The British Association of Plastic Surgeons (2003) **56**, 644–652

Three-dimensional video-analysis of facial movements in healthy volunteers☆

P. Giovanoli[a,*], C.-H.J. Tzou[a], M. Ploner[b], M. Frey[a]

[a]*Division of Plastic and Reconstructive Surgery, Department of Surgery, University of Vienna, Vienna 1090, Austria*
[b]*Department of Medical Computer Sciences, University of Vienna, Vienna, Austria*

Received 10 May 2002; accepted 9 January 2003

KEYWORDS
Facial movements;
Three-dimensional;
Healthy face; Standard

Summary The aim of this study was to determine the mean distances of facial movements in 24 healthy individuals aged between 22 and 70 years, using the digitised three-dimensional video-analysis system developed by Frey et al. The subjects were divided into three groups of eight. The first group consisted of individuals aged between 20 and 30 years (mean ± s.d. = 25.0 ± 2.33 years). Subjects in the second group were aged between 40 and 50 years (mean ± s.d. = 46.8 ± 2.53 years), and the third group consisted of subjects aged between 60 and 70 years (mean ± s.d. = 63.6 ± 3.07 years). In all groups the sexes were equally represented. No subject had had treatment to the face, nor did they have paralysis, scars or diseases of the skin. Males showed larger movements of the face than females, on average by 1.40 ± 0.73 mm (15.08%). Subjects aged between 60 and 70 years demonstrated the largest movements of the face. The evaluation of facial movements in 24 healthy volunteers showed that sex and age affect facial dynamics. Thus study generated three-dimensional standard values for healthy facial movements.

Three-dimensional (3D) quantitative analysis of movements is important in plastic and reconstructive facial surgery. In the past, several attempts have been made to measure the complex human face.[1–12] However, only a few have used instruments that provide 3D measurements and achieved promising results.[13–19]

The aim of this study was to determine the mean standard values of healthy facial movements using the digitised 3D video-analysis system developed by Frey et al.[19] Throughout the text, values are given in the form mean ± s.d.

Material and methods

We enrolled 24 subjects, aged between 22 and 70 years, in the study and divided them into three groups of eight. The first group consisted of individuals aged between 20 and 30 years (25.0 ± 2.33 years). Subjects in the second group were aged between 40 and 50 years (46.8 ± 2.53

☆ Presented at the 9th International Facial Nerve Symposium, San Francisco, CA, USA, 29 July–1 August 2001 and the Inaugural Congress of the World Society of Reconstructive Microsurgery, Taipei, Taiwan, 31 October–3 November 2001.

*Corresponding author.
E-mail address: pietro.giovanoli@akh-wien.ac.at

S0007-1226/03/$ - see front matter © 2003 The British Association of Plastic Surgeons. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/S0007-1226(03)00277-7

years), and the third group consisted of subjects aged between 60 and 70 years (63.6 ± 3.07 years). In all groups the sexes were equally represented. All 24 subjects were healthy and free from craniofacial anomalies. They had never undergone any treatment to the face nor had they had any form of facial paralysis, scarring or skin disease. Participants were of Middle European descent, had been born in Austria and lived nearby and in Vienna.

The data-acquisition apparatus[19] consisted of a mirror system, a calibration grid (both developed by the Laboratory for Biomechanics, Swiss Federal Institute of Technology, Zurich, Switzerland) and a commercial digital video camera (Fig. 1). We chose 18 standard reproducible anatomical landmarks on the face,[19] of which three were static and 15 were dynamic (Table 1 and Fig. 2). A permanent marker was used to place a 2 mm black dot at each of the dynamic landmarks. Static points were marked with a plastic light ball 5 mm in diameter. All markings, except the points central nose and philtrum, were made on both sides of the face.

Each subject was videotaped under standard conditions. All recordings were made in the same room, in the same chair, by the same examiner and at the same time of day, between 14:00 and 16:00. Light from four 1000 W Halogen Photo-Optic lamps (Osram, Munich, Germany) was used to generate uniform, symmetrical and standardised lighting. Reflected light from the face was 5500 lux, measured by a hand-held photocell.

The subject sat relaxed and upright in a normal chair without head support, eyes looking forward into the camera, which was positioned 5 m away. After the subject was positioned in the calibrated measurement field, she/he performed nine standard facial animations[19] (Table 2) in a sequential order after a verbal signal.

Table 1 Abbreviations of the standardised facial landmarks[19]

Central nose	CN
Left ala of the nose	LAN
Left brow	LBP
Left lower eyelid	LLE
Left mouth corner	LMC
Left midlateral point of the lower lip	LML
Left midlateral point of the upper lip	LMU
Left tragus	LTR
Left upper eyelid	LUE
Philtrum	PH
Right ala of the nose	RAN
Right brow	RBP
Right lower eyelid	RLE
Right mouth corner	RMC
Right midlateral point of the lower lip	RML
Right midlateral point of the upper lip	RMU
Right tragus	RTR
Right upper eyelid	RUE

Three repetitions of each set of facial animations were digitally collected and transferred to a computer, where the most suitable video sequence out of the three was edited and saved as video (.avi) and image (.uis) files. Subsequently, Facialis software[19] (Laboratory for Biomechanics, Swiss Federal Institute of Technology, Zurich, Switzerland) was used to calculate the 3D coordinates of landmarks on the face. FaciShow (Laboratory for Biomechanics, Swiss Federal Institute of Technology, Zurich, Switzerland), a specially designed program,[19] was used to visualise the data processed with the Facialis software. Two-dimensional (2D) and 3D trajectories of each landmark during movement could be presented (Fig. 3).

