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Exploring quantitative methods for evaluation of lip function

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SUMMARY The objective was to explore quantitative methods for the measurement of lip mobility and lip force and to relate these to qualitative assessments of lip function. Fifty healthy adults (mean age 45 years) and 23 adults with diagnoses affecting the facial muscles (mean age 37 years) participated in the study. Diagnoses were Möbius syndrome (n = 5), Facioscapulohumeral muscular dystrophy (n = 6) and Myotonic dystrophy type 1 (n = 12). A system for computerised 3D analysis of lip mobility and a lip force meter were tested, and the results were related to results from qualitative assessments of lip mobility, speech (articulation), eating ability and saliva control. Facial expressions studied were open mouth smile and lip pucker. Normative data and cut-off values for adults on lip mobility and lip force were proposed, and the diagnostic value of these thresholds was tested. The proposed cut-off values could identify all inviduals with moderate or

severe impairment of lip mobility but not always the milder cases. There were significant correlations between the results from quantitative measurements and qualitative assessments. The examined instruments for measuring lip function were found to be reliable with an acceptable measuring error. The combination of quantitative and qualitative ways to evaluate lip function made it possible to show the strong relation between lip contraction, lip force, eating ability and saliva control. The same combination of assessments can be used in the future to study if oral motor exercises aimed at improving lip mobility and strength could have a positive effect on lip function.

KEYWORDS: lip mobility, lip force, motion analysis, drooling, speech, eating

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Introduction

Impaired mobility of the facial muscles of any origin will interfere with facial expression. In addition, if lips are weak or the lip mobility is restricted, this may cause difficulties with feeding/eating, speech and saliva control. Depending on the underlying aetiology and severity of symptoms, interventions such as oral motor exercises, speech therapy or plastic surgery might be considered. Many clinicians and researchers working in the field of mimic muscle evaluation have underlined the need for objective, reliable and sensitive outcome measures as a supplement to subjective assessments (1–6). The Sunnybrook Facial Grading System (SFGS) was the advocated method for subjective assessment of the mimic muscles according to a review paper by Chee and Nedzelski (2000). They compared different facial nerve grading systems and found that the SFGS has proven to have good sensitivity and reliability. It allows quantification of facial paralysis and is therefore useful in patient counselling and research (7–12). However, like most protocols for mimic muscle evaluation SFGS is not adapted for patients with bilateral involvement.

Facial expression is a dynamic function that is well suited for video documentation and computerised video analysis. During the last two decades, a number of video-computer interactive systems for facial analysis have been presented in the literature (3, 13-22). Ideally, there should be a 3D motion analysis (23, 24) with automated tracking of landmarks on the face. A system that could be used for assessment of all patients, despite age and cognitive function, must have a built-in correction of head movements and allow landmark setting directly on frames on the computer without markers on the face. The results should include information about facial movements such as displacement, direction, symmetry and temporal aspects. For clinical use, the procedure should not be too time-consuming. The reliability of the analysis is fundamental and so is the possibility to reproduce the examination with accurracy (3, 10, 25). Facial expressions that are performed with maximal effort such as an open mouth smile and lip pucker have been found to be the most reproducible (22, 26, 27). All existing systems for objective facial analysis have their short comings. This is still an area that needs further research and technical improvement.

The SmartEye[®] Pro system* is a head and gaze tracking system that can measure the subject's head pose and gaze direction in full 3D. The system can be used with up to six cameras. IR diodes are used to illuminate the face and to minimise the effect of varying lighting conditions. SmartEye[®] Pro – MME is an add-on to SmartEye[®] Pro 3.7* that can track lip movements. The system uses automatic lip tracking and also offers the possibility to manually plot the lip line and measure other distances on the face. In a methodological study, Schimmel *et al.* (28) investigated the system's accuracy in measuring facial distances. The authors found it possible to measure geometrical distances with high precision and facial distances with good accuracy and precision.

Different instruments and techniques have been suggested for the measure of lip force (6, 29–36) but no method has yet become gold standard.

Lip function could be influenced by limitations in lip force and lip mobility but also by structural limitations (4–6). There is no consensus on how much lip force and lip mobility is needed for optimal lip function (29, 37). The aim of the present study was therefore to explore quantitative methods for assessment of lip mobility and lip force and to relate these to qualitative methods describing different aspects of lip function, such as, the use of the lips for facial expression, speech, eating and drinking and saliva control.

*SmartEye AB, Gothenburg, Sweden.

Table 1 Age distribution, diagnoses and number of patients involved in the study

Study group	No (males/ females)	Mean age \pm s.d.	
Healthy controls	50 (21/29)	45 ± 11	
Myotonic dystrophy type 1	12 (5/7)	40 ± 15	
Facioscapulohumeral muscular dystrophy	6 (0/6)	38 ± 14	
Möbius syndrome	5 (2/3)	29 ± 6	

s.d., standard deviation.

Materials and methods

Fifty healthy adults and 23 adults with diagnoses affecting the facial muscles participated in the study (Table 1). The diagnoses were Möbius syndrome, Facioscapulohumeral muscular dystrophy (FSHD) and Myotonic dystrophy type 1 (DM1). Three had the congenital form of DM1 and nine the classic (adult) form. The selection of diagnose groups were based on the fact that they represent different types and different degrees of facial impairment. Facial palsy is a diagnostic criterion for Möbius syndrome (38). The facial palsy is often bilateral and asymmetric. Typical for FSHD muscular dystrophy is that the most affected facial muscles are the sphincter muscles orbicularis oculi and orbicularis oris and that the muscle weakness is asymmetric (39). DM1 is a multisystemic disease with bilateral facial weakness because of myopathy and muscular atrophy (40). The healthy individuals volunteered via personal contacts and the other subgroups via the Neuromuscular Center at Sahlgrenska University Hospital, Gothenburg, or the Swedish Möbius Syndrome Association. Informed consent was obtained from all the participants and the study was approved by the Ethics Committee at the University of Gothenburg.

