Nasolabial Fold Dynamics: Implications for Facial Paralysis and Facial Reanimation Surgery

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Short Running Head: Three-Dimensional Nasolabial Fold Dynamics

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Abstract

Objectives: In patients with facial paralysis, facial reanimation surgery may be needed to normalize facial soft tissue function/movements. Critical for this normalization is the dynamics of the nasolabial folds (NLFs). The objective of this prospective, observational study was to determine the 3D morphologic dynamics of the NLFs in patients with unilateral facial palsy and normal subjects.

Settings and Sample Population: 3D facial soft tissue movement data collected from adults with unilateral, facial paralysis (Bell's Palsy, n=36); and (2) an age- and sex-frequency matched control group (n=68).

Materials and Methods: Movement data were collected during repeated animations from participants **using a video-based motion capture system**. **Movement in terms of displacement and asymmetry of the NLFs, nasal, and circumoral regions were analyzed in the lateral, vertical and depth planes; as well as movement of the commissure and NLFs relative to the lower lip midline.** Two sample *t* tests were used to test for significant group differences.

Results: Patients NLFs had less mean displacement, greater mean asymmetry, and uncoordinated movements compared with the controls. For both groups during smiling, the NLF and commissure landmarks had approximately similar magnitudes of displacement (control range = 11-14mm; patient range = 7-10mm).

Conclusion: NLF dynamics during smiling were as significant as oral commissure excursion. Thus, an immobile NLF is an unnatural feature of facial animations. Surgical treatments that address impaired NFL movements must be considered to create a more natural surgical outcome especially during smiling.

INTRODUCTION

Facial palsy is a disabling and disfiguring condition that results in impaired facial soft tissue function/movement. The impact is profound. Afflicted patients consistently report negative psychosocial sequelae and functioning.[1] Many patients experience permanent disfigurement either flaccid weakness or non-flaccid hypertonicity, and may require reanimation surgery to improve facial function and expression. Critical to successful surgical outcomes is a thorough understanding of the soft tissue muscle anatomy during facial expression movements. For example, an obvious and important factor to surgically recreate for a smile movement is oral commissure excursion, the degree to which the corner of the mouth moves from rest. In normal subjects, this movement ranges from 7 to 22 mm.[1,2] Equally important for normal esthetics is the *dynamics* of the nasolabial fold (NLF), the natural crease between the nose and mouth (Figure 1a). The orientation, depth, and direction of the NLF movement during smiling is a major predictor of paralysis severity and patients' quality of life (QOL).[3] Anatomically, the NLFs are facial crease lines or rhytids made visible by shadow formation at the junctions of the upper lip, cheek, and nasal alar on either side of the face.[4-6] With age, they become more pronounced. An important aspect of reanimation surgery is normalization of facial form and dynamics, of which the NLFs are a critical component; however, NLF dynamics remain poorly understood. Recently, we developed a suite of objective three-dimensional (3D) measures to dynamically characterize and map facial soft tissue movements for diagnosis and assessment of treatment outcomes in patients with facial paralysis.[7-8] In this study, the objective was to use these measures to determine the 3D morphologic dynamics of the NLFs during different facial expressions in normal subjects and patients with unilateral facial palsy. Emphasis was placed on understanding the NLF differences between patients and controls when the patients first presented for treatment.

MATERIALS AND METHODS

The study participants were recruited as part of a prospective study (NIDCR Grant # DE025295) to determined changes in facial soft tissue movements in adults with unilateral facial paralysis, and to compare the patients' facial movements with control participants.[7-8] Consecutive participants were recruited between June 2016 and March 2018 on first presenting for treatment at the Facial Nerve Center at Massachusetts Eye and Ear Infirmary (MEEI and the controls were patients and volunteers from Tufts University School of Dental Medicine (TUSDM) who were invited to participate either by personal contact or by responding to a posted flyer/advertisement. Eligible participants were screened by telephone based on selection criteria (Table_1_Suppinfo.pdf). Those who agreed to participate attended TUSDM Facial Animation laboratory where they were consented and data-collection completed. Based on previously published power calculations,[8] the final study sample consisted of two groups: Patients (n=36; mean age = 43.3 yrs. ±12.9) with acute, unilateral, flaccid facial paralysis (Bell's Palsy); and an age- and sex-frequency matched 'normal' control group (n=68; mean age = 42.7 yrs. ±14.5). The patient group consisted of 18 males and 18 females. Five patients self-identified as Hispanic, one as Black, two as Asian, and 28 as Caucasian. The control group consisted of 34 males and 34 females. Four of the control participants self-identified as Hispanic, five as Black, six as Asian, and 53 as Caucasian. Study consent and HIPAA documents were approved by the Tufts Health Sciences IRB. All participants had facial movement data collected.