All statistical analyses were performed at the Department of Medical Computer Sciences, University of Vienna. The tests were exploratory in nature; thus, no multiple adjustments were performed. Comparisons between two groups were made using Student's *t*-test after checking the homogeneity of the variances. Differences between more than two groups were assessed using the F-test of a one-way analysis of variance (ANOVA). $P \leq 0.05$ was considered statistically significant.

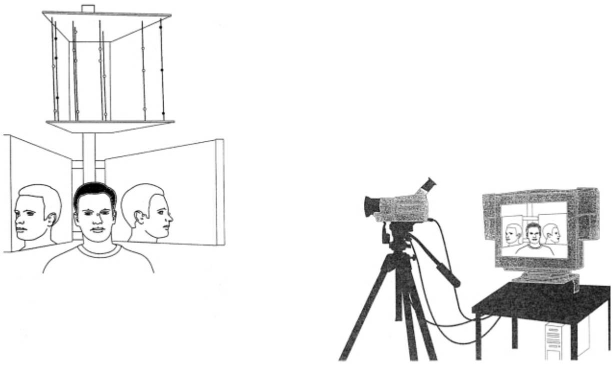


Fig. 1 Diagram of the 3D video-analysis system (from Frey et al. (1999);[19] reproduced with the permission of Lippincott Williams & Wilkins from Queen Arnette).

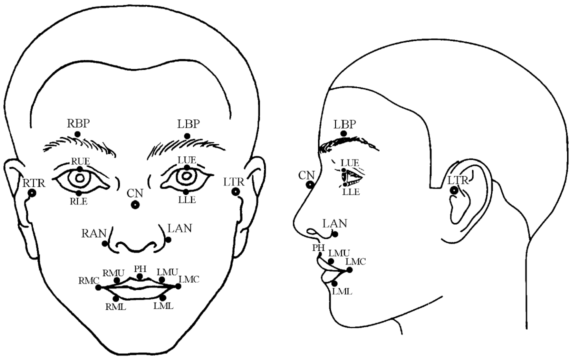


Fig. 2 Locations of the dynamic and static landmarks on the face in frontal and lateral views.

Table 2 Abbreviations of the standardised animations performed by all subjects in the order listed[19]

English version	Abbreviation	German version
Maximal lifting of the eyebrows	mha	Maximales Heben der Augenbrauen
Closure of the eyelids as in sleep	sas	Schliesen der Augen wie im Schlaf
Maximal closure of the eyelids	ml	Maximaler Lidschluss
Maximal showing of the teeth	mzz	Maximales Zähnezeigen
Maximal showing of the teeth with maximal closure of the eyelids	mlmz	Gleichzeitig Maximaler Lidschluss und Maximales Zähnezeigen
Smiling showing teeth	lzz	Lächeln mit Zeigen der Zähne
Smiling with lips closed	lgl	Lächeln mit geschlossenen Lippen
Pursing of the lips	mzp	Mund zuspitzen und pfeifen
Pulling down the mouth corners	mwu	Mundwinkel nach unten ziehen

Results

The mean facial motion in a healthy face ranged from 0.5 to 16.5 mm (Table 3) in the mouth and nose region. Gender and age had statistically significant impacts on facial motions and on the static facial morphology.

Gender

In the resting position, men generally showed statistically significantly larger distances between all landmarks than did women (Table 3(A)). The difference between male and female subjects was, on average, 6.25 ± 2.96 mm (8.26%; $P < 0.05$).