Quantitative methods

3D analysis of lip mobility. The mobility of the lips was measured using two calibrated video cameras (Sony XC-HR50) together with the software SmartEye[®] Pro 3.7 - MME.* The cameras and two IR lightings (one beside each camera) were placed on a metal bar fixed on a table. The distance between the cameras was 25 cm, and the participant was seated approximately 80 cm in front of the cameras. The cameras were run at 60 fps with a resolution of 640×480 pixels. Before

video recording, ten photographs were taken (five from each video camera) for the landmark settings. The following poses were captured on the landmark photographs: head turned slightly to the left and to the right, head upright, open mouth smile and lip pucker. Video recordings were performed during rest position (30 s) and while the participant was making a maximal retraction of the lips in an open mouth smile and a maximal contraction of the lips in a lip pucker. The tasks were repeated two times with a short break in between.

Individual landmark profiles were constructed by the same examiner (LS). Landmarks were manually plotted with the mouse on the landmark photographs (Fig. 1). All marked features in the landmark profile were part of a 3D model of the head of the subject. By detecting the positions of some of the features in the head model, the system could calculate the pose of the head using the Levenberg-Marquardt algorithm and thus the positions of all other features of the fixed head model. The head model created by the system allows for a built-in correction for any head movements accompanying the facial movements. The position of the landmarks was then automatically tracked when the video was running in tracking mode and the tracking was visualised on the screen. For this study, the 3D position of the oral commissures was registered in a log file.



Fig. 1. The position of facial landmarks in a system for 3D analysis of lip mobility.

Test results were extracted from the log files (tab separated text files) where each row in the text file contained information about the position of the coordinates in one frame. Data from the frame containing maximal distance between the x-coordinates were chosen for an open mouth smile, minimal distance for a lip pucker and median distance for rest position. To make sure that the selected frames corresponded to the maximal smile and lip pucker and to a true rest position and that the oral commissures were correctly tracked by the system, the video recordings were reviewed in tracking mode.

Rest position and voluntary movements were evaluated by comparing the horizontal, vertical and anterior-posterior position of the oral commissures. The following calculations were included in the 3D analysis of lip mobility: Mouth width (MW) was the distance between the oral commissures (Fig. 2, equation 1). Left and right mouth widths were measured from the oral commissure to the midline (Fig. 2, equation 2), and the relative mouth width asymmetry (A) was calculated (Fig. 2, equation 3). Mouth width change was the difference in distance between rest position and maximal expression. The horizontal, vertical and anteriorposterior oral commissure displacement from rest position to maximal open mouth smile or lip pucker and the resultant (R) of these values were calculated (Fig. 2, equation 4). The resultant value showed the combined 3D oral commissure displacement. Displacement was recorded as the difference between the frames at the maximum of the movement and the rest position.

Lip force measurement. The lip force meter $LF100^{\dagger}$, an electronic dynamometer, was used for the evaluation of lip force (30, 41) (Fig. 3). An oral screen [Ulmer model $(large)^{\dagger}$] was connected to the measuring instrument. A water level helped the examiner to pull in a horizontal direction. The maximum lip force (N) that the participant could exert on the oral screen was shown on a display. It was not possible to distinguish between the force exerted by the upper and the lower lip. The participants were seated in a chair with arm rests and the chair could be moved up and down allowing all participants good support for their feet. They were instructed to keep the oral screen inside the lips while

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Fig. 2. Formulas used for calculation of mouth width (MW), left mouth width (LMW), right mouth width (RMW), mouth width asymmetry (A), and the resultant (R) of the horizontal (Xlp), vertical (Ylp), and anterior-posterior (Zlp) oral commissure (OC) displacement in a lip pucker (lp). The resultant of the open mouth smile was calculated using the same formula.

Equation 1.

$$MW = \sqrt{(x_{LMW} - x_{RMW})^{2} + (y_{LMW} - y_{RMW})^{2} + (z_{LMW} - z_{RMW})^{2}}$$
Equation 2.

$$\begin{cases} x_{OC} = 0 \\ y_{OC} = y_{ROC} - \frac{y_{LOC} - y_{ROC}}{x_{LOC} - x_{ROC}} x_{ROC} \\ z_{OC} = z_{ROC} - \frac{z_{LOC} - z_{ROC}}{x_{LOC} - x_{ROC}} x_{ROC} \end{cases}$$

$$MW_{left} = \sqrt{(x_{LOC} - x_{OC})^{2} + (y_{LOC} - y_{OC})^{2} + (z_{LOC} - z_{OC})^{2}}$$

$$MW_{right} = \sqrt{(x_{ROC} - x_{OC})^{2} + (y_{ROC} - y_{OC})^{2} + (z_{ROC} - z_{OC})^{2}}$$
Equation 3.

$$A = \left| \frac{MW_{right} - MW_{left}}{MW_{right} + MW_{left}} \right| * 100$$
Equation 4.

$$R = \sqrt{(x_{Ip} - x_{rest})^{2} + (y_{Ip} - y_{rest})^{2} + (z_{Ip} - z_{rest})^{2}}$$



Fig. 3. The lip force meter LF100. An oral screen (Ulmer) is connected to the handle.

the examiner pulled the handle with an increasing force until the oral screen was dropped. The time for reaching the maximal force was limited to 10 s. The best of three values obtained was saved. The lip force measurements were made by the same dental nurse. LF100 was calibrated before use.

Qualitative assessments

Qualitative assessment of facial expression. The degree of muscle excursion during the performance of an open mouth smile and a lip pucker was evaluated on a 5-point scale according to Sunnybrook Facial Grading System (SFGS) (9). The following definitions were used: Unable to initiate movement (i); Initiates slight movement (ii); Initiates movement with mid excursion (iii); Movement almost complete (iv); Movement complete (v). It was

also evaluated whether there was an asymmetry of the face at rest or not.

Speech assessment. A complete articulation test was performed using SVANTE – Swedish Articulation and Nasality Test (42) but only three sentences were included and analysed in the present study. Each sentence contained four representations of the same bilabial speech sound (/m/,/b/or/p/) in different word positions. Test sentences were repeated. The articulation test was audio recorded (TascamHD-P2). The microphone (Sony ECM-MS957 stereo microphone) was placed approximately 50 cm in front of the mouth. The pronunciation of bilabial consonants were transcribed and evaluated as deviant or not.

