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Assessment of reproducibility and reliability of facial expressions using 3D handheld scanner

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ABSTRACT

Purpose: The three-dimensional morphological analysis of facial expressions has been becoming increasingly common and hand-held three-dimensional scanners can be advantageous in data acquisition due to their mobility. The aim of the present study was to test intra-subject, intra-observer and inter-observer reproducibility and reliability of a hand-held scanner during facial expressions.

Materials and methods: In order to investigate intra-subject reproducibility and reliability, we performed face scanning two times on 30 healthy subjects at three-month intervals. In addition, two observers scanned twice the face of 10 healthy subjects consecutively to evaluate intra-observer and inter-observer differences. Scannings were performed during facial expressions. Face asymmetry and severity of facial expression were determined using root mean square (RMS) value. Repeated-measurement ANOVA was used to test the reproducibility and correlation coefficient to determine the reliability of the facial expressions.

Results: The mean RMS values measured at different times were not significantly different for any facial expression ($p > 0.05$). The reliability of the measurements was variable depending on the facial expression ($r = 0.47$ and 0.98, $p < 0.05$).

Conclusions: Our study may contribute to the development of new techniques for examining facial expressions. Hereby, morphological analysis may be possible in the clinic and at the bedside without the need for laboratory conditions.

1. Introduction

The face has great prominence in interpersonal communication (Mehrabian and Ferris, 1967). It has a complex structure and to be able to perform facial expressions, quite a few facial muscles and their innervating nerves need to function in synergy and in a coordinated fashion. Through the activities of mimic muscles, morphological changes can be created in facial soft tissue and emotions can be expressed this way. Functional or morphological deteriorations in facial soft or hard tissue caused by trauma or neurological problems are major obstacles to the ability of a person to express himself, and make it difficult to perform the facial expressions as desired (Melvin and Limb, 2008). The loss of facial function may cause socio-economic hardship (Brooker et al., 2009; Kleiss et al., 2015). For this reason, it is very important to determine the changes in facial morphology for neurologists, plastic and reconstructive surgeons, orthodontists and craniomaxillofacial surgeons.

Although morphological studies are mostly carried out in the neutral face position and studies on facial expressions are limited, observations also should be performed during facial expressions (Gousheh and Arasteh, 2011). The analysis of dynamic excursion of facial soft tissue is more complex than the static excursion (Wang et al., 2017). Therefore, observation of the facial expressions by more detailed and three-dimensional (3D) approaches may be more helpful. Quantitative analyses of facial expressions before and after treatment may provide information in terms of performance of facial expressions and preserved functions (Claes et al., 2012; Sforza et al., 2012). The morphological studies showed that the facial alteration due to facial expressions can be successfully observed and quantitatively measured with 3D approaches (Gibelli et al., 2017). Additionally, with 3D methods, partial emotional changing can be evaluated and the regional differences can be precisely distinguished from other face regions (Gibelli et al., 2018). Furthermore, due to the possibilities offered by the new 3D

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technologies, variations or subtypes of basic facial expressions can be evaluated (Pucciarelli et al., 2018). The facial symmetry as an important parameter in the expression of emotions can also be detected by 3D methods (Nicholls et al., 2004). Therefore, the 3D methods can provide more realistic models of facial asymmetry (Meyer-Marcotty et al., 2011).

A standard method is needed to follow up the ability of patients in performing facial expressions after treatment. The current scoring methods used for this purpose are subjective (House and Brackmann, 1985; Yanagihara and Hato, 2003). There are many devices in the market for 3D scanning. However, most of these are stand-type fixed devices and they require laboratory conditions. However, nowadays, 3D scanners are getting smaller and hand-held devices are being used. The use of such mobile devices will ensure rapid and reliable measurements on outpatients, inpatients and even in the operating theater in the future. The accuracy of the widely used stand type immobile systems has been tested and found to be reliable (Weinberg et al., 2006; Lubbers et al., 2010; Dindaroglu et al., 2016). Additionally, the accuracy of handheld scanners tested during neutral facial expression and the differences according to the widely used systems were found to be clinically irrelevant (Modabber et al., 2016; Verhulst et al., 2018). The purpose of our study was to test intra-subject, intra-observer and inter-observer reproducibility and reliability of hand-held scanners during facial expressions.

