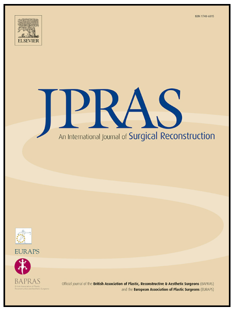


Double powered free gracilis muscle transfer for smile reanimation: A longitudinal optoelectronic study

Chiarella Sforza, Prof., Alice Frigerio, Andrea Mapelli, Filippo Tarabbia, Isabella Annoni, Valeria Colombo, Mahfuz Latiff, Claudia L. Pimenta Ferreira, Dimitri Rabbiosi, Fernanda V. Sidequersky, Matteo Zago, Federico Biglioli

PII: S1748-6815(15)00171-0

DOI: 10.1016/j.bjps.2015.03.029

Reference: PRAS 4581

To appear in: *Journal of Plastic, Reconstructive & Aesthetic Surgery*

Received Date: 27 May 2014

Accepted Date: 30 March 2015

Please cite this article as: Sforza C, Frigerio A, Mapelli A, Tarabbia F, Annoni I, Colombo V, Latiff M, Pimenta Ferreira CL, Rabbiosi D, Sidequersky FV, Zago M, Biglioli F, Double powered free gracilis muscle transfer for smile reanimation: A longitudinal optoelectronic study, *British Journal of Plastic Surgery* (2015), doi: 10.1016/j.bjps.2015.03.029.

Double powered free gracilis muscle transfer for smile reanimation: a longitudinal optoelectronic study

Chiarella Sforza[1], Alice Frigerio[2,3], Andrea Mapelli[1,4], Filippo Tarabbia[5], Isabella Annoni[1], Valeria Colombo[5], Mahfuz Latiff[5], Claudia L. Pimenta Ferreira[1,4,] Dimitri Rabbiosi[5], Fernanda V. Sidequersky[1,4], Matteo Zago[1], Federico Biglioli[5]

[1]Functional Anatomy Research Center (FARC), Laboratorio di Anatomia Funzionale dell'Apparato Stomatognatico (LAFAS), Laboratorio di Anatomia Funzionale dell'Apparato Locomotore (LAFAL), Dipartimento di Scienze Biomediche per la Salute, Facoltà di Medicina e Chirurgia, Università degli Studi di Milano, via Mangiagalli 31, I-20133 Milano, Italy

[2]Human Physiology Section, Department of Pathophysiology and Transplantation, Facoltà di Medicina e Chirurgia, Università degli Studi di Milano, Milano, Italy

[3]Carolyn and Peter Lynch Center for Laser and Reconstructive Surgery, Division of Facial Plastic and Reconstructive Surgery, Department of Otology and Laryngology, Massachusetts Eye and Ear Infirmary, Harvard Medical School, Boston, MA, USA

[4]Department of Ophthalmology, Otorhinolaryngology, and Head and Neck Surgery, School of Medicine, Ribeirão Preto, University of São Paulo, Brazil

[5]Surgical Unit of Maxillo-Facial Surgery, San Paolo Hospital, Facoltà di Medicina e Chirurgia, Università degli Studi di Milano, Milano, Italy

MS JPRAS-D-14-00650R1 submitted to the Journal of Plastic, Reconstructive & Aesthetic Surgery on 23 may 2014 – first revision 18 Nov 20. - Second revision 15 feb 2015

Running title: Double powered free gracilis muscle transfer
Number of tables: 2
Number of figures: 10
Number of supplementary videos: 3

Conflicts of Interest and Source of Funding: A. Mapelli is currently receiving a grant (Atração de Jovens Talentos - Pesquisador Colaborador no Brasil - BJT - PROGRAMA CIÊNCIA SEM FRONTEIRAS) from the Ministério da Ciência e Tecnologia – MCT CONSELHO NACIONAL DE DESENVOLVIMENTO CIENTÍFICO E TECNOLÓGICO – CNP; C.L. Pimenta Ferreira is Fellow, Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (National Council for Scientific and Technological Development – CNPq, Brazil); F. Sidequersky had a scholarship from University of Milano, and current she has a scholarship from CNPq, Brazil (Bolsa Jovens Talentos). For the remaining authors none were declared.