Questionnaire. The participants answered on a 4-point scale if they had any difficulties with eating and drinking. The choices were as follows: not at all, not really, somewhat and very much. They were also asked to specify any difficulties with eating and drinking by answering yes/no questions. Individuals who had a drooling problem were asked to indicate if the drooling was mild, moderate or severe.

Statistical analysis

Data were analysed with spss for Windows, ver. 15.0^{S} . The difference between men and women and between individuals with and individuals without drooling or eating difficulties was tested with Student's *t*-test. Pearson's correlation coefficients were used for continuous data such as lip mobility (mm) and lip force (N). Comparisons between the group of healthy controls and the diagnose groups included in the study were made with two-way ANOVA, corrected for possible gender effects and completed with Student–Newman-Keuls multiple comparison tests. The reliability of the quantitative analysis of lip mobility was determined by individual and measurement variability using the Dahlberg formula (43, 44) and the intra-class correlation coefficient (ICC).

The borders for impaired lip function and the clinical relevance of the obtained data were explored by comparing the results from the quantitative measurements of lip mobility and lip force with the results from the qualitative assessment of lip mobility (SFGS) by sorting these data in an MS Excel spreadsheet. The goal was to find a cut-off value for lip mobility and lip force that could discriminate between individuals with impairment and those without. In case there was no clear threshold between groups, the ambition was to propose a cut-off that could catch as many with lip impairment as possible (sensitivity) without including too many without impairment (specificity).

Results

3D analysis of lip mobility

The 3D analysis of lip mobility in 50 healthy adults (Table 2) showed that there was a significant difference in mouth width between men and women. As a group, the women had a higher value on relative mouth width change than the men but there was a wide variability concerning mouth width change in a lip pucker in both sexes. Most healthy individuals had a fairly symmetric mouth width at rest and when performing an open mouth smile but the lip pucker was in general less symmetric. The mean horizontal, vertical and anterior-posterior displacement of the left and right oral commissure was approximately the same in all dimensions in an open mouth smile. In a lip pucker, there was a strong anterior displacement and only a minor vertical movement. The horizontal displacement was somewhat

Table 2. The mean and standard deviation $(\pm SD)$ of mouth width, mouth width asymmetry and mouth width change in 50 healthy adults

	Healthy adults				
	Males	Females	Gender difference		
	<i>n</i> = 21	<i>n</i> = 29	<i>t</i> -value	Р	
Mouth width, mm					
Rest	50.8 ± 3.7	47.5 ± 3.5	-3.219	0.002	
Open mouth smile	66.9 ± 5.3	64.0 ± 4.3	-2.182	0.034	
Lip pucker	31.7 ± 4.2	26.8 ± 3.8	-4.316	0.001	
Mouth width asymme	etry, %				
Rest	4.7 ± 2.5	4.8 ± 3.7	0.110	0.913	
Open mouth smile	3.8 ± 2.6	3.1 ± 2.0	-1.083	0.284	
Lip pucker	8.0 ± 5.0	11.7 ± 10.0	1.727	0.091	
Mouth width change,	mm				
Open mouth smile	16.1 ± 4.3	16.5 ± 4.0	0.294	0.770	
Lip pucker	$-19{\cdot}1\pm5{\cdot}0$	-20.7 ± 4.6	-1.175	0.246	
Relative mouth width	change, %				
Open mouth smile	34.8 ± 9.9	34.8 ± 9.9	1.157	0.253	
Lip pucker	$-37{\cdot}4\pm 8{\cdot}7$	$-43{\cdot}4\pm8{\cdot}2$	-2.507	0.016	

larger in a lip pucker than in an open mouth smile (Table 3). The resultant 3D oral commissure displacement had a higher mean value in the lip pucker than in the open mouth smile. The vertical oral commissure displacement in a lip pucker was significantly more upward in men (left side: t = 3.042, P = 0.004, right

Table 3. The mean \pm standard deviation (s.d.) and confidence interval (CI) of the horizontal (x), vertical (y), anterior-posterior (z), and resultant (R) displacement of the oral commissures from rest position to an open mouth smile and a lip pucker in 50 healthy adults

:	Х	У	Z	R
Open mou	th smile			
Mean \pm	s.d.			
Right	$-8{\cdot}0\pm2{\cdot}7$	7.0 ± 3.4	-9.2 ± 5.4	$14{\cdot}9\pm4{\cdot}9$
Left	8.5 ± 2.1	$7\cdot2$ \pm $3\cdot0$	-8.8 ± 5.4	$15{\cdot}1\pm4{\cdot}0$
CI				
Right	-8.7 to -7.2	6.0 to 8.0	-10.8 to -7.7	13.5 to 16.3
Left	7·9 to 9·1	6·3 to 8·1	-10.3 to -7.2	14.0 to 16.2
Lip pucker				
Mean \pm	s.d.			
Right	10.1 ± 2.5	-1.9 ± 4.0	$21{\cdot}4\pm4{\cdot}9$	$24{\cdot}3\pm4{\cdot}7$
Left	-10.7 ± 2.9	-1.7 ± 4.5	$20{\cdot}5\pm6{\cdot}4$	$24{\cdot}9\pm5{\cdot}5$
CI				
Right	10.8 to 9.4	-3.1 to -0.8	20·1 to 22·8	22.9 to 25.6
Left	-9.8 to -11.5	-3.0 to -0.4	18·7 to 22·4	22.5 to 25.6

side: t = 3.456, P = 0.001) with a mean difference of 3.6 mm on both sides.

Mouth width and mouth width change in an open mouth smile differed significantly from the healthy adults in all diagnose groups except for FSHD, and there was a significant difference between the controls and the diagnose groups concerning mouth width change in a lip pucker (Table 4). The Möbius and FSHD groups had a broader mouth in a lip pucker in relation to the control group. The only significant difference in mouth width asymmetry was between the Möbius group and the controls.