2. Material and methods

Ethical approval for the investigation was obtained from the Ethics Committee of Clinical Research of Akdeniz University (approval number: 70904504/562). Written, informed consents were obtained from the volunteers.

The recovery in facial expression occurs at a time interval from 3 weeks to 4 months depending on the degree and the type of damage (Suderland, 1978; Jorgensen et al., 1999). In this time interval, determining the reproducibility and reliability of facial expressions in healthy individuals may be helpful in monitoring the recovery in patients. Therefore, in order to test the intra subject reproducibility and the reliability of the method, we performed facial scanning two times on 30 volunteers (13 male and 17 female) aged between 23 and 75 years (mean 39.8 ± 12.6 years old) with a handheld light scanner (Artec™ Eva, Artec Group, Luxembourg) at three-month intervals.

Additionally, in order to test intra-observer and inter-observer reproducibility and reliability, two observers scanned the faces of 10 healthy subjects (4 male and 6 female) twice consecutively. The subjects were between 25 and 44 years old (mean 33.7 ± 6.6 years old). All of the volunteers were of Caucasian ethnic origin. They had no history of underlying trauma, palsy or muscular disorders, burns, scars, dermal fillers and botulinum toxin injections, skin disease or surgery of the facial region and had not undergone any previous orthodontic treatment or surgery. In order to eliminate the interpersonal variation of the same expression, the photographs of the emotional expressions obtained from the study of Ekman et al. (Ekman et al., 2002) were shown to the subjects and they were requested to reproduce each type of expressions (Fig. 1). In order to draw attention to detail in the photo, the differences in each action were described to the subjects.

2.1. Scanning procedure

The face of each volunteer was scanned using a 3D scanner. The volunteers were seated on a chair and asked to keep a natural head position. The natural head position was determined by the volunteers own feeling of a natural head balance. In order to avoid motion artifacts, the volunteers were asked to remain still during scanning. We classified the facial expressions as the primer and emotional facial expressions. Each volunteer was scanned during primer (Neutral, Maximal lifting of the eyebrows, Maximal closure of the eyelids, Maximal showing of the teeth, whistling, Maximal compression of teeth) and emotional facial expressions (Surprised, Angry, Sad, Frightened, Happy, Disgust).

Each face scanning took around 10 s. The ideal scan distance was determined by the distance adjustment indicator available in the Artec Studio 11 Software (version 11.2.2.16; Artec Group, Luxembourg, licensed). Using a distance indicator, true localization of the scanner was adjusted, either moving it closer or farther away to obtain the best possible face scan. The scanning was performed at a speed of 15 frames per second and the depth of the scanning field was adjusted to 400 mm for near and 1000 mm for far. The given data of the scanner by the manufacturer is between 0.4 and 1 m for work distance, up to 0.1 mm for 3D accuracy and up to 0.5 mm for 3D resolution. The 3D surfaces were created by Artec Studio 11 software in STL file format.

2.2. Image processing

The scanned masks of each subject were imported into the workspace of Artec Studio 11 Software. Each scan was then oriented manually according to the established coordinate system (X-axis, left/right; Y-axis, superior/inferior; Z-axis, anterior/posterior) using translation and rotation in all three directions. The common origin of the three axes was set at a mid-endocanthion point (a point halfway between the inner corners of the eyes), as previous research has shown that its position changes the least with time (Toma et al., 2008, 2009). Unwanted extraneous data, i.e. the ears, the hairline, and the neck were excluded. Then the facial masks were automatically aligned by the software.