Data Collection

The methods and analyses for the collection of the facial movement data specific for patients with facial paralysis were described in previous publication,[7-8] and a brief summary is provided here. A video-based motion tracking system (Motion Analysis ™, Motion Analysis Corporation, Santa Rosa, CA, USA; Figure 1b&c) was used to record the movement during eleven facial animations of 64 retro-reflective markers placed on specific facial soft tissue landmarks (Figure 1b—facial landmarks in gray). The animations were gentle eye closure (gec), natural smile (nsm), and the following maximum movements— brow raise (br), tight eye closure (tec), "ee" sound (ee), "oo" sound (oo), smile (msm), grimace (gr), lip purse (lp), check puff (cp), and mouth opening (mo). Each animation was repeated ten times by the subjects. The raw data were tracked off-line, and the tracked data consisted of a time series of 3-D vectors defined by x, y, z where x, y and z represented the position in space at 60 frames per second (60 Hz) for 4 seconds.

Data Analysis

For each repeated movement of an animation, the average "at-rest" facial landmark configuration of each participant was computed by extracting the first "at-rest" frames and computing the Procrustes mean. Then, the mean at-rest facial landmark configuration for the control participants was computed. This mean control face was symmetrized and rotated into a level and upright position and served as a standardized template upon which the at-rest faces of each participant were rotated onto using Procrustes conformation **which also controls for facial size**. Then for each animation, each frame of the movement was rotated on to the corresponding at-rest frame for that participant, and the frame at which the greatest distance from rest occurred was selected. The latter was translated so that the landmark on the bridge of the nose coincided with the rest frame. The nose bridge landmark was considered a fixed point during the movements. Further analysis focused on two landmarks on each side of face that localized the right and left NLFs and landmarks on the nose and around the mouth (Figure 1b—facial landmarks highlighted in white).

Three different comparisons of displacement were made of the right and left NLF landmarks of the patients and controls. For these calculations, the data were reflected so that the left side of the patients' face was always the affected (paralyzed) side. Also, given that there were ten replicates for each participant/animation combination, this was reduced to a single measure by taking the median.

(1) NLF Displacement
For the control participants, the mean displacement of the left and right pairs of NLF landmarks was computed; and for the patients the mean displacement of the NLF landmark pairs for the affected or paralyzed left side of the face and the contralateral right side of the face was computed.

(2) NLF Asymmetry. For each control and patient participant, the mean absolute difference in displacement between the two NFL landmarks on the left and the corresponding two landmarks on the right sides of the face was calculated.

(3) Lateral, Vertical, and Depth (Antero-Posterior) NLF Displacement.
For the right and left landmark pairs located at the upper and lower ends of

the NLFs, respectively, the distance (mm) travelled from rest to maximum displacement was calculated for each animation. For the patients and controls, further analyses were based on separate plots of the mean displacement in the lateral, vertical, and depth (antero-posterior) facial planes of space for upper and lower NLF landmark pairs.

In addition, to determine the displacement of the NLFs relative to the mouth corners or commissures, the distances at rest and at the maximum of each animation were calculated from the landmark on the midpoint of the lower lip to the right and left commissure landmarks, the right and left upper NLF landmarks, and the right and left lower NLF landmarks. The midpoint of the lower lip landmark was considered relatively stable during smiling.

Statistical Analysis

A 2-sample *t*-test was used to test for significant differences in displacement and asymmetry between the patients and control participants.

RESULTS

The results for mean displacement and asymmetry in the patient and control groups (Tables 1 and 2) show that, as might be expected, there was less displacement and greater asymmetry of the NLFs for the patients especially for the maximum smile (msm), natural smile (nsm), and grimace (gr) animations.

