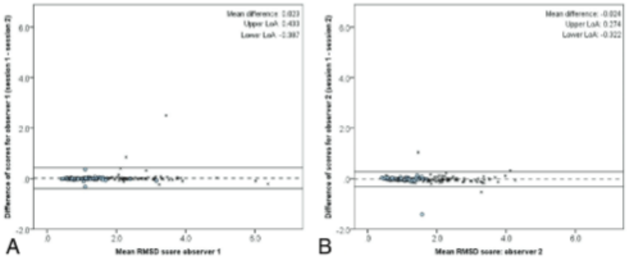

FIGURE 3. A and B. Bland-Altman plots for the intraobserver limits of agreement. Dashed line represents the mean difference ($\bar{d}$). Continuous lines represent the upper and lower limit of agreement, calculated as $\bar{d} \pm 1.96 \times SD_{difference}$. Patients are (X), controls (o).

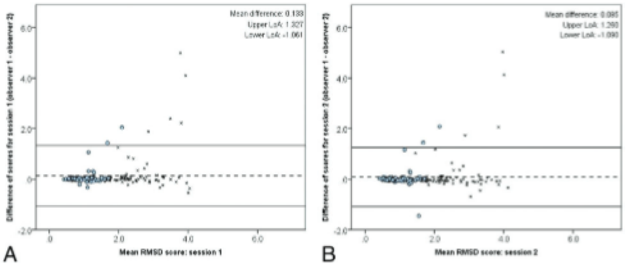

FIGURE 4. A and B. Bland-Altman plots for the interobserver limits of agreement. Dashed line represents the mean difference ($\bar{d}$). Continuous lines represent the upper and lower limit of agreement, calculated as $\bar{d} \pm 1.96 \times SD_{difference}$. Patients are (X), controls (o).

When looking at all patients together, the contribution of error variance to the total variance was 83.2%, versus 16.8% patient variance. By far the largest contribution to the error variance was made by 'participant status' (70.9%). When looking at facial palsy patients only, the contribution of error variance to the total variance was 60.8%. Largest contributions to the error variance were made by the interaction of 'facial expression' and 'participant' (33.4%), the interaction of 'observer' and 'participant' (28.5%), and 'facial expression' (19.1%). Residual variance remained 17.2%. In control subjects the contribution of error variance to the total variance was 46.7%. Again, the interaction between 'facial expression' and 'participant' made the largest contribution to the error variance (32.7%) although residual variance remained 45.6% (Supplemental Digital Content, Table 3, http://links.lww.com/SCS/B104).

Using backward model selection a linear mixed regression model was established estimating the effect of age, sex, patient or control status, and the photo (rest, closed mouth smile, or maximum smile) on the RMSD. The interaction between age and patient or control status was examined but not statistically significant ($P = 0.363$), hence excluded from the model. Sex was not statistically significantly associated with RMSD values ($P = 0.231$) and excluded from the final model. RMSD values increased with age, were larger for patients compared to controls, and were larger for the smile measurements compared to the rest measurement (Supplemental Digital Content, Table 4, http://links.lww.com/SCS/B104).

DISCUSSION

We found that all intraobserver reliability measures were adequate, while interobserver reliability was on average acceptable, with 13 out of 24 ICCs above our threshold of 0.70 for adequate reliability. When looking at the lower limit of the 95% confidence interval for the ICC this difference becomes even more apparent, with lower limits reaching as far down as 0.089 for interobserver reliability. However, interpreting the confidence intervals should be done with care since they heavily depend on sample size and our subgroup of controls consisted of 29 subjects. No clear difference in reliability of the measurements was found between facial palsy and control subjects. A significant difference in RMSD values was found between measurements in facial palsy patients compared to controls, with larger RMSD values for facial palsy patients compared to controls. This is in line with previous research.[10]

RMSD values were significantly larger for the smile measurements compared to the rest measurement. This has previously been reported in healthy volunteers,[19] but an observation using a similar RMSD assessment in facial palsy patients was lacking. Increased asymmetry with smile compared to a neutral facial expression in facial palsy patients has previously been reported in studies using 2D photographs and other 3D motion analyses.[20] Especially relevant for the measurements in our study is the reliability of the smile expression images. We observed that the reliability did not uniformly decrease in smile images. The lowest ICC for smile expression assessment was observed in control subjects (0.442); the lowest ICC observed in facial palsy patients was 0.523. Eighteen out of 24 ICCs of smile expression remained above 0.70.

