The reproducibility of the dynamics of facial expressions in unilateral facial palsy

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Abstract:

The aim of this study was to assess the reproducibility of non-verbal facial expressions in unilateral facial paralysis using the dynamic 4D imaging. Di4D system was utilized to record 5 facial expressions of 20-adult patients. The system captured 60 3D images/second; each facial expression took 3-4 seconds to record which generated a set of 180 3D facial images for each expression. The procedure was repeated after 30 minutes to assess the reproducibility of the expressions. A mathematical facial mesh which consists of thousand of quasi points "vertices" was conformed to the face to disclose the morphological characteristics in a comprehensive manner. The vertices of the conformed mesh were tracked throughout the sequence of the 180 3D images. Five key 3D facial frames of each sequence of images were analyzed.. We compared the 3D facial morphology at each of the five key frames of the first and the second capture of each facial expression to assess the reproducibility of the facial movements. The corresponding images were aligned using partial Procrustes analysis, the root square mean of the distances between these was calculated and statistically analyzed using paired student t-test at P=0.05. Facial expressions of lip purse, cheek puff and raising of the eyebrows were reproducible. The facial expressions of maximum smile and forceful eye closure were not reproducible. The limited coordination of various groups of facial muscles contributed to the lack of reproducibility of these facial

expressions. The 4D imagining is a useful clinical tool for the assessment of facial expressions.

Introduction:

The assessment of the functional and morphological deficits of facial muscle movements and/or recovery is crucial for the diagnosis, management of facial paralysis and for the follow-up of various treatment modalities. Measuring facial nerve function is challenging due to the inherent complexity of the nerve physiology, the multi-regional motor function, and the complex autonomic control of blinking, lacrimation and salivation. Facial nerve paralysis/weakness results in varying degrees of dysfunction. "The ideal method for the assessment of facial nerve should be sensitive, specific and reliable [(1)]

Over the years, various methods have been proposed for the assessment of facial palsy [(1-9)] however, each has its own limitations [(10)]. The House-Brackmann [(11, 12)]and the Sunnybrook Facial Grading System [(13)]are the two main scales for the evaluation of facial palsy. Both are subjective and have a limited value in quantifying facial paralysis and its related asymmetry. The introduction of two-dimensional facial imaging that are based on photographs and/or video cameras to quantify facial movement is a positive step toward the standardized evaluation of facial expressions. Gross et al., 1996 demonstrated that two-dimensional recording of facial expressions underestimated muscle movements by about 43%. [(14)]

The assessment of facial expressions using static 3D imaging is more comprehensive than using 2D photographs, however, it has fallen out of favor due to the insufficient recording of the path of facial muscle movements. This has been addressed by the development of four-dimensional facial imaging systems which are now available to capture and reconstruct the dynamics of 3D facial morphology with a satisfactory clinical accuracy [(15)].

In an attempt of recording the 3D dynamic of facial expressions the movements of the muscles was tracked by applying reflective markers on the patient's face [16]. For each facial expression a sequence of 3D images, which represents the movements of the facial muscles, was generated. Tracking the changes of the position of the reflective markers throughout the course of a facial expression provided an accurate recording of muscle movements in real time (4D). One of the limitations of this method is the error associated with the direct placement of markers on the patients' face. In addition, this approach is labor intensive and time consuming which limits the practicality of the method for the regular clinical use [17].

An innovation of stereophotogrammetry facilitated the development of marker-less recording of facial expressions. The method is based on tracking the optical flow of the recorded 3D facial images. Therefore, the facial landmarks, which are digitizes on the first 3D frame of the set of images, are tracked automatically through a video image sequence. This allows the analysis of motion patterns and evaluation of the magnitude and direction of facial movements [18].

The analysis of the video sequence f 3D facial images is complex. Landmarks based analysis of the 4D images provides a limited representation of the comprehensive morphology of 3D surface during facial expressions. The maximum number of reproducible landmarks that could be utilized for 4D facial analysis is still limited to express the complete morphological characteristics of facial expressions.