Lateral Movement of the NLF

Figures 2 is a plot of the lateral displacement of the control subjects' right and left landmark pairs at the upper end of the NLF for each animation. The horizontal axis shows the displacements of the landmark on the left side of the face where values to the left of the origin ('0') indicate displacement to the left of the face (displacement outwards). The vertical axis show the displacements of the landmark on the right side where values above the origin indicate movement to the right side of the face (displacement outwards). Points close to and on the origin would indicate little or no displacement as seen for brow raise (br) and gentle eye closure (gec). In general, the plots show a strong negative correlation which is expected since normal displacement would be symmetric (outwards on either side of the face). For the smile animations (nsm & msm) and ‘eeee’ sound (ee), both landmarks are in the upper left quadrant because they both move outwards while the landmarks for lip purse (lp) animation and ‘oooo’ sound (oo) are in the lower right quadrant because they move inwards. Figure 3 shows the same plot for the patients. As can be seen, the strength of the correlation is much reduced.

Vertical Movement of the NLF

The vertical displacement of upper NLF landmark pairs for the control subjects is shown in Figure_1_Suppinfo.pdf. The correlations are strong and positive because both landmark pairs move in the same direction—either upwards or downwards. For the patients (Figure_2_Suppinfo.pdf), similar plots show a weaker correlation but stronger overall than the plots for the lateral displacement.

Depth (Antero-Posterior) Movement of the NLF

The depth displacement for the control subjects upper NLF landmark pairs is shown in Figure_3_Suppinfo.pdf. Again, the correlations are strongly positive. For some animations, the landmark pairs move mostly forward such as for lip purse (lp) and cheek puff (cp) and ‘oo’ sound (oo). For other animations, the landmark pairs move mostly backwards, for example, both smiles (msm & nsm) and the ‘ee’ sound (ee). The plots for the patients (Figure_4_Suppinfo.pdf) show a weak correlation. Plots for landmark pairs at the lower end of the NLFs demonstrated similar correlations and these plots are available upon request.

Figure 4 is a composite set of schematic plots for each animation comparing the mean positions of the NLFs at rest and at maximum displacement for the patient and control groups. As stated previously, the left side of the face was set as the affected or paralyzed side. The mean landmark positions for the control face at rest is in black and lines connect the landmarks on the nose, mouth, and NLF regions. The upper and lower NLF landmarks at maximum displacement are connected by a red line for the control group and by a blue line for the patient group. The plots show that the greatest differences in maximum displacement of the NLFs between the patients and controls for the affected (left) side are seen for the smile (msm and nsm) and grimace (gr) animations and ‘ee’ sound.

Tables_2_Suppinfo.pdf and Table_3_Suppinfo.pdf give the mean displacement from rest to the maximum of the smile movements, of the upper NLF landmarks, lower NLF landmarks, and commissure landmarks relative to the middle of the lower lip for the patients and controls, respectively. Because the smile animation is the focus of facial reanimation surgery, the results for the smile are reported here. The results for the other animations are available on request. Overall, for the smile, the difference in mean displacement from rest for the **commissure** landmarks ranged from 11.3 to 14.0 millimeters for the control group and 7.2 to 10.2 millimeters for the patient group. For the patients and controls, the upper and lower NLF landmarks had approximately similar magnitudes of displacement as the commissure landmarks (~ 1cm for the controls and variable for the patients). **Also, the 'at rest' distances from the middle of the lower lip to the upper NLF landmarks ($p<0.05$), and from the middle of the lower lip to the commissure landmarks ($p<0.01$) were less for the patients. Finally, the distributions and normality of the data can be seen in the plots in the supplementary material. P-values were reported so the reader can choose their own alpha level. Any age, sex, and ethnicity effects that exist were not possible to detect without a much larger study. The analysis in this study controls for size and initial shape so that these effects would be relatively small.**

DISCUSSION

This study is the first to provide an in-depth analysis of the NLF dynamics and associated asymmetry in patients with facial paralysis and control subjects. Previous methods of quantification involved the use of 2D measures and analyses[9-10] and focused on the asymmetry of the brow, upper and lower eyelids, and oral commissures—much more limited in scope compared with the analyses presented here. Moreover, the issue of validity of 2D analyses is a concern.[7-8] In our study, an objective and highly detailed 3D facial movement analysis was conducted that provided insights into both normal NLF animation dynamics and the dynamics of the folds in patients with unilateral facial paralysis. Such an analysis is important to understand the relationships of normal movement of the NLF in all three planes of space—transversely, vertically, and antero-posteriorly (depth), but as demonstrated, the analysis also can be used to diagnose impaired movements in patients as well as assess outcomes of reconstructive surgeries.