2.3. Three-dimensional assessment of facial asymmetry

For each facial expression, a mirror image of the face was generated by Autodesk Netfabb software (Netfabb, Parsberg, Germany, Free trial version) and superimposed on the original image of the corresponding facial expression. Afterward, for quantitative facial asymmetry analyses, the distance between the original face and its mirrored face image was automatically computed by the Artec Studio 11 software and colored distance maps were created (Figs. 2A and 3A). The asymmetry value of the movement was indicated by using the root mean square (RMS) value of the distance between the original and the mirrored image. The volume or shape differences between two surfaces are evaluated using RMS value (Taylor et al., 2014; Patel et al., 2015; Kornreich et al., 2016). This value is the indicator of the variation between two surfaces in 3D and shows the disparity or similarity between the compared shapes. While the lower values indicate a more similar shape, the higher values indicate greater diversity. For a perfect overlapping, the value should optimally be as close to zero as possible. In our previous study, we tested different formulations to determine global and partial facial asymmetry during neutral facial expression in healthy individuals (Ozsoy, 2016). We indicated that RMS is a more appropriate calculation method for determining the severity of asymmetry. Please see the study of Ozsoy for further detail about the RMS.

2.4. Three-dimensional assessment of morphological changes versus neutral face position: Intensity of the movement

The morphological changes in the facial soft tissue are created by the action of the facial muscles. In order to evaluate the changes in

Fig. 1. Picture showing face scan with 3D hand-held scanner. Scanning was performed by rotating around the subject when the image of the desired facial expression is shown to the subject.

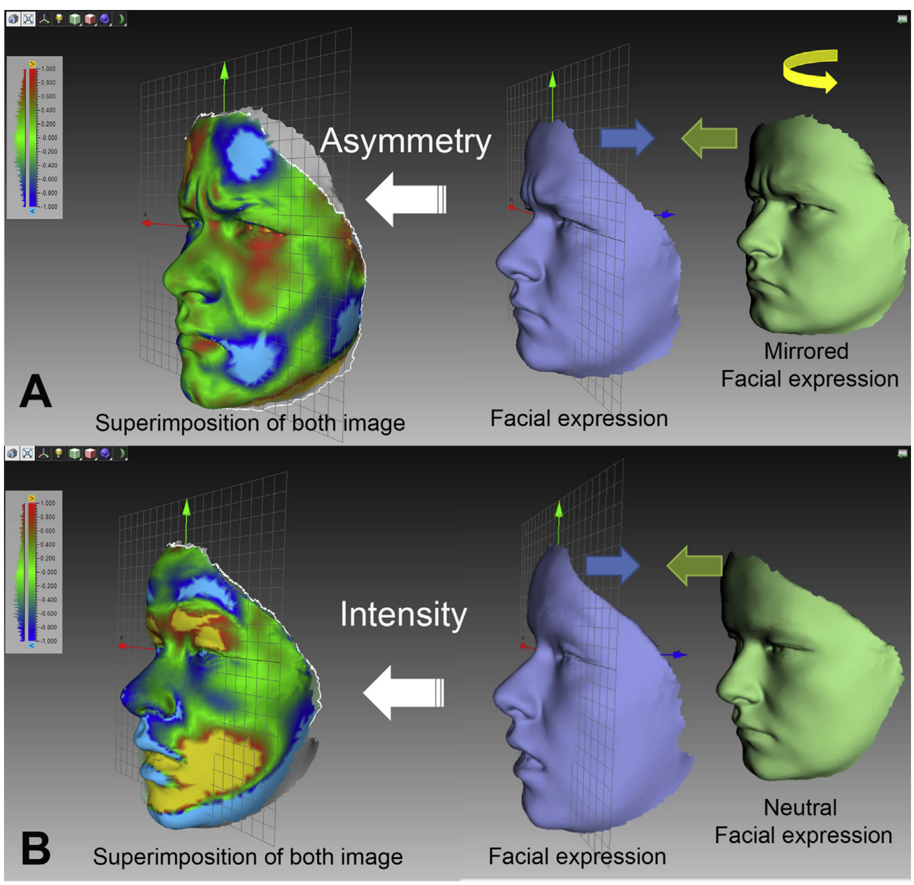

Fig. 2. Creating color distances maps and calculating RMS values. A: Superimposing the 3D image of the facial expression on the mirror image of the same expression. Thus, the asymmetry of the face is determined by the calculated RMS value. B: Superimposing the 3D image of facial expression to the neutral facial expression to determine the intensity of movement.

morphology according to the neutral face position, we superimposed the facial masks of expression to the neutral facial expression. The RMS value between two surfaces was automatically calculated by the Artec Studio 11 software and colored distance maps were created (Figs. 2B and 3B). Higher RMS value indicates higher muscle activity and thus higher magnitude of facial movement.