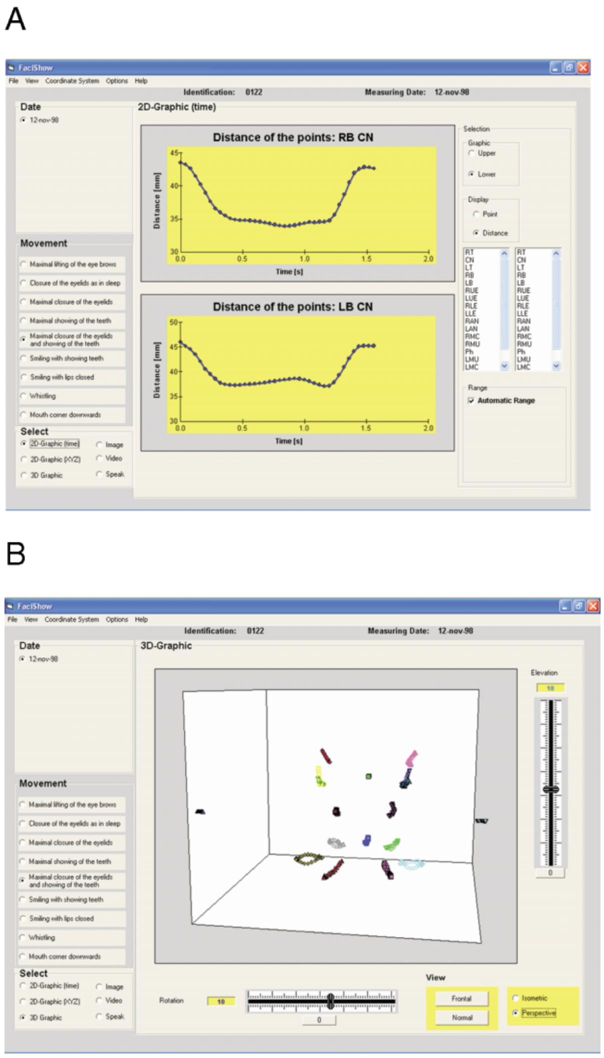
Larger movements of the face were also observed in males than in females, by, on average, 1.40 ± 0.73 mm (15.08%). A statistically significant difference was seen in the mouth region, where men showed larger movements of the mouth corner than women (tragus-mouth corner: men: 16.5 ± 1.87 mm (14.6%); women: 13.7 ± 3.11 mm (13.1%); $P < 0.05$). Moreover, the excursion of the upper lip was statistically significantly larger in men than in women (central nose-upper lip: men: 7.9 ± 2.55 mm (11.2%); women: 5.6 ± 1.87 mm (8.9%); $P < 0.05$). One exception was observed: on pursing the lips women were found to have a statistically significantly larger excursion than men (tragus point-mouth corner: men: 10.0 ± 3.56 mm (8.8%); women: 11.8 ± 2.16 mm (11.2%); $P < 0.04$; and mouth corner-philturm: men: 6.3 ± 2.39 mm (15.8%); women: 7.7 ± 1.69 mm (28.0%); $P < 0.04$).

Age groups

The effect of age was found to be statistically significant. The mean difference at rest between the oldest age group and subjects in their 20s is 5.68 ± 3.29 mm (6.94%) and the mean difference between the oldest age group and subjects in their 40s is 2.52 ± 1.26 mm (e.g. 4.40%) (Table 3(B)).

Statistically significant differences between the age groups at rest were seen in the nose region, which was represented by the distance central nose-ala of the nose (20-30 years: 41.1 ± 3.07 mm; 40-50 years: 43.4 ± 2.62 mm; 60-70 years: 45.9 ± 5.29 mm, $P < 0.05$). Moreover, at rest, the oldest age group was observed to have the statistically significantly largest distances in the mouth region, as seen by the distance central nose-upper lip (20-30 years: 61.6 ± 3.91 mm; 40-50 years: 67.0 ± 4.40 mm; 60-70 years: 70.7 ± 8.43 mm; $P < 0.05$). There was one exception in the frontal region: the oldest age group showed statistically significantly shorter distances between the central nose and the brow (20-30 years: 43.8 ± 3.42 mm; 40-50 years: 44.6 ± 2.97 mm; 60-70 years: 39.3 ± 4.91 mm; $P < 0.05$).

The effect of age on facial movement was also found to be statistically significant. Subjects aged between 60 and 70 years demonstrated the statistically significantly largest movements in the face. They showed, on average, larger facial movements than subjects in their 20s (by 2.10 ± 1.09 mm (33.36%)) and subjects in their 40s (by 1.86 ± 0.60 mm (30.54%)). They were observed to have particularly large changes in the nose region. Statistically significant differences were seen in the distance central nose-ala of the nose (20-30 years: 4.38 ± 1.67 mm (11.03%); 40-50 years: 5.54 ± 2.37 mm (12.52%); 60-70 years: 7.68 ± 3.16 mm (16.76%); $P < 0.05$). Moreover, they were observed to have larger changes in the mouth region, which is represented by the distance central nose-midlateral point of the upper lip, than the other age groups (20-30 years: 5.33 ± 0.98 mm (8.64%); 40-50 years: 6.76 ± 2.89 mm (9.91%); 60-70 years: 8.20 ± 2.48 mm (11.45%); $P < 0.05$).



Identification: 0122 Measuring Date: 12-nov-98

Date: ● 12-nov-98

Movement:
- ○ Maximal lifting of the eye brows
- ○ Closure of the eyelids as in sleep
- ○ Maximal closure of the eyelids
- ○ Maximal showing of the teeth
- ● Maximal closure of the eyelids and showing of the teeth
- ○ Smiling with showing teeth
- ○ Smiling with lips closed
- ○ Whistling
- ○ Mouth corner downwards

Select (A): ● 2D-Graphic (time) ○ 2D-Graphic (XYZ) ○ 3D Graphic ○ Image ○ Video ○ Speak

Graphic: ● Lower; Display: ● Distance; ☑ Automatic Range

Select (B): ○ 2D-Graphic (time) ○ 2D-Graphic (XYZ) ● 3D Graphic ○ Image ○ Video ○ Speak

View: ● Perspective

Fig. 3 FaciShow®; (A) visualisation of the distances between landmarks (right brow-central nose and left brow-central nose) during the movement 'maximal closure of the eyelids and showing of the teeth' in two dimensions; points represent the movement (mm) of the landmark over time (s); and (B) visualisation of the movement of each landmark during the whole movement 'maximal closure of the eyelids and showing of the teeth' in a perspective 3D view.