Correspondence:
prof. Chiarella Sforza
Dipartimento di Scienze Biomediche per la Salute
via Mangiagalli 31 - I-20133 MILANO - ITALY
TEL. +39 – 02 503 15407 - FAX +39 – 02 503 15387
e-mail chiarella.sforza@unimi.it

ABSTRACT

The choice of the motor donor nerve is a crucial point for free flap transfer algorithms. In case of unilateral facial paralysis, the contralateral healthy facial nerve can provide coordinated smile animation and spontaneous emotional expression, but with unpredictable axonal ingrowth into the recipient muscle. Otherwise, the masseteric nerve ipsilateral to the paralysis can provide a powerful neural input, without a spontaneous trigger of the smile. Harvesting a bulky muscular free-flap may enhance quantity of contraction but esthetic results are unpleasant. So, the logical solution to obtain high amplitude of smiling combined with the spontaneity of movement is to couple neural input: the contralateral facial nerve plus the ipsilateral masseteric nerve.

Thirteen patients with unilateral dense facial paralysis underwent a one-stage facial reanimation with a gracilis flap powered by a double donor neural input, provided by both the ipsilateral masseteric nerve (coaptation by an end-to-end neurorrhaphy with the obturator nerve) and the contralateral facial nerve (coaptation through a cross-face nerve graft: end-to-end neurorrhapy on the healthy side and end-to-side neurorrhaphy on the obturator nerve, distal to the masseteric/obturator neurorrhaphy). Their facial movements were evaluated with an optoelectronic motion analyzer.

Before surgery, on average the paretic side had a total three-dimensional mobility smaller than the healthy side, with a 52% activation ratio and more than 30% of asymmetry. After surgery, the differences significantly decreased (ANOVA, $p<0.05$), with an activation ratio between 75% (maximum smile) and 91% (maximum smile with teeth clenching), and less than 20% of asymmetry. Similar modifications were seen for the performance of spontaneous smiles.

The significant pre-surgical asymmetry of labial movements reduced after surgery. The use of a double donor neural input permitted both movements that were of force similar to that of the healthy side, and spontaneous movements elicited by emotional triggering.

Key words: facial nerve paresis; 3D; motion analysis; mimetics; asymmetry.

INTRODUCTION

Long standing facial paralyses are characterized by irreversible fibrosis and absence of fibrillations of the mimetic musculature at electromyographic investigation. Among those cases it is not worth to give a new neural input to the musculature, as that does not have the possibility to recover from its degeneration. Reanimation, particularly smile recovery, is rather accomplished by means of free muscle flap transposition. That represents the gold standard treatment for chronic paralysis with severely injured or extirpated facial nerve and no recovery over the course of 12 months, or for chronic paralysis of congenital or developmental origin.

The gracilis free muscle transfer is a reliable means for smile reanimation and it is the most widely used flap in dynamic procedures, based on predictable pedicle anatomy, an acceptable donor site morbility, and favorable muscle microarchitectural features resulting in fast and robust excursion when activated[1].

Decision-making for the choice of the suitable motor donor is still a challenge in unilateral smile reanimation planning. If the ipsilateral masseteric nerve is compared to a tiny contralateral facial nerve branch, the first one seems to guarantee a major neural input to the free flap because of the reduced length and the higher axonal count. On the contrary, only the facial nerve gives certainties relatively to the spontaneity of the outcome[2-4]. Moreover, despite the transferred muscles enjoy relatively few vascular failures, adequate axonal ingrowth of the donor nerve into the recipient muscle is still unpredictable, particularly when driven by a cross-face nerve graft[1]. A further aspect is muscle mass: harvesting a bulky muscular free-flap may enhance quantity of contraction, but the resulting esthetic results are unpleasant.

Since the recovery of emotional smile represents the cornerstone for the quality of life of the patients, substantial effort is being put forth by investigators to improve techniques for obtaining spontaneous and symmetrical activation of the flap. Watanabe et al.[5] first reported a one-stage free latissimus dorsi transplantation powered by a double motor source, by neurotizing the hilum of the flap with a denuded area of the underlying masseter muscle. We also sought an algorithm combining the reliability of the masseteric nerve as motor donor and the spontaneous triggering of the smile from the contralateral facial nerve[6].