Lip force

There was no significant difference between sexes concerning lip force among the healthy adults (P = 0.879) in this study group. They had a mean (\pm s.d.) lip force of 29 ± 9 N. In Möbius syndrome, the mean (\pm s.d.) lip force was 9 ± 10.7 N, in FSHD 13 ± 8.8 N and in DM1 12 ± 5.5 N. The difference in lip force between subgroups was statistically significant (P = 0.001). Post hoc tests showed (after adjustment for multiple testing) that there was a significant difference (P < 0.05) between the healthy controls and a homogeneous subset of the diagnose groups.

Table 4. The mean and standard deviation (\pm s.d.) of mouth width, mouth width asymmetry and mouth width change in healthy adults, and adults with Möbius syndrome, Facioscapulohumeral muscular dystrophy (FSHD) and Myotonic dystrophy type 1 (DM1) and the statistical difference between groups (two-way ANOVA analysis)

Dependent variables	Independent variables							
	Healty adults	Möbius syndrome	ESHD	DMI	Group difference			
	n = 21	n = 5	n = 6	n = 12	f	Р		
Mouth width, mm								
Rest	48.9 ± 3.9	45.7 ± 9.3	47.7 ± 3.2	$44{\cdot}0\pm4{\cdot}6$	5.095	0.003		
Open mouth smile	$65\cdot2\pm4\cdot9$	$52.9\pm8.6*$	60.9 ± 6.0	$54.9 \pm 7.5*$	15.824	0.001		
Lip pucker	$28{\cdot}8 \pm 4{\cdot}6$	$38.5 \pm 8.4*$	$38.8 \pm 6.1*$	$32\cdot2\pm3\cdot7$	17.649	0.001		
Mouth width asymmetry	7, %							
Rest	4.7 ± 3.2	8.3 ± 6.3	5.0 ± 2.8	9.6 ± 7.0	3.968	0.011		
Open mouth smile	3.4 ± 2.3	$14.3 \pm 10.8*$	$3\cdot2\pm3\cdot1$	5.1 ± 6.2	3.395	0.023		
Lip pucker	10.1 ± 8.4	8.1 ± 9.8	6.1 ± 4.6	8.3 ± 7.7	1.287	0.286		
Mouth width change, m	m							
Open mouth smile	16.3 ± 4.1	$7.3 \pm 5.3*$	$13\cdot2\pm3\cdot1$	$10.9 \pm 5.3*$	10.528	0.001		
Lip pucker	$-20{\cdot}0\pm4{\cdot}8$	$-7.1 \pm 10.6*$	$-8.9 \pm 6.5*$	$-11.8 \pm 5.7*$	17.767	0.001		
Relative mouth width ch	nange, %							
Open mouth smile	33.8 ± 9.5	$17.1 \pm 14.3*$	27.6 ± 5.7	$24{\cdot}8\pm12{\cdot}2$	6.580	0.001		
Lip pucker	-40.9 ± 8.8	$-14.2 \pm 20.9*$	$-18.4 \pm 12.9*$	$-26.1 \pm 11.8*$	19.988	0.001		

*Significant difference (P < 0.05) in relation to the group of healthy adults after adjustment for multiple testing (Student–Newman-Keuls multiple comparison test).

Qualitative assessments

One of the healthy adults reported mild eating problems; otherwise, there were no self-reported or observed impairments in this group (Table 5). The most frequent dysfunction among the diagnose groups was impaired lip pucker (n = 18), followed by eating and drinking difficulty (n = 15), impaired open mouth smile (n = 13) and drooling (n = 8). When asked whether they had any eating and drinking difficulties, nine answered "not really" and six "somewhat". Specified difficulties were the following: It takes more than 30 min to finish a main dish (n = 7); Food and liquids leak out of corners of mouth (n = 5); Swallows large pieces of food without chewing (n = 3); Has difficulty in getting food off spoon with lips (n = 3), Food is left in the mouth after the meal is finished (n = 3); Coughs during meals (n = 1). Six reported mild drooling and two moderate drooling. Two individuals had deviant pronunciation of bilabial consonants, one with Möbius syndrome and one with the congenital form of Myotonic dystrophy. The qualitative assessment identified five individuals with an asymmetric mouth at rest and six individuals with asymmetric lip mobility. Three had a maximal side difference of one SFGS-score, two of two SFGS-scores and one of three SFGS-scores.

Cut-off values

Cut-off values that would identify adults with impaired lip function were proposed for the quantitative mea-

surements (Tables 6 and 7). The diagnostic value of these thresholds was evaluated for two subgroups. First, the results from individuals with impaired facial expression according to the SFGS assessment were related to the results from individuals without facial impairment (Table 6). In this subgroup, the specificity for the proposed thresholds was high but the sensitivity was not so good, except for lip force. Secondly, the results from individuals with moderate or severe facial impairment (SFGS-score <4 on any side) were related the results from individuals with mild (SFGS-score 4/4 or 4/5) or no facial impairment (SFGS-score 5/5) (Table 7). When the milder cases were excluded from the group with impairments, the sensitivity increased and the specificity was still good.

Correlations

There was a significant correlation between mouth width change and the corresponding SFGS scores for all groups (open mouth smile: r = 0.618, P = 0.0001; lip pucker: r = 0.786, P = 0.0001). Lip force correlated significantly with mouth width change in a lip pucker (r = 0.591, P = 0.0001) (Fig. 4). The group of individuals who reported drooling and those who reported eating difficulties had significant reduction in lip mobility and lip force in relation to the rest of the group (Table 8).

Two individuals had deviant production of bilabials. They reported eating difficulties and drooling and had results below cut-off on the lip force measurements

	Healthy	Möbius	FSHD	DM1	Total
Impairment	<i>n</i> = 50	<i>n</i> = 5	<i>n</i> = 6	<i>n</i> = 12	<i>n</i> = 73
Self-reported					
Eating and drinking difficulty	1	3	4	8	16
Drooling	0	2	3	3	8
Evaluated					
Deviant pronunciation of bilabials	0	1	0	1	2
Impaired open mouth smile (SFGS-score<5)	0	5	1	7	13
Impaired lip pucker (SFGS-score<5)	0	4	5	9	18
Asymmetry of the lips at rest	0	5	0	0	5
Measured					
Weak lips, lip force <12 N	0	4	4	7	15
Mouth width change <9 mm, smile	1	3	1	5	10
Mouth width change <11 mm, lip pucker	1	3	4	5	13
OC Resultant <8 mm, smile	3	3	2	5	13
OC Resultant <12 mm, lip pucker	0	3	3	6	12

Table 5. The distribution of selfreported (questionnaire), evaluated (SFGS, SVANTE) and measured (3D analysis of lip mobility and lip force) oro-facial dysfunctions in a study group of 50 healthy adults and 23 individuals with diagnoses affecting the facial muscles to varying degrees

FSHD, Facioscapulohumeral muscular dystrophy; DM1, Myotonic dystrophy type 1; N, Newton; OC Resultant, the resultant of the 3D displacement of the oral commissures.