Asymmetry

Each of the 24 subjects demonstrated differences between the right and left sides of the face. To evaluate side dominance the mean distances on the right and left were compared, and no statistically significant difference was observed. The symmetry in facial motion was stronger than the symmetry in the resting position. In other words, the face in motion is more symmetrical than the face in its resting position.

Gender

An asymmetry of 0.61–4.77 mm (0.54–15.67%) was observed in resting position. No statistically significant influence of gender was found in the asymmetry of the resting position (men: 0.82–4.77 mm; women: 0.61–3.77 mm).

An asymmetry of 0.69–2.68 mm (0.15–6.56%) was observed in facial movements of males and females (men: 0.69–2.50 mm; women: 0.8–2.68 mm) (Table 4(A)).

Age groups

Among the age groups the asymmetry between the right and left sides of the face ranged from 0.71 to 4.66 mm for subjects aged 20–30 years, 0.68–5.62 mm for subjects aged 40–50 years and 0.65–4.15 mm for subjects aged 60–70 years. No statistically significant differences between the right and left sides were found (Table 4(B)).

Age has no statistically significant impact on asymmetry during facial motion: asymmetry in those aged 20–30 years ranged from 0.52 to 2.78 mm; in those aged 40–50 years it ranged from 0.65 to 3.2 mm; and in those aged 60–70 years it ranged from 0.65 to 3.10 mm (Table 4(B)).

Discussion

Population sample

It is reported that the three major geographical races—African, Asian and European—have each evolved a characteristic set of facial features,[20] and this has been confirmed by anthropometric research.[21–23] One ethnic group is predominant in a number of European countries (e.g. France, Germany, Italy, Spain, Scandinavia, the Czech Republic, Hungary and Poland), in comparison with the multi-ethnic population of North America. Therefore, to create a representative population sample, we studied healthy facial movements in subjects only of Middle European descent, and individuals living in the eastern part of Austria were invited to take part in this study.

3D system

Standards already exist in the anthropometric measurement of faces. This study provides the first standards for the 3D assessment of healthy facial movements. This objective 3D video-analysis technique[19] used a mirror system, a calibration grid, a commercial digital video camera, analysis software (Facialis) and visualisation software

Table 3 Mean distances (mm) between the points indicated at rest (D(0)) and during movement for (A) males and females and (B) all age groups ($n = 24$). (A: in each set of three columns, the left-hand column is the data for males and females, the middle column is the data for males only and the right-hand column is the data for females only; B: in each set of three columns, the left-hand column is the data for subjects aged 20-30 years, the middle column is the data for subjects aged 40-50 years and the right-hand column is the data for subjects aged 60-70 years)

(A)															
Frontal region		D (0)		Maximal lifting of the eyebrows											
BP-CN	42.6	43.9	41.2	7.8	8.6	7.0									
Eye region		D (0)		Closure of the eyelids as in sleep											
UE-LE	7.6	7.9	7.2	7.6	8.0	7.2									
Nose/mouth		D (0)		Smiling with lips closed			Maximal showing of teeth			Smiling showing teeth			Pursing of the lips		
TR-MC	109.0	113.3	104.8	9.0	10.3	7.6	15.1	16.5	13.7	12.9	14.0	11.7	10.9	10.0	11.8
CN-AN	42.0	43.7	39.5	2.5	2.6	2.4	5.9	6.9	4.9	3.8	4.5	3.1			
CN-MU	66.4	70.5	62.3	3.4	3.8	3.0	6.8	8.0	5.6	5.3	5.9	4.7			
TR-PH	134.3	139.2	129.3	2.8	3.1	2.4	5.6	6.0	5.2	4.1	4.6	3.6			
CN-ML	77.1	80.6	73.5	4.6	5.4	3.8	7.7	8.3	7.1	5.6	6.2	4.9			
MC-PH	36.5	39.7	26.9										7.0	6.3	7.7
(B)															
Frontal region		D (0)		Maximal lifting of the eyebrows											
BP-CN	43.8	44.6	39.3	7.1	7.3	8.9									
Eye region		D (0)		Closure of eyelids as in sleep											
UE-LE	7.9	6.7	8.1	7.9	6.7	8.1									
Nose/mouth		D (0)		Smiling with lips closed			Maximal showing of the teeth			Smiling showing teeth			Pursing the lips		
TR-MC	108.7	109.7	107.8	8.8	8.8	9.3	16.0	13.9	15.5	11.3	12.3	15.0	9.6	12.4	10.8
CN-AN	41.1	43.4	45.9	2.1	2.0	3.5	4.4	5.5	7.7	2.5	3.2	5.6			
CN-MU	61.6	67.0	70.7	2.7	3.1	4.4	5.3	6.8	8.2	4.1	4.3	7.5			
TR-PH	133.4	135.0	134.5	2.3	2.2	3.7	5.1	5.0	6.7	3.3	4.3	4.6			
CN-ML	73.6	78.0	79.6	4.1	3.7	6.1	9.1	7.0	6.9	5.0	5.0	6.7			
MC-PH	36.0	36.3	37.1										6.2	7.1	7.6

(FaciShow) to capture all facial dimensions and movements of interest.