2.5. *Statistical Analysis*

Analysis was performed in GraphPad Prism Software (GraphPad Prism version 6.05, GraphPad Software Inc, San Diego, CA). The results were expressed as mean $\pm$ SE. A value of $p \leq 0.05$ was considered as statistically significant.

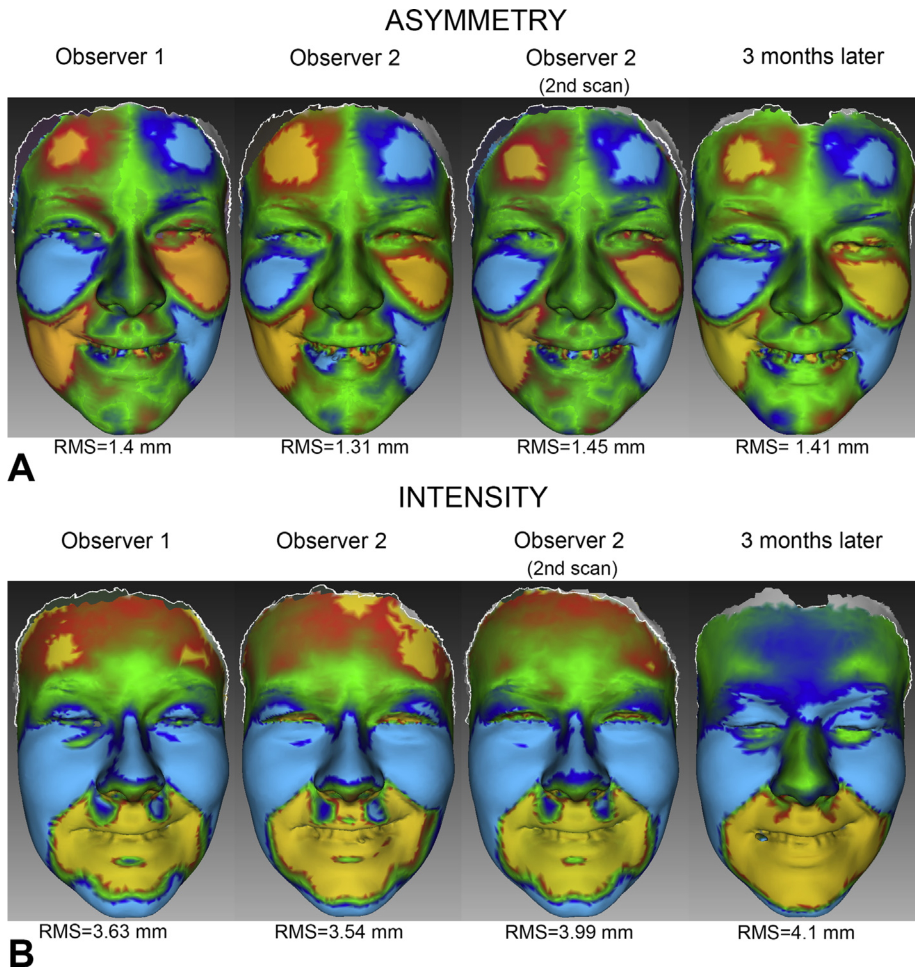

Fig. 3. Color distance maps and the corresponding RMS values of the happy facial expression. Data obtained by different observers at different time intervals. Determined A: asymmetry and B: intensity data.

Repeated measures one-way ANOVA with Greenhouse-Geisser correction and Sidak's multiple comparisons test were applied to compare repeated RMS values.

To investigate the correlation between RMS values the correlation coefficient values were calculated. For normally distributed data, a Pearson's correlation coefficient was calculated, while a Spearman's correlation coefficient was computed for any abnormally distributed data.