Currently, there is no universal agreement on a measurement system or outcome measure for facial palsy.[11] A more recent review of the literature highlighted the need for multiple validated outcome measures in order to capture all domains of successful surgical reanimation and included **P**atient-Reported Outcome Measures, **A**utomated and Clinician-Graded Facial Palsy Grading Systems, **L**ayperson Assessment Equivalent, and **S**pontaneous Smile Anal**y**sis.[11] In the present study, the focus was on measuring facial soft tissue movement with an emphasis on the NLFs. One popular measure for this purpose is the eFACE which is a scale used by clinicians to grade the severity of the facial paralysis using specific software.[12-13] The clinician subjectively rates or scores facial regions according to the degree of facial symmetry at rest and at the maximum of the smile movement only. Experts who rated patients' disfigurement with this scale deemed that the NLF morphology and symmetry were two very influential parameters when assessing paralysis.[14]

In fact, static NFL suspension is one of the most common ancillary surgical procedures performed in treating facial palsy because the cheek position at rest, as delineated by the NLFs, is of critical importance **(Figure_5_Suppinfo.pdf).[15] Yet, restoration of NLF dynamics is not generally considered important by reanimation specialists (Figure_4_Suppinfo.pdf).[15]** From a dynamic perspective, we found herein that there was considerable movement of the NLFs during smiling and other animated movements. During normal smiling, the mean 3D movement of the NLFs was of similar magnitude to that of the oral commissures, around the order of one centimeter. In addition, symmetry of the *normal* NFL movements was highly coordinated in all three planes of space between the right and left sides of the face. However, in affected patients the movement was limited in magnitude and highly uncoordinated, and the movement in the lateral and antero-posterior directions was much more uncoordinated than the vertical movements. These findings suggest that an immobile NLF is an unnatural feature of the smile movement/animation, and that surgical treatment strategies that address impaired NFL movements during animations must be considered to create a more natural surgical outcome. It is likely that the level of NFL dynamism will need to be tailored to an individual patient's dynamic anatomy **and many surgeons may already incorporate strategies to restore dynamic movement to the NLF. Increased awareness of the importance of restoring this**

dynamic feature of smiling is needed. The 3D outcome measures described in this and other studies afford an approach to personalize facial soft tissue movement outcomes in patients.

CONCLUSION

This study is the first to provide an in-depth, 3D analysis of the NLF dynamics in patients with facial paralysis and control subjects. This analysis can be used to diagnose impaired facial soft tissue movements in patients as well as assess outcomes of reconstructive surgeries. From a dynamic perspective based on the analysis we found considerable movement of the NLFs during smiling and other animated movements. During normal smiling, movement of the NLFs was highly coordinated, symmetrical, and of similar magnitude to that of the oral commissures—around the order of one centimeter. Affected patients had highly uncoordinated and asymmetrical movements that were limited in magnitude suggesting that an immobile NLF is an unnatural feature of the smile movement/animation, and surgical treatment strategies tailored to a patients' specific needs that address impaired NFL movements during animations must be considered to create a more natural surgical outcome.

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Table 1. Mean displacement (mm) of the NLF landmark-pairs for the patient (FP) and control (NS) groups for each animation (br=brow raise, mcp=maximum cheek puff, ee=eeee sound, gec=gentle eye closure, gr=maximum grimace, lp=maximum lip purse, mo=maximum mouth opening, msm=maximum smile, nsm=natural smile, oo=oooh sound, tec=tight eye closure). The displacement for the control group was calculated as the mean of the left and right landmark-pair maximum displacement from rest; and for the patients as the affected side maximum displacement from rest. T-tests for significant differences between the patient and control group means.

Significance levels: n=non-significant; *=p<0.05; **=p<0.01, ***=p<0.001. DF is degrees of freedom. LCI and UCI are the 95% confidence intervals for the difference.