Currently, three-dimensional (3D) motion analysis is well recognized as an objective, non-invasive and quantitative method to assess facial movements before and after surgical rehabilitation, and several investigators have developed instruments and software to the scope[7-14].

In our case series, 13 patients underwent a one-stage free gracilis transplantation powered by a double donor neural input for unilateral dense facial paralysis. The baseline situation before surgery, and the clinical outcomes after regaining facial mobility, were assessed by quantifying smile excursion by means of a 3D optoelectronic motion analyzer[7,8]. Even if all patients were submitted to surgical reanimation in other parts of the face, the current paper reports only data about smile function.

MATERIALS AND METHODS

Patients

The research protocol was approved by the ethical committee of the University of Milan Medical School in accordance with the standards of the 1964 Declaration of Helsinki.

Over a 40-month period, from October 2009 through January 2013, a total of 26 consecutive patients with unilateral dense facial paralysis underwent a one-stage facial reanimation with a gracilis flap powered by a double donor neural input. All patients included in the study were grade VI of House-Brackman classification (complete facial paralysis), confirmed by absence of any electromyographic signal. Thirteen out of 26 patients who were ready for the post-operative analysis in January 2013 were enrolled in the study.

The mean age of the patients at surgery was 41 years (SD 17 years; range, 9-75 years). Facial nerve injury was due to previous surgery in 12 patients (6 acoustic neurinomas, 3 cavernous hemangiomas, 2 total parotidectomies, 1 meningioma) and congenital palsy in 1 patient.

Surgical procedure

A facelift-type skin incision is made on the paralyzed hemiface, extended for 6-8 cm into a cervical crease, 2 cm below the inferior mandibular border[6]. An anterior skin flap is elevated into the deep subcutaneous tissue coming up medially 1 cm over the ideal position of the nasolabial fold. Four to six 2-0 polyethylene stitches are positioned across the residual fibers of the orbicularis oris or deep subcutaneous tissue, if the muscle is no more available. Their exact position is one centimeter medial to the ideal nasolabial fold. Suture threads are pulled together intraoperatively to mime smiling in order to check their effect forming the fold. If that is not convincing, stitches position is changed.

The masseteric nerve is identified into the muscle parenchyma. The muscle is approached 1 cm below the zygomatic arch and 1 cm medial to its posterior border. The nerve lies 1.5-2 cm deep to the muscle surface and is well visible by gently dissecting muscle fibers along their axis (almost vertical). A 2.5-3 cm length nerve trunk segment is released after cutting its small collateral branches, if necessary. The nerve is cut at this level and turned superficially in order to easily accomplish the neurorrhaphy.

An 8 x 5 cm gracilis muscle flap is simultaneously harvested from the medial thigh in the standard manner. The flap is transferred into the face pocket and stabled only with the medial attachment defined by the previously inserted stitches. Vascular anastomosis are accomplished end-to-end between flap vessels and facial ones. Subsequently, the end-to-end coaptation between the anterior branch of the obturator nerve and the masseteric nerve is made.

On the healthy side of the face, a face-lift type of incision is carried on, traced posteriorly into the mastoid region. An anterior skin flap dissection allows identifying a middle branch of the facial nerve direct to the zygomatic major muscle. The branch is tested with the electrostimulator to verify its involvement into smiling movement. A 20-25 cm portion of the sural nerve is grafted at the same time by a second team. When ready, the nerve is cross-faced in a reverse manner. The distal end is connected end-to-end with the branch of the facial nerve previously identified. On the paralyzed side of the face, the proximal end of the sural nerve is connected end-to-side to the anterior obturator branch, between the hilum of the flap and the connection to the masseteric nerve. An epineural window is opened to allow the end-to-side connection.

Finally the lateral side of the flap is anchored to the periosteum overlaying the zygomatic arch and lateral zygomatic bone. Care must be taken in order to reach a correct tension of the flap.