One way to overcome this obstacle is the use of the "dense correspondence analysis [19]. The method is based on the application of generic facial mesh, a mathematical face mask which consists of a fixed number of thousands of quasi landmarks (vertices) [20]. The mesh is conformed “wrapped” on the 3D image of the face for the comprehensive representation of the facial morphology. The method has been used for the analysis of static 3D facial images but has not been applied yet for the dynamic assessment of facial expressions.

Aim of the study:

The present study was carried out to investigate the reproducibility of facial expressions in patients with unilateral facial paralysis using advancement morphometric methods. The rational of this investigation is to identify which expressions could be reliably used to quantify facial muscle movements for the clinical analysis and measure the outcome of various treatment modalities.

Mat**erials and Methods:**

Ethical approval was obtained from the South Central Oxford C Research Ethics Committee (Reference: 16/SC/0191) and Research & Development National Health Services Greater Glasgow and Clyde Health Board (Reference: GN16SG128).

The sample size was determined according to “Johnston et al., 2003 (21), “at standard assumption of 70% power and significance level P=0.05, a numerator value of 8 was indicated (22).To be able to detect 0.5 mm change between similar expressions, 20 subjects were needed for this study (21)

This study was cross sectional and carried out on 20 adult patients who suffer from unilateral facial paralysis (Table.1).

4D Facial Capture System

Di4D system (Dimensional Imaging Ltd, Hilington Park, Glasgow, UK) was used to record the dynamics of facial expressions. The method of 3D imaging is based on passive stereophotogrammetry., t. The system consisted of 2 gray-scale cameras (Model avA 1600-65km/kc - Resolution 1,600x1,200 pixels). Sensor model KAI-02050 (Kodak, Basler, Germany), 1 color camera, and a lighting system (Model DIV-401-DIVALITE; Kino Flo Corporation, Burbank, CA, USA). The grey-scale cameras captured the video sequences of facial movements at a rate of 60 3D facial frames/second, and the color camera captured the surface texture. The system was connected to a personal computer to build the sequence of the 3D facial images of each facial expression.

Imaging Protocol:

Before each capturing session, the system was calibrated according to an established protocol to configure the 3D orientation of the cameras to the face [(18)]. Participants were then shown photographic cue cards, which illustrate each of the facial expressions to avoid the emotional impact of facial muscle movements. Each participant was seated in front of the 4D imaging system where the full face could be captured and the head could befreely adjusted as demonstrated in our previous study. [(23)] Each participant was given a 5 minutes training session, patients were asked to perform each of the recorded facial expressions starting from the rest position to reach the maximal magnitude of muscle movements and then return to the rest position. Each facial expression was recorded over 3 seconds at a rate of 60 3D frame/ second, this generated 180 3D image sequence of each facial expression. Participants were invited back for the second capturing session after 30 minutes to record the same expressions following the same imaging protocol.

Five facial expressions were recorded; the maximal smile (E1), lip purse (E2), cheek puff (E3), maximal eyebrow raising (E4) and, forceful eye-closure (E5) (Figure.1).

Data Processing & statistical analysis:

A set of 23 landmarks which proved their reliability by our research team [18, 23], were manually digitized on the first frame of the 3D image sequence of each facial expression. These landmarks were only used to conform the generic mesh (Figure 2) to the first 3D facial frame for each set of 3D sequence of facial images of each expression to generate the "conformed mesh". The vertices of the mesh were tracked throughout the sequence of the 3D images of each facial expression.

The reproducibility of the landmarks digitization was assessed on 10 randomly selected facial expressions. The landmarks were digitized twice and those associated with non-significant digitization errors were automatically tracked throughout the sequence of the 3D images of each facial expression. The Di4D facial imaging system has satisfactory proven automatic landmark tracking accuracy of 0.55mm [24]

Five key 3D facial frames of each sequence of the 180 3D images/expression were used for the analysis, these were the initial rest pose, first quartile 3D image, maximum expression, third quartile 3D image, the rest pose at the end of the expression (Figure 3).

The reproducibility of facial expressions was investigated by measuring the dissimilarity of the five key frames for each of the repeated five expressions. The morphological dissimilarities between the corresponding images were measured according to well recognised technique where the rest position was considered the ground truth. The 3D facial morphology at each key frame was aligned on the corresponding frame at rest using partial Procrustes method [19]. The disparities of the location of the quasi-landmarks between the corresponding images were measured. The differences in the morphology at each key frame in relation to the frame at rest were measured.. Paired sample t-test was applied to assess the statistical differences at each key frame of the image sequences of the second capture and its corresponding frame of the first captured of each facial expression. .