Animations	**FP Mean (mm)**	**NS Mean (mm)**	**T test statistic**	**DF**	**LCI**	**UCI**	**p value**
br	2.92	5.10	-5.53	66.24	-2.97	-1.39	0.000***
cp	14.54	18.08	-2.79	62.37	-6.07	-1.01	0.007**
ee	7.27	17.43	-8.28	70.27	-12.62	-7.72	0.000***
gec	1.44	1.61	-0.67	40.71	-0.70	0.35	0.509n
gr	11.02	22.09	-8.11	60.65	-13.80	-8.34	0.000***
lp	8.79	15.54	-7.32	67.77	-8.59	-4.91	0.000***
mo	17.03	15.40	1.38	50.68	-0.74	3.99	0.174n
msm	9.31	22.32	-9.94	51.39	-15.63	-10.38	0.000***
nsm	10.77	22.97	-8.78	41.99	-15.01	-9.39	0.000***
oo	7.32	13.21	-5.97	71.07	-7.85	-3.92	0.000***
tec	8.64	10.25	-1.00	49.29	-4.83	1.62	0.322n

Table 2. Mean asymmetry of the NLF landmark-pairs for the patient (FP) and control (NS) groups for each animation (br=brow raise, mcp=maximum cheek puff, ee=eeee sound, gec=gentle eye closure, gr=maximum grimace, lp=maximum lip purse, mo=maximum mouth opening, msm=maximum smile, nsm=natural smile, oo=oooh sound, tec=tight eye closure). The asymmetry for the patient and control groups was calculated as the mean absolute difference in displacement from rest between the landmark pairs on the left and right sides of the face. T-tests for significant differences between the patient and control group means.

Significance levels: n=non-significant; *=p<0.05; **=p<0.01, ***=p<0.001. DF is degrees of freedom. LCI and UCI are the 95% confidence intervals for the difference.

Animations	**FP Mean**	**NS Mean**	**T test statistic**	**DF**	**LCI**	**UCI**	**p value**
br	0.94	0.56	2.82	44.54	0.11	0.65	0.007**
cp	2.83	1.24	3.44	32.91	0.65	2.54	0.002**
ee	6.83	1.61	5.61	30.01	3.32	7.11	0.000***
gec	0.49	0.42	0.65	60.99	-0.15	0.30	0.516n
gr	8.52	1.91	6.56	28.16	4.55	8.67	0.000***
lp	4.17	1.50	4.89	33.76	1.56	3.78	0.000***
mo	2.52	1.50	2.04	34.63	0.00	2.04	0.049*
msm	10.04	1.98	7.77	29.50	5.94	10.18	0.000***
nsm	8.74	1.80	6.56	28.42	4.78	9.11	0.000***
oo	3.65	1.46	3.93	31.72	1.05	3.32	0.000***
tec	2.45	1.76	1.37	36.73	-0.33	1.70	0.179n