Our method of assessing movements of dynamic landmarks on the face differs from those used in recent research.[10,24] Those studies used 2D measurements, an approach that is nowadays considered unacceptable. According to Frey et al., important information is lost and accuracy of measurement is sacrificed by projecting 3D data into 2D.[18] Moreover, Frey et al. stated that only a 3D analysis could adequately and objectively document the extremely complex facial movements.[18] Gross et al. found significant differences between the 3D and 2D amplitudes of measurements of, on average, up to 3.0 mm when facial motion was greatest.[25] Further, they also pointed out that projection error arose from the inability of the 2D method to detect any anterior-posterior motion of the landmarks. Projection errors also resulted from misalignment between the frontal plane of the face and the image plane of the camera sensors.

These errors might have affected Burres' study, in which a 2D technique was applied to 30 normal subjects.[26] He found that the maximal movement of any specific point on the face did not exceed 10 mm. In contrast, when we assessed facial movements with 3D video-analysis, we found that the maximal excursion of a landmark (the mouth corner) was 27.97 mm, in male subjects aged between 60-70 years, when smiling showing teeth.

2D error was also found in photogrammetry,[27] a

Table 4 (A) Asymmetry (mm) at rest (D(0)) and during movement for (A) males and females and (B) all age groups ($n = 24$). (A: in each set of three columns, the left-hand column is the data for males and females, the middle column is the data for males only and the right-hand column is the data for females only; B: in each set of three columns, the left-hand column is the data for subjects aged 20-30 years, the middle column is the data for subjects aged 40-50 years and the right-hand column is the data for subjects aged 60-70 years)

(A)															
Frontal region		D(0)		Maximal lifting of the eyebrows											
BP-CN	3.0	3.4	2.7	1.1	1.2	1.0									
Eye region		D(0)		Closure of eyelids as in sleep											
UE-LE	0.8	0.8	0.8	0.0	0.0	0.0									
Nose/mouth		D(0)		Smiling with lips closed			Maximal showing of the teeth			Smiling showing teeth			Pursing the lips		
TR-MC	3.8	4.3	3.3	1.9	2.4	1.3	2.1	2.1	2.1	2.6	2.5	2.7	2.1	2.0	2.2
CN-AN	1.8	1.6	2.0	0.9	0.8	1.0	1.4	1.5	1.3	1.1	1.1	1.1			
CN-MU	1.2	1.3	1.1	0.8	0.8	0.8	1.4	1.4	1.3	1.0	1.0	1.0			
TR-PH	3.8	4.3	3.2	0.9	1.0	0.8	1.2	1.0	1.4	0.9	0.9	0.9			
CN-ML	1.0	1.3	0.7	1.2	1.2	1.2	1.3	1.3	1.3	1.0	0.7	1.2			
MC-PH	2.1	2.0	2.2										1.2	0.9	1.4
(B)															
Frontal region		D(0)		Maximal lifting of the eyebrows											
BP-CN	2.7	4.2	2.1	0.7	1.1	1.4									
Eye region		D(0)		Closure of eyelids as in sleep											
UE-LE	1.0	0.7	0.7	0.0	0.0	0.0									
Nose/mouth		D(0)		Smiling with lips closed			Maximal showing of the teeth			Smiling showing teeth			Pursing the lips		
TR-MC	3.2	5.1	3.2	2.4	1.4	1.8	2.1	2.4	1.6	2.8	1.9	3.1	1.4	3.2	1.7
CN-AN	1.0	1.9	2.5	0.7	0.9	1.1	1.2	1.0	1.9	0.8	1.1	1.4			
CN-MU	0.9	1.2	1.5	0.7	0.6	1.0	0.9	1.4	1.7	1.0	1.1	0.9			
TR-PH	3.7	3.7	3.9	0.9	0.8	0.7	1.5	0.7	1.4	1.1	0.8	0.8			
CN-ML	1.0	0.9	1.2	0.9	0.8	0.9	0.6	1.7	1.5	1.1	0.8	1.0			
MC-PH	2.0	2.2	2.0										0.9	1.6	1.0

widely used technique in which measurements of faces are taken from standardised photographs. The photographs were not sharp enough to allow accurate identification and marking of some landmarks on the photographs in all cases (e.g. ala of the nose and upper and lower eyelids). Therefore, in order to produce the best results, the subject had to be photographed with the landmarks marked on the skin.[27] The marking of landmarks in our 3D video-analysis was done before videotaping the subjects' facial movements. This procedure was fully accepted by the participants, who were cooperative and informed. Facial movements were not influenced by the marking method used in this study.