Our pre-set threshold of ICC $>$ 0.70 for adequate reliability is the advised minimum threshold for measurements in research. In clinical use, a higher ICC, up to a threshold of 0.90, is advised.[17] Most of our intraobserver ICC estimates, both point estimates and 95% confidence interval lower limit, meet that threshold of 0.90. This is not the case for interobserver reliability. Additionally, the Bland-Altman limits of agreement on interobserver agreement were considerably wider (-1.061 to 1.327 and -1.090 to 1.260) compared to intraobserver agreement (-0.387 to 0.433 and -0.322 to 0.274). Median RMSD values for facial palsy patients were only 1.87. Hence, when using the proposed measurement in making clinical decisions, we propose that all measurements are done by the same person.

Linear mixed regression showed that asymmetry increased with age; the interaction term between age and patient versus control status was not significant, meaning that this relationship between age and asymmetry was similar for patients and control subjects. However, we did not include the full range of possible ages in our analysis and results of our regression analysis only hold for the range of values included in our study. In a recent study, the relationship between age and facial asymmetry in healthy volunteers was studied, using the same 3D stereophotogrammetry system and a similar study protocol. Similar results were found for facial asymmetry in rest.[21] We advise future researchers to either correct for age by including age in their analysis or perform age-matching.

Our study was based on a surface analysis as opposed to a landmark analysis approach. We chose this approach because it has been proven more reliable than landmark-based approaches,[22,23] and because a previous report used a similar surface selection protocol which was described to be reliable.[10] The major differences with that study are our measurements of smiling patients, and the fact that we did not place black dots on the landmarks to be selected prior to taking the 3D photograph. Our reason for the latter being the time this would take our medical photographer during an already busy clinic, and the inconvenience for the patient. While we expected that this choice might have influenced our measurement result, we did still find adequate reliability. The previous study did not report ICCs to compare ours to, but did report mean difference and Bland-Altman limits of agreement.[10] They were slightly smaller than ours, but this can be expected from the prior landmark selection in that study.

Additionally, the author of the previous study performed an overall and regional analysis.[10] Their facial thirds were based on embryologic origin and – in our opinion – clinically less relevant since facial palsy related procedures would often cross those thirds. Therefore we chose not to perform regional analysis, but include facial expression in our analysis.

Although the results from our study suggest that the presented measurements are reliable when performed by one observer, we did not study validity, responsiveness or additional benefit of the method compared to current measurements of facial asymmetry in facial palsy. These measurement properties should be topics of future studies. Some work suggests that 3D measurements are closer to reality compared to 2D measurements.[24] However, the authors who performed all the measurements in this study (MMvV and JHAtB) thought the practical use of the software was rather tedious and time consuming, most notably the great amount of steps that had to be taken to perform one measurement. Besides, the software does not automatically generate an output with the measurements. The fact that highly specialized software was necessary to view and analyze the photographs severely limited practicality of the assessment. On the other hand, some recent advances in automated facial measurements using 2D photographs have made those measurements much more easy to use.[25] Until 3D measurements become as easy to perform as most 2D measurements, we expect that the applicability of 3D stereophotogrammetry will remain somewhat limited.

Furthermore, our analysis protocol was limited in the sense that the software could not capture facial hair. Hence, men with a beard or moustache were excluded from our study. This is especially relevant since it is our clinical impression that men with facial palsy often choose to grow a beard to mask some of the asymmetry around the mouth.

Another limitation is that we only used one photograph per facial expression, while facial expressions are known to be somewhat limited in their reproducibility.[26,27] Although the same holds for more traditional 2D or clinician-graded measurements, this might affect the accuracy of the measurements in longitudinal studies.

CONCLUSION

Our study proposed a new 3D facial asymmetry measurement in facial palsy patients. We found adequate intraobserver reliability (ICCs 0.715 to 0.999), while interobserver reliability was markedly less (ICCs 0.442 to 0.929). Because of the better intraobserver reliability, we advise that future studies and clinical follow-up only include measurements of one observer to ensure that differences reflect true differences instead of measurement error between observers. Until interobserver agreement improves – through studies or different assessment protocols – the clinical use of the proposed measurement may be limited. Future work should be done to establish an universally accepted measurement protocol, an automated system and study the additive value of 3D stereophotogrammetry compared to current 2D systems.

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