Results:

Manual Digitization Error:

A paired-sample t-test comparing manual landmarking errors showed no statistically significant difference ($P<0.05$) between the two marking sessions. P values for X, Y and Z were $P=0.11$, $P=0.22$, $P=0.73$, respectively. The absolute distance between the average repeated landmarking was 0.99mm. Landmarks No19, 20 were associated with the largest digitization error.

Reproducibility of Facial Expressions:

Reproducibility of Maximal Smile:

Table.3 shows that there was no statistical significant difference of the 3D images at rest between the first and second captures ($P >0.05$) which indicates that the facial position at rest was reproducible. However, there were statistical significant differences between the repeated maximal smile at the beginning and at the end of the expression ($P<0.05$).

Reproducibility of Lip Purse:

Table.4 shows that no statistical significant differences were detected at any of the five key facial frames of the repeated expression ($P >0.05$).

Reproducibility of Cheek Puff:

Table.5 shows that no statistical significant differences were detected at any of the five key facial frames between the repeated cheek puffs ($P > 0.05$).

Reproducibility of Maximum Raising of Eyebrows:

Table.6 shows that no statistical significant differences were detected between the repeated raising of the eyebrows ($P > 0.05$).

Reproducibility of Forceful Eye-Closure:

Table.7 shows that there was no statistical significant difference between the 3D facial images at rest between the first and second captures. However, there were statistical significant differences between the repeated forceful eye closure ($P < 0.05$). Box plot ,figure5, demonstrates the facial morphological differences at the maximum movements of the five facial expressions.

Discussion:

Several methods have been considered for the assessment of facial paralysis. However, there is a lack of objective, comprehensive and clinically applicable measures. This study investigated the feasibility of 4D imaging and the application of advanced geometric morphometrics for the analysis of the dynamics of the distorted movements of facial muscles. The facial expressions of maximum smile, lip purse, cheek puff, maximum raising of the eyebrows and forceful eye-closure were chosen for the assessment of facial nerve function. It was contemplated that these facial expressions display the various movements of muscles supplied by each of the main branches of the facial nerve. To the best of our knowledge this is the first study that investigates the reproducibility of facial expressions in this group of patients. Of the 20 recruited individuals, male participants accounted for 3, and 17 were females; therefore the relationship between different genders on expression reproducibility was not explored. An innovative approach that is based on deformable generic models was applied. The use of generic mesh, which composed of 42000 vertices, provided a dense representation of the full facial surface. The non-rigid surface-based registration between the generic mesh and the 3D facial models of each patient ensured a custom-made conformation of the mesh to the morphological characteristics of each face. While each conformed mesh is different geometrically they are all consist of the same number of vertices. This provided an unprecedented comprehensive analysis of facial morphology.

The results of this study confirmed that the facial expressions of lip purse, cheek puff and maximum raising of the eyebrows were reproducible. On the other hand, the facial expressions of forceful eye closure and maximum smile were not reproducible. Facial shape at resting facial position was shown to be reproducible for all of the recorded facial expressions. Researchers have investigated the reproducibility of facial expressions in healthy volunteers [25-28]. Our findings suggest a stark difference in the reproducibility of facial expressions between healthy individuals and those suffer from unilateral facial paralysis. It has been shown that maximum smile is one of the reproducible facial expressions in those who do not suffer from facial paralysis [29].

There are several factors that explain the non-reproducibility of forceful eye closure and maximum smile. The most likely explanation is the lack of coordination between the right and left sides of the face, as well as on the same facial side, of the various muscles groups responsible for these complex facial movements. This is further supported by the fact that in the facial expressions of cheek puff, lip purse and, maximum raising of the eyebrows, which were reproducible, are controlled by a limited group of muscles which require less coordination than maximum smile. The orbicularis oris muscle is exclusively responsible of lip purse; cheek puff is dependent on the action of buccinators muscle; and, the raising of the eyebrows is the sole action of the anterior belly of the occipito-frontalis muscle. On the other hand, to achieve a maximum smile the orbicularis oris muscles relax and the levator labii superioris, levator anguli oris and the cheek muscles, and zygomaticus muscles contract with a simultaneous pulling of the lips laterally and upward by risorius, muscle. This is also true for forceful eye closure. The coordination of the eye muscle groups is one of the most complex functions. During forceful eye closure, the orbicularis occuli and palpebral muscles contract whereas the anterior belly of the occipito-frontalis and contributory zygomaticus muscles relax.