3. Results

3.1. Intra subject evaluation

Tables 1 and 2 show the mean RMS values of repeated facial expressions at 3-month intervals. No significant differences were observed within subjects (Column 2–3 in Tables 1–2, $p > 0.05$). Significance was observed in 7 out of 11 intensity measurements (Table 1, column 5 $p < 0.05$) and in all asymmetry measurements (Table 2, column 5 $p < 0.05$). Significant correlation coefficients ranged between 0.59 and 0.79 in intensity measurements. The value was highest for lifting eyebrows and lowest for showing teeth. These values varied between 0.47 and 0.94 for asymmetry measurements. The highest value was observed in the neutral facial expression and the lowest value was observed in the frightened facial expression.

3.2. Intra observer evaluation

No statistically significant differences within observers were found in asymmetry nor in intensity measurements (Column 7–8 in Tables 3 and 4, $p > 0.05$). Correlation coefficients were variable depending on facial expressions. A significant correlation coefficient was observed in 7 out of 11 intensity measurements (Table 3, column 10, $p < 0.05$) ranging between 0.69 and 0.89 in angry and compressing teeth facial expressions, respectively. Significant values were observed in 11 out of 12 asymmetry measurements (Table 4, column 10, $p < 0.05$) ranging between 0.60 and 0.98 in whistling and closing eyelids facial expressions, respectively.

3.3. Inter observer evaluation

There were not any significant differences between the observers in asymmetry nor intensity measurements of facial expressions (Column 2–3 in Tables 3 and 4, $p > 0.05$). The correlation coefficient of 8 out of 11 intensity analyses (Table 3, column 5 $p < 0.05$) were significant and ranged between 0.56 and 0.90 in surprised and whistling facial expression respectively. Significant values were observed in 10 out of 12 asymmetry analyses (Table 4, column 5, $p < 0.05$) ranging between 0.82 and 0.96.

Table 1
Intra-subject evaluation of the intensity of the facial expressions. The table shows the mean values, standard error (SE) and correlation coefficient of the measurements at three-month intervals. Any significant differences were not observed between the mean values of measurements. * indicates $p < 0.05$.

Intensity	Intra-Subject				
Facial Expression	First Scan (Day 0) Mean RMS in mm	Second Scan (3th month) Mean RMS in mm	SE of differences	Correlation coefficients (r)	n
Lifting eyebrows	1.11	1.08	0.05	0.79*	30
Closing eyelids	1.56	1.41	0.11	0.61*	30
Showing teeth	3.84	3.98	0.15	0.59*	30
Whistling	2.20	2.26	0.07	0.74*	30
Compressing teeth	0.78	0.75	0.07	0.28	30
Surprised	3.22	3.02	0.18	0.27	30
Angry	1.13	1.08	0.06	0.62*	30
Sad	1.37	1.02	0.27	0.11	30
Frightened	2.46	2.18	0.16	0.64*	30
Happy	3.42	3.31	0.13	0.63*	30
Disgust	2.81	3.22	0.24	0.29	30

Table 2
Intra-subject evaluation of the asymmetry of the facial expressions. The table shows the mean values, standard error (SE) and correlation coefficient of the measurements at three-month intervals. Any significant differences were not observed between the mean values of measurements. * indicates $p < 0.05$.

Asymmetry	Intra-Subject				
Facial Expression	First Scan (Day 0)	Second Scan (3th month)	SE of diff.	Correlation coefficients (r)	n
Neutral	1.09	1.05	0.03	0.94*	30
Lifting eyebrows	1.10	1.06	0.03	0.92*	30
Closing eyelids	1.16	1.11	0.04	0.87*	30
Showing teeth	1.55	1.45	0.06	0.73*	30
Whistling	1.14	1.14	0.04	0.84*	30
Compressing teeth	1.11	1.07	0.03	0.89*	30
Surprised	1.41	1.31	0.06	0.67*	30
Angry	1.15	1.15	0.03	0.92*	30
Sad	1.12	1.16	0.03	0.89*	30
Frightened	1.33	1.28	0.08	0.47*	30
Happy	1.40	1.35	0.06	0.73*	30
Disgust	1.33	1.42	0.06	0.77*	30

Table 3
Intra and inter-observer evaluation of the intensity of the facial expressions. The table shows the mean values, standard error (SE) and correlation coefficient of the measurements. Any significant differences were not observed between the mean values of measurements. * indicates $p < 0.05$.