Table 6. The sensitivity and specificity of proposed cut-off values in a study group of 50 healthy adults and 23 adults with diagnoses affecting the facial muscles. The relation between individuals who were evaluated to have lip impairment corresponding to an SFGS-score <5 on an open mouth smile (n = 13) or a lip pucker (n = 18) and individuals with no lip impairment was tested. Lip force was correlated with lip pucker

	SFGS-score <5		Consitivity	C
Cut-off value	Yes	No	%	%
Open mouth smile				
Mouth width change <9 mm	8	2	62	
Mouth width change ≥9 mm	5	58		97
OC Resultant <8 mm	8	5	62	
OC Resultant ≥8 mm	5	55		92
Lip pucker				
Mouth width change < 11 mm	11	2	61	
Mouth width change ≥11 mm	7	53		92
OC Resultant <12 mm	12	6	67	
OC Resultant ≥12 mm	6	49		89
Lip force				
Lip force <12 N	13	2	87	
Lip force ≥12 N	5	53		91

SFGS, Sunnybrook Facial Grading System; OC Resultant, the resultant of the 3D displacement of the oral commissures; N, Newton.

	SFGS-score <4		0	0	
Cut-off value	Yes No		%	Specificity %	
Open mouth smile					
Mouth width change <9 mm	5	1	83		
Mouth width change ≥9 mm	5	62		93	
OC Resultant <8 mm	5	1	83		
OC Resultant ≥8 mm	8	59		88	
Lip pucker					
Mouth width change <11 mm	9	2	82		
Mouth width change ≥11 mm	4	58		94	
OC Resultant <12 mm	8	3	73		
OC Resultant ≥12 mm	4	58		94	
Lip force					
Lip force <12 N	12	3	92		
Lip force ≥2 N	1	57		98	

SFGS, Sunnybrook Facial Grading System; OC Resultant, the resultant of the 3D displacement of the oral commissures; N, Newton.

(mean = 2.5 N), and the 3D analysis of mouth width change in an open mouth smile (mean = 4.8 mm) and in a lip pucker (mean = -1.0 mm).

Measuring mouth width asymmetry could not differentiate between individuals with mild facial asymmetry and those who were evaluated to have symmetric function.

Evaluation of error of methods

Video recordings from 22 individuals (30%) were randomly chosen for testing the accuracy of the analyses generated by the 3D analysis of lip mobility. The first examiner remade the landmark profiles for the testing of intra-individual reliability. Another examiner made new landmark profiles on the same video recordings to investigate inter-individual reliability. The two examiners were calibrated in the following way. First, they made one landmark profile together, agreed on landmark positions and made log files according to a manual. Secondly, they made another landmark profile separately and afterwards penetrated the cause for differences that remained. Intra-individual variation of the performance of facial expressions in the randomly chosen group was controlled for by comparing two different video recordings from the

Table 7. The sensitivity and specificity of proposed cut-off values in a study group of 50 healthy adults and 23 adults with diagnoses affecting the facial muscles. The relation between individuals who were evaluated to have moderate or severe lip impairment corresponding to an SFGS-score <4 on an open mouth smile (n = 6) or a lip pucker (n = 11) and individuals with no or mild lip impairment was tested. Lip force was correlated with lip pucker



Fig. 4. The correlation between lip force and decreased mouth width when performing a lip pucker in 73 adults; 50 healthy controls, five with Möbius syndrome, six with Facioscapulohumeral muscular dystrophy (FSHD) and 12 with Myotonic dystrophy type 1 (DM1). The horizontal line at 12 N suggests a threshold value for lip weakness in adults. The vertical line suggests a threshold value for a decrease in mouth width in a lip pucker.

same individual using the same landmark profile. The testing of intra-individual reliability resulted in a standard deviation of 1·2 mm for mouth width at rest (*ICC* = 0·997), 1·3 mm for mouth width in an open mouth smile (*ICC* = 0·994) and 1·8 mm for mouth width in a lip pucker (*ICC* = 0·997). Standard deviations for inter-individual reliability were 1·3 mm for mouth width at rest (*ICC* = 0·997), 1·8 mm for mouth width in an open mouth smile (*ICC* = 0·997), 1·8 mm for mouth width in an open mouth smile (*ICC* = 0·997) and 2 mm in a lip pucker (*ICC* = 0·997). The intra-individual variation test showed a standard deviation of 1·1 mm for mouth width in an open mouth smile (*ICC* = 0·994) and 1·4 mm for mouth width in a lip pucker (*ICC* = 0·997).

Lip force measurements. To control for intra-individual variability, maximal lip force was tested on 12 healthy adults on two occasions with at least 24 h between

Table 8. Comparisons between quantitative and qualitative results in a study group of 50 healthy adults and 23 adults with diagnoses affecting the facial muscles. The differences between individuals with eating and drinking difficulties (n = 16) or drooling (n = 8) and the rest of the group are presented

	Impairment mean \pm SD		Group differen	ce
	Yes	No	t	Р
Eating/drinking				
Lip force, N	11.9 ± 9.8	$24{\cdot}9\pm10{\cdot}1$	5.266	0.001
Mouth width ch	ange, mm			
Open mouth smile	12.7 ± 4.2	$15\cdot1\pm5\cdot3$	1.662	0.101
Lip pucker	-10.0 ± 7.7	-18.8 ± 5.9	-4.941	0.001
Drooling				
Lip force, N	8.0 ± 6.4	$25{\cdot}5\pm10{\cdot}8$	4.452	0.001
Mouth width ch	ange, mm			
Open mouth smile	8.7 ± 5.3	15.3 ± 4.7	3.778	0.001
Lip pucker	-7.7 ± 6.8	-18 ± 6.6	-4·210	0.001

N, Newton.

measurements. The mean standard deviation between the first and the second measurement was 3.2 N.