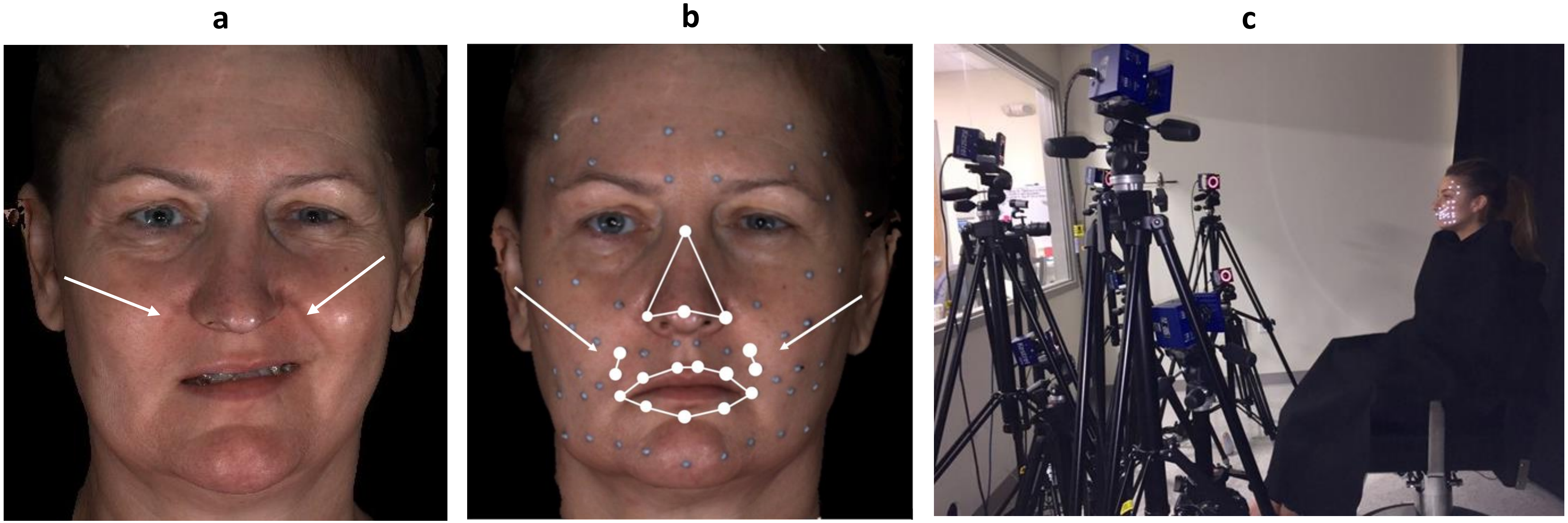


Figure 1a,b,&c. Arrows point to the nasolabial fold areas (a&b), the facial landmarks (b), and the video-based motion tracking system.