Data collection

Both clinical evaluation and optoelectronic motion analysis were performed prior to and at least 11 months after surgery (up to 20 months; mean 17 months, SD 3). The 13 patients (10 women, 3 men) out of 26 who were ready for the post-operative analysis in January 2013 were enrolled in the study. Among the original case series of 26 patients, 2 (7.69%) did not recover any function: this negative datum is doubled because both patients are included in the sample of 13 complete cases analyzed in the study; the final percentage of failures is brought up to 15.38%. This high rate of failures may be due to axonal ingrowth disturbance or microvascular impairments.

In all 13 patients, examinations were performed at least five months after facial mimicry had clinically recovered (on average, 10 months, SD 3; maximum interval 16 months). This interval was used because five months is considered to be a time lap sufficient to obtain significant consolidation of muscle function, though it is well know that final reinnervation may last for several years.

The data collection protocol has been previously described[7,8,15,16]. Briefly, facial motion was captured by means of an optoelectronic 3D motion analyzer sampling at a 60 Hz rate (SMART System, BTS, Milano, Italy). Participants sat on a stool inside a working volume (44 x 44 x 44 cm^3, width x height x depth) defined by nine high-resolution infrared sensitive video cameras. Prior to each acquisition, metric calibration and optic/electronic distortion correction are performed, with a resulting mean dynamic accuracy of 0.121 mm (SD 0.086), corresponding to 0.0158% of the diagonal of the working volume[15]. Patients performed five repetitions of three standardized facial expressions: maximum smile without clenching (before and after surgery), maximum smile with clenching on their posterior teeth (only after surgery), spontaneous smile (recorded in both sessions during the airing of a funny video, the participants being unaware of the purpose of that acquisition phase). The voluntary smile animations were explained and shown to the patients, who practiced to perform them before data acquisition; in contrast, no instructions were given for spontaneous smiles.

During the execution of the animations, for each camera a software identified the two-dimensional (2D) coordinates of 11 passive markers taped epicutaneously on facial landmarks (Fig. 1). All coordinates were then converted into metric data, and a set of 3D coordinates was gathered for each marker, in each frame, for every performed movement[7,8,15,16].

Round reflective 2-mm adhesive markers were taped on the skin of: n, nasion; right and left: ft, frontotemporale; ng, naso-genian; cph, crista philtri; ch, cheilion; li, lower lip midpoints. Markers' positions do not interfere with facial movements[16].

Within- and between-session repeatability of the protocol was previously assessed in healthy subjects; within session, single landmarks technical error of the measurement was, on average, 0.5-3.38 mm, showing a sufficient reproducibility. Between sessions, all facial movements had standard deviations lower than 1 mm[15]. For commissurae landmarks, the average error during free and maximum smile was 16%. The method could detect and quantify total and local facial motion; in patients with facial nerve palsy, collected data (amount of motion in single landmarks, synkinesis and movement asymmetries) were in good accord with House-Brackman classification[13].

Data analysis

The method has been previously described[7,8,15]. To mathematically eliminate head and neck movements during the animations, all data were referred to a head reference system defined by nasion and frontotemporale landmarks. The analysis was therefore restricted to the movements occurring in the face (activity of mimetic muscles), but no actual limitations or physical restrictions were given to the patients[8,16].

During each facial animation, the 3D movements of the eight labial markers (naso-genian, crista philtri, cheilion, lower lip) were computed, and their 3D maximum displacement from rest was calculated (Fig. 2 and 3). For each side (paretic and healthy), total labial mobility was obtained from the sum of the displacements of the landmarks. To quantify the side differences, two indices were obtained: the ratio of paretic to healthy side[8-10], and the asymmetry index (percentage ratio between the difference and the sum of the healthy/ paretic displacements; –100%, complete paretic side prevalence during the movement; +100% complete healthy side prevalence)[7,15]. A 2D analysis was also performed, and the latero-lateral (right-left direction) component of the maximum displacement of the crista philtri, cheilion and lower lip landmarks was also computed[11].