Qualitative assessment of lip mobility. A qualitative evaluation of the lip muscles from video recordings was independently performed by two speech-language pathologists according to SFGS allowing calculation of inter-rater reliability presented as percentage agreement compared point-by-point. In case of disagreement, they watched the video recording together and made a consensus decision used as the result. The inter-rater reliability test of the subjective evaluation of rest position and the performance of open mouth smile and lip pucker showed an exact percentage agreement of 82%. Disagreement was never more than one SFGS-score. The final results are based on consensus agreement.

Speech evaluation. The blinded speech evaluation was independently performed by two speech-language pathologists, the first author (LS) and one external not involved in and without any knowledge about the project. When disagreement arose, the second author (AL) made the final decision. They listened to an audio file containing test sentences from the study populations in a random order and made a narrow transcription using the international phonetic alphabet with extensions for disordered speech (45, 46) of bilabial

sounds only. Fifty-six randomly chosen sentences (25%) were presented twice on the listener file, to control for intra-transcriber reliability. Exact inter-transcribers' percentage agreement compared point-by-point on single phonemes was 97% and intra-transcribers' percentage agreement was 95% and 100%. The main difficulty was to decide whether the articulation of a bilabial speech sound was weak or not. Weak articulation was not included in the final results.

Discussion

In this study, normative data on quantitative measures on lip mobility and lip force were collected and related to results from qualitative assessments of individuals with impaired facial expression to explore the border between complete and incomplete voluntary lip movements. The analyses resulted in proposed cut-off values. With these thresholds it was possible to identify all cases with moderate and severe impairement of facial expression but not all the milder cases who (by definition) had almost complete facial movements. Thresholds that would incorporate the milder deviations would also increase the number of false positives. Mild deviations in lip mobility were not expected to cause any subjective symptoms for the individual or change the course of intervention and were therefore not considered to be as important to identify as the more clinically relevant deviations. The statistic analyses showed a significant correlation between the 3D analysis of lip mobility and the corresponding SFGSscores for open mouth smile and lip pucker. This was a first attempt to propose cut-off values for impaired lip mobility and lip force in adults. However, the diagnostic value of these thresholds needs to be challenged in further studies and in different study populations.

Mean results from the 3D analysis of lip mobility from the different diagnose groups included were presented together with the mean results from the healthy adults. The intention was not to give a description of the diagnoses but to describe the groups involved in the study and the variety of lip impairment that they represented.

Whether the typical face is symmetric or not has been studied with different methods and the findings are often contradictory (47). In the present study, some degree of mouth width asymmetry was a frequent finding in both healthy individuals and individuals with a diagnosis affecting the facial muscles. Asymmetry was

most pronounced when performing a lip pucker. One explanation for this could be a deviation not only caused by the lips but also by the lower jaw. The qualitative evaluation could detect asymmetries in lip shape but not mouth width asymmetry, and the quantitative measurements could identify mouth width asymmetry but not an asymmetric lip shape. This illustrates and confirms earlier findings (48) that quantitative measurements cannot completely replace qualitative evaluations but can be a complement for a more reliable and quantifiable evaluation of treatment and for research. The study results also showed some differences between men and women when making a smile and a lip pucker. To study gender and age differences were not within the scope of this study but would be interesting subjects for further research.

The 3D analysis revealed the pronounced anterior movement of the oral commissures in a lip pucker. The oral commissures are protruded not only by lip activity but also by an anterior movement of the lower jaw. Coulson et al. (2) also used the coordinates in a 3D system to study the displacement of facial markers in healthy adults. The mean resultant oral commissure displacement in a maximal smile/open mouth smile was about the same in both studies. Like us, they found a predominant movement in the anterior-posterior axis in a pout/lip pucker but it was not as predominant as in the present study. The error of methods has to be taken into account in both studies, and the choice of vocabulary might have had an influence on how the expression was performed (49, 50). It should also be noted that in the present study the position of the oral commissures on a single frame during rest was related to a frame at the point of maximum movement but the movement characteristics between these points were not presented.

A cut-off value for lip force in adults was suggested. It is important, though, to underline that this value is dependent on the equipment used. An oral screen made in another size or in another material would result in another cut-off value. Using other instruments, lip force could be measured as the force exerted on the teeth (34), the pressure between the lips (29) or between the oral commissures (36) and the upper and lower lips can be measured separately (6). In a survey of children and adolescents with DM1 (41) and a matched control group, the same equipment was used as in the present study with the exception that the preschool children had a smaller oral screen. The lip force (mean \pm s.d.) in the patient group was 7 ± 3.5 N and in the matched control group 21 ± 7.8 N. Hägg *et al.* (51) studied lip force in patients after stroke and a control group using the same lip force meter but a different type of oral screen. The patients had a lip force of 9.5 ± 5.5 N and the healthy controls 24.4 ± 6.2 N. Differences in results between these studies could partly be explained by age differences. Studying lip force in different age groups is a subject for further research.

It could be expected to find an interrelationship between maximal contraction of the lips in a lip pucker and lip force as both these activities activates the orbicularis oris muscle. This assumption was confirmed as there was a strong correlation between lip force and lip contraction and both sensitivity and specificity was high when comparing lip force and the qualitative assesment of lip pucker. Impaired lip pucker and weak lips were found in all or nearly all individuals with deviant production of bilabials, drooling or eating difficulties. To be able to smile is important for communication and social interaction but impaired lip retraction does not seem to interfere with eating. Two individuals with impaired speech had profound difficulties in all areas tested. Another individual who also had severely impaired lip force and lip function could despite this pronounce bilabial consonants correctly. Many different factors are thought to have an impact on the capability to compensate for impaired oral motor function such as structural prerequisits, cognitive function and access to speech therapy.