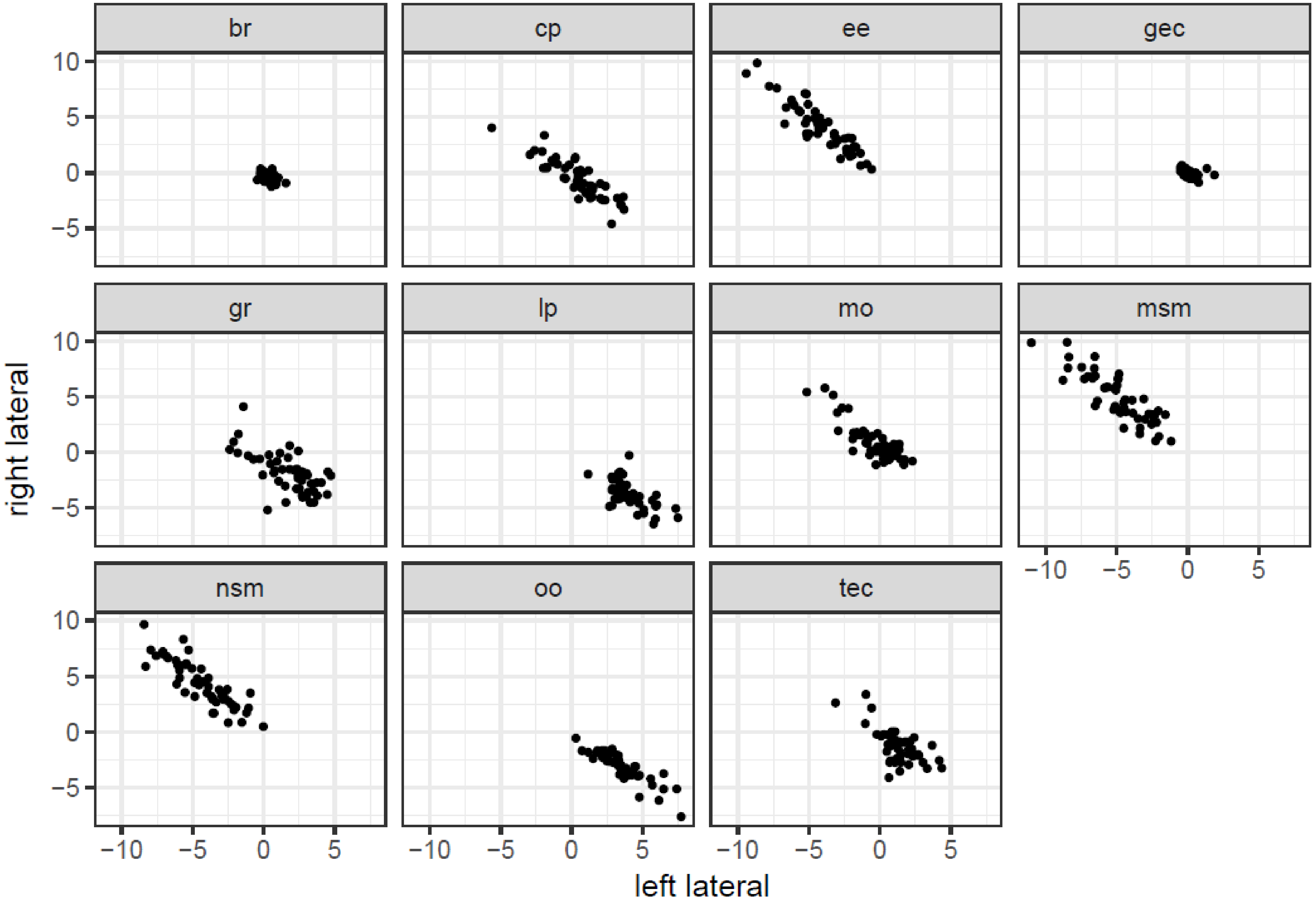


Figure 2. Lateral displacement of the control subjects right and left landmark pairs at the upper end of the NLFs for each animation.