Intensity	Inter-Observer					Intra-observer				
Facial Expression	Observer 1 Mean RMS in mm	Observer 2 Mean RMS in mm	SE of diff.	Correlation coefficients (r)	n	Scan 1 Mean RMS in mm	Scan 2 Mean RMS in mm	SE of diff.	Correlation coefficients (r)	n
Lifting eyebrows	0.89	0.95	0.05	0.74*	10	0.88	0.90	0.08	0.57	10
Closing eyelids	1.29	1.35	0.06	0.77*	10	1.30	1.29	0.10	0.47	10
Showing teeth	4.06	4.48	0.22	0.63*	10	4.16	3.97	0.20	0.28	10
Whistling	1.99	1.98	0.11	0.90*	10	1.96	2.02	0.12	0.88*	10
Compressing teeth	0.61	0.63	0.05	0.86*	10	0.61	0.61	0.06	0.89*	10
Surprised	2.63	2.36	0.13	0.56*	10	2.76	2.50	0.26	0.11	10
Angry	0.93	0.88	0.13	0.29	10	1.04	0.82	0.16	0.69*	10
Sad	0.90	0.88	0.08	0.36	10	0.94	0.86	0.05	0.74*	10
Frightened	2.35	2.46	0.17	0.64*	10	2.23	2.47	0.12	0.86*	10
Happy	3.55	3.62	0.11	0.87*	10	3.53	3.57	0.12	0.86*	10
Disgust	3.31	3.63	0.24	0.26	10	3.21	3.41	0.21	0.81*	10

4. Discussion

This study revealed that the data obtained with a 3D hand-held scanner has high reproducibility and reliability for most of the facial expressions. To the best of our knowledge, this is the first study on this subject.

In our study, we performed 3D data acquisition and analyzed whole facial surface instead of analyzing definite landmarks as performed in previous studies (Weinberg et al., 2006; de Menezes et al., 2010; Metzler et al., 2014). By this method, more than 10.000 points (vertexes) were evaluated for each facial motion. Therefore, errors arising from conflicting localization of the landmark were minimized. We also analyzed facial asymmetry by comparing the whole face with its mirror image instead of measuring the distances of certain landmarks according to the midline line. The estimation of the facial asymmetry plane should be based on a global approach that considers the whole face, not just a few reference points (Berssenbrugge et al., 2014) because the landmarks used in determining the middle line also undergo deviation with morphological deterioration and thus negatively affect the

Table 4
Intra and inter-observer evaluation of the asymmetry of the facial expressions. The table shows the mean values, standard error (SE) and correlation coefficient of the measurements. Any significant differences were not observed between the mean values of measurements. * indicates $p < 0.05$.

Asymmetry	Inter-Observer					Intra-observer				
Facial Expression	Observer 1	Observer 2	SE of diff.	Correlation coefficients (r)	n	Scan 1	Scan 2	SE of diff.	Correlation coefficients (r)	n
Neutral	0.83	0.88	0.03	0.87*	10	0.84	0.83	0.02	0.95*	10
Lifting eyebrows	0.84	0.89	0.03	0.86*	10	0.84	0.84	0.02	0.95*	10
Closing eyelids	0.85	0.87	0.02	0.96*	10	0.88	0.83	0.03	0.98*	10
Showing teeth	1.23	1.39	0.08	0.84*	10	1.32	1.14	0.05	0.78*	10
Whistling	0.92	0.97	0.05	0.85*	10	0.94	0.90	0.06	0.60*	10
Compressing teeth	0.87	0.90	0.02	0.93*	10	0.88	0.86	0.03	0.92*	10
Surprised	1.00	1.06	0.05	0.82*	10	1.01	0.99	0.05	0.78*	10
Angry	0.92	0.92	0.04	0.86*	10	0.97	0.87	0.06	0.70*	10
Sad	0.88	0.98	0.04	0.86*	10	0.90	0.86	0.04	0.78*	10
Frightened	1.19	1.21	0.09	0.43	10	1.08	1.24	0.10	0.27	10
Happy	1.15	1.17	0.04	0.91*	10	1.16	1.14	0.07	0.63*	10
Disgust	1.44	1.33	0.24	0.39	10	1.70	1.17	0.40	0.65*	10