Intra-individual variability tests confirmed earlier findings (27, 52) that the same individual repeats an open mouth smile and a lip pucker with only small variations. It is a limitation, though, that the facial expressions were only performed twice and with only a few minutes between repetitions. Inter-reliability and intra-reliability testing of the 3D analysis of lip mobility showed that the measurement error was within acceptable limits. Schimmel et al. (28) did not use the automated tracking of facial landmarks in their evaluation of the system. They considered that the function was not reliable enough. In the present study, it was possible to use automated tracking of the oral commissures. The oral commissures were in general clearly distinguished on the frames and thereby possible for the system to track. In exceptional cases, manual plotting was used to guide the automated tracking to the right position. The individual landmark profile is to a great extent manually constructed, which is thought to be the main reason for the measuring error. Most difficult was to identify the exact position of the oral commissures in a lip pucker. It is of great importance that the profile constructers are experienced and calibrated (44).

The 3D system for analysis of lip mobility that was tested allows for free head movements and no markers have to be attached to the face. These were important prerequisites for chosing this system so that it could also be used with patients with intellectual disability and neuropsychiatric disorders. With the present version, it took about one hour for a trained person to construct an individual landmark profile. It is recognised in the literature that quantitative analyses of facial movements in general are time-consuming (3) and are therefore difficult to implement in clinical settings. Another obstacle for clinical use is the relatively high cost for both hardware and software. However, if valid and reliable methods are used for the evaluation of treatment, this will eventually lead to more effective interventions, better patient care and more efficiently used resources.

The results from this study indicate that the strength of the muscles activated in the lip force measurement is important for optimal lip function. Hägg *et al.* (51) showed in an intervention study that lip training with an oral screen could improve lip force and swallowing in patients after stroke. The possibility for patients with Möbius syndrome, FSHD and DM1 to strengthen the muscles and improve oro-facial functions through oral motor exercises needs to be evaluated through research. The explored instruments for 3D analysis of lip mobility and lip force could be recommended as reliable tools for evaluation of treatment together with documention of speech, eating/feeding, facial expression and saliva control.

Conclusions

The system for automated analysis of lip mobility tested provides a possibility to measure 3D positions and different distances on the face and can also provide information about temporal aspects of facial movement. The only function tested and validated in this study of lip function was the 3D position of the oral commissures at rest and the displacement of the oral commissures when performing an open mouth smile and a lip pucker. These measurements are reliable and clinically relevant, and they could be used for evaluation of treatment as a supplement to qualitative methods. The method is non-invasive and could be used in different patient populations.

The combination of quantitative and qualitative methods for the evaluation of lip function made it possible to show the strong relation between lip contraction, lip force, eating ability and saliva control. The same combination of assessments can be used in the future to study if oral motor exercises aimed at improving lip mobility and strength could have a positive effect on lip function.

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References

- Ritter K, Trotman CA, Phillips C. Validity of subjective evaluations for the assessment of lip scarring and impairment. Cleft Palate Craniofac J. 2002;39:587–596.
- Coulson SE, Croxson GR, Gilleard WL. Quantification of the three-dimensional displacement of normal facial movement. Ann Otol Rhinol Laryngol. 2000;109:478–483.
- Wachtman GS, Cohn JF, VanSwearingen JM, Manders EK. Automated tracking of facial features in patients with facial neuromuscular dysfunction. Plast Reconstr Surg. 2001;107: 1124–1133.
- Trotman CA, Phillips C, Essick GK, Faraway JJ, Barlow SM, Losken HW *et al.* Functional outcomes of cleft lip surgery. Part I: Study design and surgeon ratings of lip disability and need for lip revision. Cleft Palate Craniofac J. 2007;44:598–606.
- Trotman CA, Faraway JJ, Losken HW, van Aalst JA. Functional outcomes of cleft lip surgery. Part II: quantification of nasolabial movement. Cleft Palate Craniofac J. 2007;44:607–616.
- Trotman CA, Barlow SM, Faraway JJ. Functional outcomes of cleft lip surgery. Part III: measurement of lip forces. Cleft Palate Craniofac J. 2007;44:617–623.
- Hu WL, Ross B, Nedzelski J. Reliability of the Sunnybrook Facial Grading System by novice users. J Otolaryngol. 2001;30:208–211.

- Kayhan FT, Zurakowski D, Rauch SD. Toronto Facial Grading System: interobserver reliability. Otolaryngol Head Neck Surg. 2000;122:212–215.
- 9. Ross BG, Fradet G, Nedzelski JM. Development of a sensitive clinical facial grading system. Otolaryngol Head Neck Surg. 1996;114:380–386.
- 10. Chee GH, Nedzelski JM. Facial nerve grading systems. Facial Plast Surg. 2000;16:315–324.
- Kanerva M, Poussa T, Pitkaranta A. Sunnybrook and House-Brackmann Facial Grading Systems: intrarater repeatability and interrater agreement. Otolaryngol Head Neck Surg. 2006;135:865–871.
- Coulson SE, Croxson GR, Adams RD, O'Dwyer NJ. Reliability of the "Sydney," "Sunnybrook," and "House Brackmann" facial grading systems to assess voluntary movement and synkinesis after facial nerve paralysis. Otolaryngol Head Neck Surg. 2005;132:543–549.
- 13. Linstrom CJ, Silverman CA, Susman WM. Facial-motion analysis with a video and computer system: a preliminary report. Am J Otol. 2000;21:123–129.
- Mehta RP, Zhang S, Hadlock TA. Novel 3-D video for quantification of facial movement. Otolaryngol Head Neck Surg. 2008;138:468–472.
- Frey M, Giovanoli P, Gerber H, Slameczka M, Stussi E. Threedimensional video analysis of facial movements: a new method to assess the quantity and quality of the smile. Plast Reconstr Surg. 1999;104:2032–2039.
- Meier-Gallati V, Scriba H, Fisch U. Objective scaling of facial nerve function based on area analysis (OSCAR). Otolaryngol Head Neck Surg. 1998;118:545–550.
- Mishima K, Yamada T, Ohura A, Sugahara T. Production of a range image for facial motion analysis: a method for analyzing lip motion. Comput Med Imaging Graph. 2006;30: 53–59.
- Johnson PC, Brown H, Kuzon WM Jr, Balliet R, Garrison JL, Campbell J. Simultaneous quantitation of facial movements: the maximal static response assay of facial nerve function. Ann Plast Surg. 1994;32:171–179.
- Trotman CA, Gross MM, Moffatt K. Reliability of a threedimensional method for measuring facial animation: a case report. Angle Orthod. 1996;66:195–198.
- Cohn JF, Zlochower AJ, Lien J, Kanade T. Automated face analysis by feature point tracking has high concurrent validity with manual FACS coding. Psychophysiology. 1999;36:35–43.
- Neely JG, Cheung JY, Wood M, Byers J, Rogerson A. Computerized quantitative dynamic analysis of facial motion in the paralyzed and synkinetic face. Am J Otol. 1992;13: 97–107.
- 22. Houstis O, Kiliaridis S. Gender and age differences in facial expressions. Eur J Orthod. 2009;31:459–466.
- Lin SC, Chiu HY, Ho CS, Su FC, Chou YL. Comparison of twodimensional and three-dimensional techniques for determination of facial motion–absolute movement in a local face frame. J Formos Med Assoc. 2000;99:393–401.
- Gross MM, Trotman CA, Moffatt KS. A comparison of threedimensional and two-dimensional analyses of facial motion. Angle Orthod. 1996;66:189–194.