Many systems have used markers up to 6.4 mm in diameter to determine landmarks on the face (Kohn et al.[8] 6.4 mm; Bajaj-Luthra et al.[10] 5.0 mm; Johnson et al.[24] 5.0 mm; Gross et al.[25] 5.0 mm; and Trotman et al.[16] 4.0 mm). In this study a permanent marker was used to place a 2 mm black dot at each of 16 dynamic landmarks, which proved to be very practical. The dots did not interfere with facial motion at any time during the measurement and were definitely more advantageous than the landmarks (plastic balls) previously used to mark dynamic points. The three static points were essential for calibrating the space in the mirror system and were marked with plastic light balls of 5.0 mm in diameter. The large size of the static landmarks has no effect on measurement bias, since the centre-marking principle was used to determine their positions.

Standardised procedures

In order to maximally eliminate errors from all aspects, the procedures in this study were standardised. All recordings were made in the same room, in the same chair, by the same examiner, at the same time of day—between 14:00 and 16:00—and under the same lighting conditions. Reproducible and standardised landmarks,[19] set up and standardised in the International Registry for Neuromuscular Reconstruction in the Face,[18] were selected and marked. The 3D video-analysis is able to visualise the exact coordinates of each point in the mirror complex. Moreover, it is also able to illustrate the velocity and direction of each landmark within the 3D space of interest.

This objective method differs from those of previous studies that were able to analyse differences between the resting and maximal positions only, except for Trotman et al.,[16] who demonstrated a video-analysis system, which provided data on facial movements in 3D. However, in their system, absolute measurements of changes in distance between landmarks were impossible.

Another advantage of this video system compared with a laser system is the real-time taping of the subjects. Vannier et al. reported that the time a person can remain motionless and expressionless is approximately 1 s.[28] Thus, using a laser scanning system, which usually needs around 8–30 s on average,[29] might cause motion artefacts. The real-time recording used by this 3D video system prevents motion artefacts and fatigue of the subject's mimic system.

This sensitive standardised 3D video-analysis system has been used to assess the functional recovery of the facial nerve. It has been applied in clinical practice at the Division of Plastic and Reconstructive Surgery, Department of Surgery, General Hospital Vienna since 1998. Degrees of asymmetry have been successfully quantified and evaluated before and after surgery in patients suffering from facial paralysis.

Mean facial movements

Generally, gender and age seem to have a great impact on facial movements. Men and older subjects demonstrated larger distances both at rest and in facial movements.

Gender

Men have statistically significantly larger facial distances than women. This might be due to increased growth of the male facial musculature and skull as compared with the lighter features of the female face, which has been reported to be about four-fifths the size of the male face.[21,30] In this study, the distance between the right and left tragus points, representing the width of the face, shows a noticeable difference between males and females (men: 162.2 ± 4.76 mm; women: 149.4 ± 4.76 mm).

Farkas observed that the eye-fissure distance (upper eyelid–lower eyelid) in females is 0.9 mm larger than in males.[21] However, in this study, differences in the eye-fissure distance between the sexes were not statistically significant: women had a mean of 7.22 mm and men had a mean of 7.93 mm.

The shortening of the distance between the tragus point and the mouth corner when smiling showing teeth is, on average, 11.7 mm for women and 14.0 mm for men. Women show an excursion of only 83.5% of that shown by men. The larger excursion of the mouth corner in men probably results from their larger facial dimensions. Paletz et al. demonstrated similar results using a 2D video system.[6] They reported that the movement when smiling showing teeth in females was 90% of that in males, measuring absolute changes only.

Age

At rest and in motion, most distances are statistically significantly larger (by up to 9.28 mm) in subjects aged between 60 and 70 years than in younger subjects. This finding might relate to changes occurring in the face with age: the nasolabial folds become more pronounced, the nose gets bigger with a down-turned nasal tip and the skin becomes thinner and more wrinkled.[31] Age-related changes in the face suggest that faces with wrinkled and surplus skin will show larger excursions of landmarks during facial movements, which is assumed to be due to the long-term effects of gravity.

Statistically significant differences between the age groups can be clearly seen in excursions around the nose and mouth, particularly in the distances between the central nose and the mouth (upper lip and lower lip): whereas subjects aged 60–70 years show, on average, the largest excursions of 12.12%, subjects aged 40–50 years show average excursions of 8.23% and subjects aged 20–30 years show average excursions of 7.31%.

Asymmetry

Differences between the right and left sides of the face are observed in all facial motions. Gender and age have no statistically significant impact on the asymmetry of facial dimensions. A slight left dominance is seen in facial movements in both sexes and all age groups. Slight left dominance in resting position is also observed in both sexes and in the first age group (20–30 years); however a right dominance in resting position increases with increasing age (40–50 and 60–70 years). Often facial asymmetry cannot be seen with the human eye, but marginal differences between the right and left sides of the face of up to 4.77 mm at rest and up to 2.68 mm during facial motion can be measured.