precision of measurements (Ferrario et al., 1994; Meyer-Marcotty et al., 2011). Additionally, by means of colored distance map acquired after superimposition of facial masks, the morphological differences can be quantitatively observed on the 3D facial image in different colors depending on the intensity of the motion or asymmetry. It is also possible to calculate asymmetry indices by quantifying color differences between the original and mirrored images (Berssenbrugge et al., 2015).

The most important feature of the handheld scanners is the mobility. By means of its mobility, it can be used easily in hospitalized patients. The equivalent devices with several or big size cameras need stable laboratory conditions and cannot be used at the bedside. In addition, the price of the handheld scanners, which is quite low compared to the stand-type devices, provides convenience in terms of availability. Unlike other devices, it does not require additional costs due to the lack of modular attachments for recording different body regions.

Artec Eva scanner takes the face image by rotating around the subject. This makes it possible to perform more accurate measurements than photographic methods that take a face image from a single camera via mirror construction around the subject's head (Modabber et al., 2016). However, this causes a relatively long scanning time compared to photogrammetric methods. In our method, the scanning takes about 10 s, while the stereo photogrammetry method is performed in milliseconds. During the facial expression scanning, the subject must maintain the same expression. Therefore, in some cases unexpected slight movements of the subject may cause artifacts. Such artifacts should be taken into account by the operator and the acquisition should be repeated in such a case. Thus, more difficulties may be encountered in a 3D scanning method in non-cooperative patients or infants compared to conventional photographic methods.

A significant mean deviation of 0.26 ± 0.24 mm between the most commonly used 3dMDface system and Artec Eva has been reported in the literature (Verhulst et al., 2018). The researchers concluded that the difference was not clinically relevant since it was less than 0.5 mm. Moreover, they stated that multicenter studies could use the results obtained with these devices. Modabber et al. measured a Lego brick pasted on the forehead of the subject to determine the measurement error of Artec Eva and reported a value of 0.23 ± 0.05 mm (Modabber et al., 2016). A similar result was reported as 0.24 ± 0.09 for the bricks attached to the cheek area. The same measurements with FaceScan3D, a mirror-based stand type 3D imaging system, were 0.523 ± 0.144 mm and 0.63 ± 0.136 mm, respectively. As a result, they stated that Artec Eva had a higher measurement accuracy than FaceScan3D ($p < 0.001$). They expressed that the results obtained with Artec Eva are comparable with the results obtained with other scanners in the literature.

When the results of our study were examined, the fact that there was no significant difference between the average values of the first and second measurements of any facial expression, suggesting that our methodology has satisfactory reproducibility. On the other hand, we found that the correlation coefficients varied according to the facial expression performed. Although we try to standardize, we think that this difference is due to the fact that facial expression is context and individual specific and based on the relevance of the event; implications for major needs; ability to deal with these consequences and normative significance of the event (Scherer et al., 2013). Thus, interpersonal differences are inevitable in facial expressions. Therefore, it is essential to develop a more appropriate methodology that provides a clear set of protocols and guidelines for both patients and observers.

5. Conclusion

The results of our study may contribute to the development of noninvasive 3D techniques which will be used to examine the effect of treatment on facial expressions. In this way, patient comfort can be increased and data collection can be facilitated.

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Declarations of interest

None.

Authors' contributions

All authors designed and carried out the study, performed the statistical analyses and contributed to interpretation of results and writing the manuscript.

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