Another possible explanation for the non-reproducibility of the maximum smile could be psychological. These patients tend to avoid smiling which might result in cognitive deterioration of this expression. However, this requires further investigation to substantiate. It is also important to highlight that the impact of emotional aspects of facial expression was eliminated from the study by showing the participants a set of images, which demonstrated the designated facial expression therefore minimize the psychological and emotional aspects of each movements.

We acknowledge the different etiological causes of the unilateral facial paralysis in this stuy. However, the main objective of this investigation was the assessment of the feasibility and the reproducibility of facial expressions regardless to the cause, age, gender or the received treatment. It would be interesting to evaluate if the cause or the treatment of facial paralysis would influence the reproducibility of facial expressions, this will require sample size to be explored

Four-dimensional imaging is a useful tool for the assessment of the dynamics of facial expressions and could be utilized clinically. The non-invasive nature of recording facial expressions provides an ideal method for the assessment of facial muscle movement. The application of advanced geometric morphometrics provided comprehensive analysis of facial expressions. The novel findings of this research, this should be taken in consideration in any future clinical studies.

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Conflict of Interests
None

Ethical approval

Ethical approval was obtained from the South Central Oxford C Research Ethics Committee (Reference: 16/SC/0191) and Research & Development National Health Services Greater Glasgow and Clyde Health Board (Reference: GN16SG128).

Consent:

Written consents were obtained from all study participants. Another consent was obtained from those who agreed to disclose their photographs for publication purposes

I confirm that all authors have viewed and agreed to the submission

Legends of the figures:

1. Figure 1: The five recorded facial expressions
2. Figure 2: The generic facial mesh
3. Figure 3: The conformation of the generic mesh, from the left to the right representing the universal Generic mesh, 3D facial image, the conformed mesh.
4. Figure 4: The five key 3D facial frames that were used in the analysis and represented the start of motion from rest, the 1st quartile of the expression, the maximum motion, the 3rd quartile of the expression, and the end of motion.
5. Figure 5: Box plot shows facial shape differences at the maximum movements of the six facial expressions, rest position, maximal smile, lip purse, cheek puff, maximal eyebrow raising, and forceful eye closure.