- 25. Linstrom CJ, Silverman CA, Colson D. Facial motion analysis with a video and computer system after treatment of acoustic neuroma. Otol Neurotol. 2002;23:572–579.
- 26. Miyakawa T, Morinushi T, Yamasaki Y. Reproducibility of a method for analysis of morphological changes in perioral soft tissue in children using video cameras. J Oral Rehabil. 2006;33:202–208.
- 27. Johnston DJ, Millett DT, Ayoub AF, Bock M. Are facial expressions reproducible? Cleft Palate Craniofac J. 2003;40: 291–296.
- Schimmel M, Christou P, Houstis O, Herrmann FR, Kiliaridis S, Muller F. Distances between facial landmarks can be measured accurately with a new digital 3-dimensional video system. Am J Orthod Dentofacial Orthop. 2010;137:580.e1–580.e10.
- Williams WN, Vaughn AO, Cornell CE. Bilabial compression force discrimination by human subjects. J Oral Rehabil. 1988;15:269–275.
- Hägg M, Olgarsson M, Anniko M. Reliable lip force measurement in healthy controls and in patients with stroke: a methodologic study. Dysphagia. 2008;23:291–296.
- Barlow SM, Abbs JH. Force transducers for the evaluation of labial, lingual, and mandibular motor impairments. J Speech Hear Res. 1983;26:616–621.
- Thiele E. Functional measuring of muscle tone. Int J Orofacial Myology. 1996;22:4–7.
- 33. Ingervall B, Eliasson GB. Effect of lip training in children with short upper lip. Angle Orthod. 1982;52:222–233.
- Jung MH, Yang WS, Nahm DS. Effects of upper lip closing force on craniofacial structures. Am J Orthod Dentofacial Orthop. 2003;123:58–63.
- 35. Satomi M. The relationship of lip strength and lip sealing in MFT. Int J Orofacial Myology. 2001;27:18–23.
- Chu SY, Barlow SM, Kieweg D, Lee J. OroSTIFF: Facereferenced measurement of perioral stiffness in health and disease. J Biomech. 2010;43:1476–1478.
- 37. Clark HM. The role of strength training in speech sound disorders. Semin Speech Lang. 2008;29:276–283.
- Möbius PJ. About congenital bilateral abducens and facialis palsy (1888). Strabismus. 2008;16:39–44.
- Padberg GW, Brouwer OF, de Keizer RJ *et al.* On the significance of retinal vascular disease and hearing loss in facioscapulohumeral muscular dystrophy. Muscle Nerve. 1995;2:73–80.

- 40. Harper PS. Myotonic dystrophy: a multisystemic disorder. In: Harper PS, van Engelen BGM, Eymard B, Wilcox DE, eds. Myotonic dystrophy, present management, future therapy. New York: Oxford University Press, 2004:3–13.
- Sjögreen L, Engvall M, Ekström AB, Lohmander A, Kiliaridis S, Tulinius M. Orofacial dysfunction in children and adolescents with myotonic dystrophy. Dev Med Child Neurol. 2007;49:18–22.
- Lohmander A, Borell E, Henningson G, Havstam C, Lundeborg I, Persson C. SVANTE, Swedish Articulation and Nasality Test. Malmö: Pedagogisk Design, 2005.
- 43. Battagel JM. A comparative assessment of cephalometric errors. Eur J Orthod. 1993;15:305–314.
- Houston WJ. The analysis of errors in orthodontic measurements. Am J Orthod. 1983;83:382–390.
- 45. IPA. Handbook of the International Phonetic Association. Cambridge: Cambridge University Press, 1999.
- IPA. International Phonetic Alphabet. 2005 [cited 2010; Available from http://www.langsci.ucl.ac.uk/ipa/].
- Coulson SE, Croxson GR, Gilleard WL. Three-dimensional quantification of the symmetry of normal facial movement. Otol Neurotol. 2002;23:999–1002.
- Trotman CA, Phillips C, Faraway JJ, Ritter K. Association between subjective and objective measures of lip form and function: an exploratory analysis. Cleft Palate Craniofac J. 2003;40:241–248.
- 49. Schmidt KL, VanSwearingen JM, Levenstein RM. Speed, amplitude, and asymmetry of lip movement in voluntary puckering and blowing expressions: implications for facial assessment. Motor Control. 2005;9:270–280.
- Denlinger RL, VanSwearingen JM, Cohn JF, Schmidt KL. Puckering and blowing facial expressions in people with facial movement disorders. Phys Ther. 2008;88:909–915.
- 51. Hägg M, Anniko M. Lip muscle training in stroke patients with dysphagia. Acta Otolaryngol. 2008;128:1027–1033.
- 52. Ghani S, Mannan A, Kaucer A, Sen SL, Clarke A, Butler P *et al.* Facial motion analysis of acid burn victims–development of a new facial motion impairment index. Burns. 2007;33: 495–504.

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