One of the explanations for facial asymmetry was suggested by Peck et al.[32] They found that the strongest asymmetry in well-balanced faces is in the distance between the tragus and a point at the angulus maxillae. They suggested that, since these two landmarks are related anatomically through dental occlusion, tooth position might have a significant impact on the asymmetry of the face. Melnik suggested that craniofacial asymmetry might be due to relative growth imbalances between the right and left sides.[33] Asymmetry seems to be the rule rather than the exception[34] and an intrinsic characteristic of the human face.[35]

Our finding that asymmetry at rest may be up to 15.67% does not match the findings of Lu, who claimed that only facial asymmetry greater than 3% is clinically discernable.[35] The discrepancy between this and Lu's study might be due to different systems of measuring the facial dimensions. 2D errors may have been important in Lu's study, where radiographs of heads were used to measure facial dimensions.

Right facial dominance was reported in asymmetry analyses by Shah and Joshi[36] and Ferrario et al.[15] Woo suggested that right craniofacial dominance may be naturally favoured for neuroanatomical development reasons.[37] However, other studies have found a tendency toward left-side dominance, which was interpreted to imply a genetic predisposition.[34,38,39]

Asymmetry in facial motion, of up to 2.68 mm, was a common finding in this study. However, statistically significant dynamic asymmetry was not observed.

Dynamic asymmetry was also found by Scriba et al., who reported an asymmetry of 7–9% in motion, which they considered to be physiological; like us, they found no side dominance.[40] Asymmetry in movements was also observed by Ferrario et al. and was particularly evident in the middle and lower parts of the face.[15]

However, owing to differences in methods, measurements and sample characteristics (age, sex, race), it is difficult to compare these studies. It may be that some of the differences are methodological in nature.

Conclusion

In this study asymmetry was found in healthy subjects, which shows that normal faces have natural asymmetry.

The evaluation of facial movements in 24 healthy volunteers showed that males have greater facial motion than females. Moreover, this study demonstrated that age has an impact on facial dimensions, since the subjects aged between 60 and 70 years had statistically significantly larger distances between landmarks than the other age groups.

Ethnicities seem to have a significant impact on static and dynamic facial dimensions. Subsequent studies will find healthy standard values for other ethnic populations using this 3D video-analysis system.

Furthermore, the application of this objective 3D video-analysis system to provide a standardised outcome measure of surgical success is the focus of present and future research.

Acknowledgements

This study was conducted at the Division of Plastic and Reconstructive Surgery, Department of Surgery, General Hospital Vienna, Medical School, University of Vienna, Austria, in collaboration with the Laboratory for Biomechanics of the Swiss Federal Institute of Technology, Zurich, Switzerland. The study was supported by grant #GZ308.974, entitled '3-Dimensional analysis of movements in reconstructive facial surgery', from the Austrian Federal Ministry of Science and Transport, Vienna, Austria. This project was designed to establish an international reference centre for neuromuscular reconstructions in the face and to build up an international development project and a prospective multicentre study. The study was supported in part by Grant #90296554 (doctoral dissertation grant for Chieh-Han John Tzou, Förderungsstipendium an der Medizinischen Fakultät der Universität Wien 1999) from the Dean of the Medical School, University of Vienna.

References

1. Takasaki H. Moire topography. *Appl Optics* 1970;**9**:1467–72.
2. Burke PH, Banks P, Beard LF, et al. Stereophotographic

measurement of change in facial soft tissue morphology following surgery. *Br J Oral Surg* 1983;**21**:237–45.