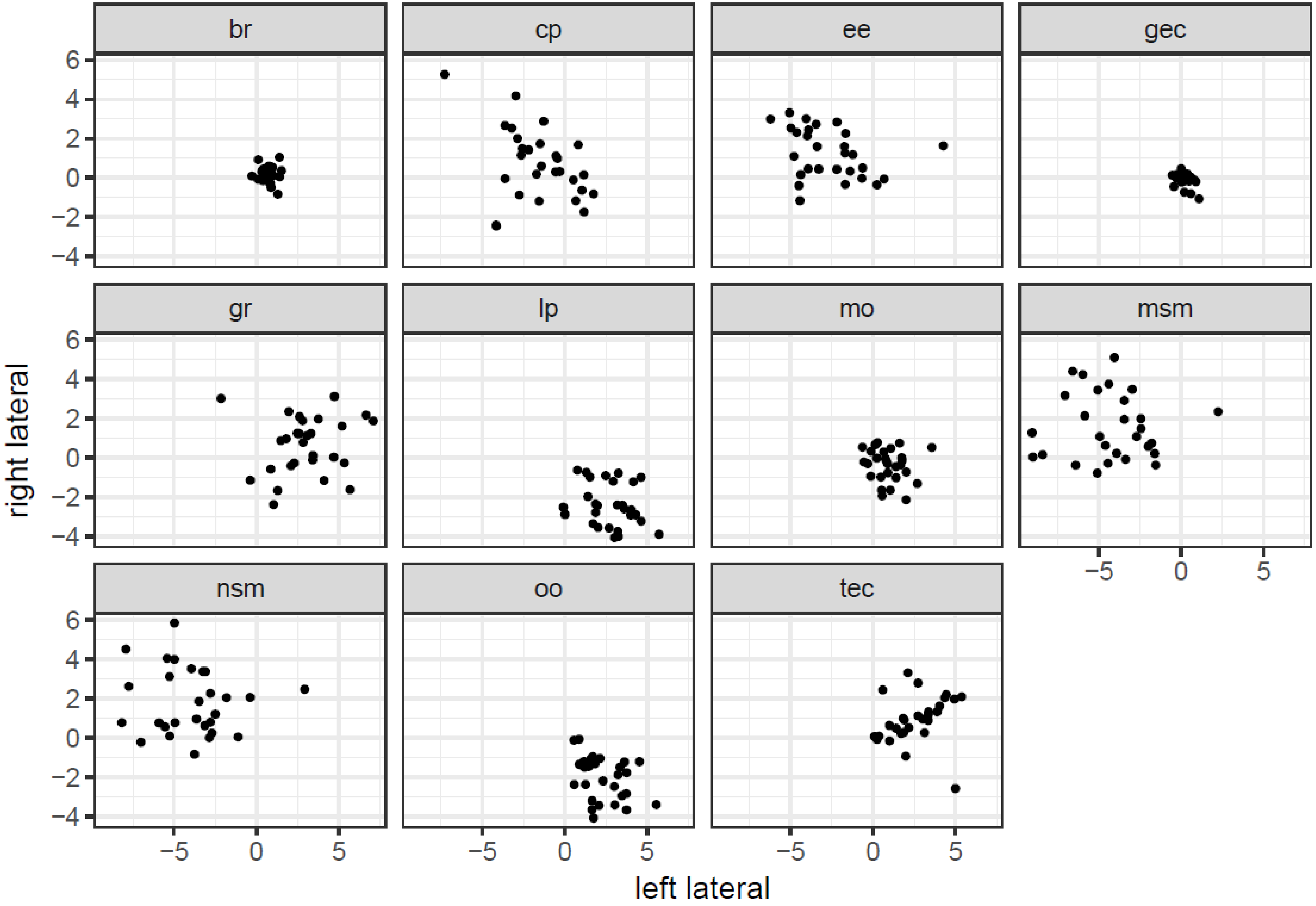
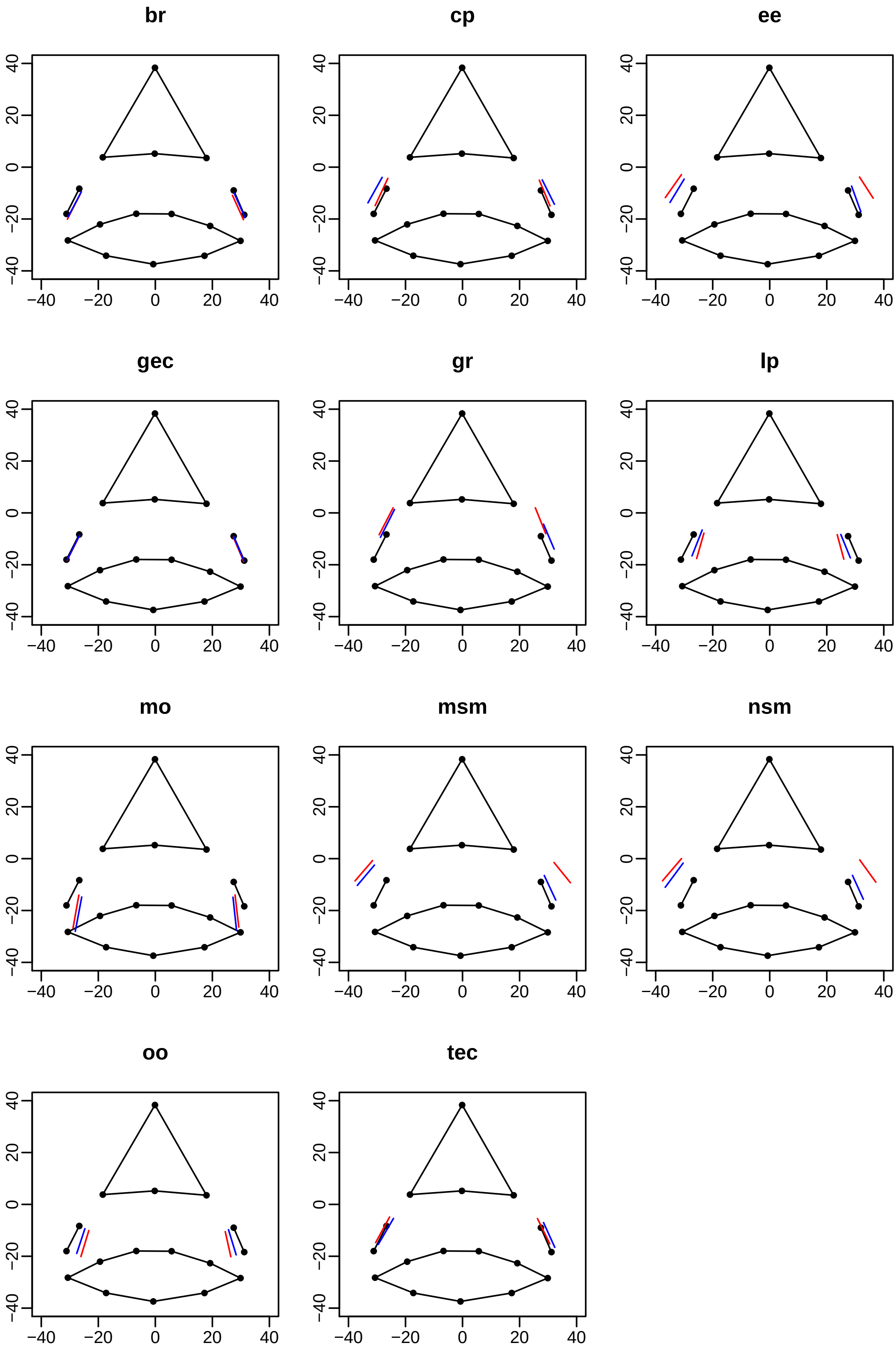


Figure 3. Lateral displacement of the patients' right and left landmark pairs at the upper end of the NLFs for each animation.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