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Table.1: Study Participants

Patient No	Code	Age	Gender	Ethnicity	Etiology	Affected Side	Incidence	Treatment
P1	03CA05SM16	55	Female	Caucasian	Facial Neuroma	Left Side	June 2012	Facial Reanimation with free muscle transfer (September 2014)
P2	03MA05CL16	64	Female	Caucasian	Congenital	Right Side	August 1952	Temporalis transfer (2004)
P3	03LI05WI16	51	Female	Caucasian	Bell's Palsy	Left Side	August 2014	Cross face nerve graft & Sural nerve transfer (February 2016)
P4	17ST05MC16	27	Female	Caucasian	Basal Skull Fracture	Right Side	2008	None
P5	17AN05ST16	62	Female	Caucasian	Acoustic Neuroma	Right Side	2005	Brow Life (2014), Botox {(May 2014), (Oct 2014), (Sept 2015), May 2016)}
P6	17KA05DO16	29	Female	Caucasian	Bell's Palsy	Right Side	Dec 15	None
P7	31AN05MC16	59	Female	Caucasian	Congenital	Left Side	1954	Static support left face (2009), Free muscle transfer to left face (May 2016)
P8	14LI06KE16	25	Female	Caucasian	Iatrogenic	Left Side	2006	Free muscle transfer on the nerve to master (2011)
P9	31BR05HE16	47	Male	Caucasian	Ramsay Hunt Syndrome	Right Side	2014	None
P10	14CH06LE16	68	Female	Caucasian	Bell's Palsy	Right Side	April 2015	None
P11	14DE06GE16	47	Female	Caucasian	Bell's Palsy	Right Side	2005	Cross face nerve graft (2007), Free muscle transfer (2007), Face life (2014), Free muscle transfer (Jan 2015), Fat graft (April 2016)
P12	14RO06WI16	63	Female	Caucasian	Cholesteoma	Right Side	2011	None
P13	14FE06BE16	53	Female	Caucasian	Acoustic Neuroma	Left Side	2009	Brow lift (2015), Botox (March 2016, June 2016)
P14	17IA05MC16	45	Male	Caucasian	Acoustic Neuroma	Left Side	1994	Cross face nerve graft (September 2015)
P15	03CH05SH16	36	Female	Caucasian	Bell's Palsy	Right Side	October 2013	Botox for synkinesis (Nov 17, 2015 - May 03, 2016)
P16	26HE07SI16	62	Female	Caucasian	Bell's Palsy	Right Side	2014	Brow lift (2016)
P17	26KA07SH16	51	Female	Caucasian	Acoustic Neuroma	Left Side	2005	None
P18	26LY07MU16	23	Male	Caucasian	Trauma	Right Side	April 2013	Nerve repair (2013)
P19	26BA07KI16	48	Female	Caucasian	Bell's Palsy	Left Side	2002	Botox (2012 & every six monthly thereafter)
P20	26MO07LA16	59	Female	Caucasian	Bell's Palsy	Left Side	1996	Free muscle transfer (2013), fat graft to left face (2015), Brow lift (2016)

Table.2: Landmarks

Landmark Number	Landmark Name	Definition
1 and 4	Exocanthion	The point at the outer commissure of the eye fissure, located slightly medial to bony exocanthion
2 and 3	Endocanthion	The point at the inner commissure of the eye fissure, located lateral to bony landmark
5	Pronasale	The most protruded point of the nose identified in lateral view
6 and 7	Alar curvature	The most lateral point on the curved base line of each ala, indicating the facial insertion of the nasal wing base
8 and 12	Cheiliom	The point located at the corner of each labial commissure
9 and 11	Crista Philtre	The peak of Cupid’s bow
10	Labrale superius	A point indicating the maximum convexity of the muco-cutaneous junction of the upper lip and philtrum
13	Labrale inferius	A point indicating the maximum convexity of the muco-cuteneous border of the lower lip
14 and 15	Mid-Labrale Superius	A point indicating the mid-distance between 8 & 9 and 11 & 12, respectively.
16 and 17	Mid-Labrale Inferius	A point indicating the mid-distance between 12 & 13 and 8 &13, respectively.
18	Pogonion	The most anterior midpoint of the chin
19 and 20	Zygion	The most prominent point on the cheek area beneath the outer canthus
21 and 22	Superciliary	Midpoint of the eyebrow identified at greatest convexity
23	Nasion	The point in the midline of both the nasal root and the nasofrontal suture, always above the line that connects the two inner canthi, identical to bony nasion

Table.3: Reproducibility of Maximal Smile

	Start of Expression	First quartile	Maximal Animation	Third Quartile	End of Motion
P values	**0.0885**	0.0042	0.0009	0.0002	0.0250

Table.4: Reproducibility of Lip Purse

	Start of Motion	First quartile	Maximal Animation	Third Quartile	End of Motion
P values	**0.3057**	**0.1667**	**0.1964**	**0.1626**	**0.1862**

Table.5: Reproducibility of Cheek Puff

	Start of Motion	First quartile	Maximal Animation	Third Quartile	End of Motion
P values	**0.2846**	**0.2081**	**0.2315**	**0.1838**	**0.1898**

Table.6: Reproducibility of Maximum Raising of Eyebrows

	Start of Motion	First quartile	Maximal Animation	Third Quartile	End of Motion
P values	**0.2454**	**0.2759**	**0.1167**	0.0287	**0.2559**

Table.7: Reproducibility of Forceful Eye-Closure

	Start of Motion	First quartile	Maximal Animation	Third Quartile	End of Motion
P values	**0.2708**	0.0058	0.0062	0.0092	0.0394