3. Deacon AT, Anthony AG, Bhatia SN, et al. Evaluation of a CCD-based facial measurement system. *Med Inform (Lond)* 1991;**16**:213–28.
4. Neely JG, Cheung JY, Wood M, et al. Computerized quantitative dynamic analysis of facial motion in the paralyzed and synkinetic face. *Am J Otol* 1992;**13**:97–107.
5. Sato K, Inokuchi I. A range-imaging system utilizing a nematic liquid crystal mask. *IEEE 1st ICCV*. London: IEEE; 1987. p. 657.
6. Paletz JL, Manktelow RT, Chaban R. The shape of a normal smile: implications for facial paralysis reconstruction. *Plast Reconstr Surg* 1994;**93**:784–9.
7. Bush K, Antonyshyn O. Three-dimensional facial anthropometry using a laser surface scanner: validation of the technique. *Plast Reconstr Surg* 1996;**98**:226–35.
8. Kohn LA, Cheverud JM, Bhatia G, et al. Anthropometric optical surface imaging system repeatability, precision, and validation. *Ann Plast Surg* 1995;**34**:362–71.
9. Ras F, Habets LL, van Ginkel FC, et al. Quantification of facial morphology using stereophotogrammetry–demonstration of a new concept. *J Dent* 1996;**24**:369–74.
10. Bajaj-Luthra A, Mueller T, Johnson PC. Quantitative analysis of facial motion components: anatomic and nonanatomic motion in normal persons and in patients with complete facial paralysis. *Plast Reconstr Surg* 1997;**99**:1894–902.
11. Bajaj-Luthra A, Van Swearingen J, Thornton RH, et al. Quantitation of patterns of facial movement in patients with ocular to oral synkinesis. *Plast Reconstr Surg* 1998;**101**: 1473–80.
12. Meier-Gallati V, Scriba H, Fisch U. Objective scaling of facial nerve function based on area analysis (OSCAR). *Otolaryngol Head Neck Surg* 1998;**118**:545–50.
13. Caruso AJ, Stanhope SJ, McGuire DA. A new technique for acquiring three-dimensional orofacial nonspeech movements. *Dysphagia* 1989;**4**:127–32.
14. Vannier MW, Pilgram TK, Bhatia G, et al. Quantitative three-dimensional assessment of face-lift with an optical facial surface scanner. *Ann Plast Surg* 1993;**30**:204–11.
15. Ferrario VF, Sforza C, Poggio CE, et al. Distance from symmetry: a three-dimensional evaluation of facial asymmetry. *J Oral Maxillofac Surg* 1994;**52**:1126–32.
16. Trotman CA, Gross MM, Moffatt K. Reliability of a three-dimensional method for measuring facial animation: a case report. *Angle Orthod* 1996;**66**:195–8.
17. Trotman CA, Faraway JJ, Silvester KT, et al. Sensitivity of a method for the analysis of facial mobility. I. Vector of displacement. *Cleft Palate Craniofac J* 1998;**35**:132–41.
18. Frey M, Jenny A, Giovanoli P, et al. Development of a new documentation system for facial movements as a basis for the international registry for neuromuscular reconstruction in the face. *Plast Reconstr Surg* 1994;**93**:1334–49.
19. Frey M, Giovanoli P, Gerber H, et al. Three-dimensional video analysis of facial movements: a new method to assess the quantity and quality of the smile. *Plast Reconstr Surg* 1999;**104**:2032–9.
20. Goetz PW. Face. *Encyclopaedia Britannica*, 15th. Chicago: Encyclopaedia Britannica; 1991. p. 651.
21. Farkas LG. *Anthropometry of the head and face*. New York: Raven Press; 1994.
22. Farkas LG. Accuracy of anthropometric measurements: past, present, and future. *Cleft Palate Craniofac J* 1996;**33**: 10–18.
23. Farkas LG, Ngim RC, Lee ST. The fourth dimension of the face: a preliminary report of growth potential in the face of the Chinese population of Singapore. *Ann Acad Med Singapore* 1988;**17**:319–27.
24. Johnson PJ, Bajaj-Luthra A, Llull R, et al. Quantitative facial motion analysis after functional free muscle reanimation procedures. *Plast Reconstr Surg* 1997;**100**:1710–9.
25. Gross MM, Trotman CA, Moffatt KS. A comparison of three-dimensional and two-dimensional analyses of facial motion. *Angle Orthod* 1996;**66**:189–94.
26. Burres SA. Facial biomechanics: the standards of normal. *Laryngoscope* 1985;**95**:708–14.
27. Farkas LG, Bryson W, Klotz J. Is photogrammetry of the face reliable? *Plast Reconstr Surg* 1980;**66**:346–55.
28. Vannier MW, Pilgram TK, Bhatia G, et al. Facial surface scanner. *IEEE Comput Graph Appl* 1991;72–80.
29. Yamada T, Sugahara T, Mori Y, et al. Rapid three-dimensional measuring system for facial surface structure. *Plast Reconstr Surg* 1998;**102**:2108–13.
30. McNeill D. *The Face*. London: Hamish Hamilton Ltd; 1998.
31. Medina JJ. *The clock of ages: Why we age–how we age–winding back the clock*. New York: Cambridge University Press; 1996.
32. Peck S, Peck L, Kataja M. Skeletal asymmetry in esthetically pleasing faces. *Angle Orthod* 1991;**61**:43–8.
33. Melnik AK. A cephalometric study of mandibular asymmetry in a longitudinally followed sample of growing children. *Am J Orthod Dentofac Orthop* 1992;**101**:355–66.
34. Williamson EH, Simmons MD. Mandibular asymmetry and its relation to pain dysfunction. *Am J Orthod* 1979;**76**:612–7.
35. Lu KH. Harmonic analysis of the human face. *Biometrics* 1965;**21**:491–505.
36. Shah SM, Joshi MR. An assessment of asymmetry in the normal craniofacial complex. *Angle Orthod* 1978;**48**:141–8.
37. Woo TL. On the asymmetry of the human skull. *Biometrika* 1931;**22**:324–52.
38. Vig PS, Hewitt AB. Asymmetry of the human facial skeleton. *Angle Orthod* 1975;**45**:125–9.
39. Chebib FS, Chamma AM. Indices of craniofacial asymmetry. *Angle Orthod* 1981;**51**:214–6.
40. Scriba H, Stoeckli SJ, Veraguth D, et al. Objective evaluation of normal facial function. *Ann Otol Rhinol Laryngol* 1999; **108**:641–4.