Statistical calculations

For each patient, the five repetitions of facial movements were averaged. Mean and standard deviation were obtained for the total displacement of the healthy and paretic sides (3D analysis), the lateral displacement (2D analysis), the ratios and the asymmetry indices. Calculations were performed separately for the each kind of smile, before and after surgical facial reanimation. Two quantitative exclusion criteria were arbitrarily set to remove from statistical calculations those animations too small to be worth consideration: the healthy side had to present a total 3D mobility greater than 10 mm and the lateral displacement of its commissura larger than 1 mm.

Comparisons between maximum smiles performed before surgery, and maximum smiles performed after surgery either without (facial nerve stimulus) or with teeth clenching (masseter nerve stimulus) were made by 1-way ANOVA for repeated measurements. For significant values, post hoc test were made by paired Student's t test.

Comparisons between spontaneous smiles (before vs. after surgery) were made by Wilcoxon rank tests. For all analyses, the alpha level was set at 5% ($p < 0.05$), with a Bonferroni correction for post hoc tests ($p < 0.017$).

RESULTS

All patients performed the requested maximum smile animations correctly, but only nine of them (six women and three men, 69.23% of the patients) performed spontaneous smiles that on average, and in both sessions, were wide enough to be further considered according to the established criteria. In the maximum smiles recorded during the first data collection session (pre-operatively), the average total 3D mobility of the paretic side was lower than that of the healthy side, with a 52% activation ratio and more than 30% of asymmetry (Table 1). In the second, post-operative data collection session, differences significantly decreased, with an activity ratio between 75% (maximum smile) and 91% (maximum smile with teeth clenching) and less than 20% of asymmetry. For both the activity ratio and the asymmetry index, post hoc tests showed that the difference was significant between pre-surgical and post-surgical values with teeth clenching. The effect was due to both a reduction of the healthy side motion (significant difference among the three smile animations, ANOVA, $p = 0.036$), and an increment of the paretic side motion due to the masseteric motor source (ANOVA, $p = 0.012$, significant post hoc difference between post-surgical maximum smiles with and without teeth clenching).

Similar modifications were seen for the performance of spontaneous smiles (Table 2), with a significant reduction of healthy side motion, and a trend toward increased activity ratios and reduced asymmetry.

Before surgery, during the maximum smile animation all labial landmarks moved toward the healthy side (2D, right-left direction, Fig. 4); after surgery, the movement was more symmetrical, with significant differences (ANOVA) for almost all landmarks: paretic side ch and cph, $p < 0.001$ (post hoc comparisons: before surgery vs. after surgery with/out teeth clenching, $p = 0.001$), li, $p < 0.001$ (post hoc comparisons: before surgery vs. after surgery with/out teeth clenching, $p = 0.002$); healthy side: cph, $p = 0.001$ (post hoc comparisons: before surgery vs. after surgery with/out teeth clenching, $p = 0.002$), li, $p = 0.002$ (post hoc comparisons: before surgery vs. after surgery with/out teeth clenching, $p = 0.006$). In particular, the labial commissura of the rehabilitated side moved toward the corrected side of the face, while the philtrum followed it only in about half of the patients (SD bars extending in both sides).

Surgical treatment also modified the execution of the spontaneous smiles, with more symmetrical movements of the rehabilitated side landmarks, and reduced motion of the healthy side ones (Fig. 5). The largest effects were seen for the labial commissurae (Wilcoxon test, $p = 0.012$) and lower lip ($p = 0.02$) of the paretic side, and for the lower lip of the healthy side ($p = 0.05$).

Figures 6 to 9 show one of the analyzed patients before and after surgical treatment, whose dynamic movements while smiling can be seen in the supplementary videos (Movies 1-3).

DISCUSSION

In the present study, we assessed three kinds of smiles, two voluntary made by the patient, and one spontaneous; according to the activity ratios and asymmetry indices, the best results were obtained when patients elicited the contraction of their mimetic muscles by clenching on their posterior teeth. Indeed, the surgical technique used part of the ipsilateral masseteric nerve to provide new motor fibers to the facial nerve[6], and they were instructed to clench insofar they wanted to contract their labial elevator muscles[10,17]. At the same time, the patients also regained spontaneous activity of their paretic side mimetic muscles via the cross-face cable graft[6]. The surgical technique, therefore, tried to combine the best results from both donor nerves: force by the masseteric nerve, and spontaneous triggering from the facial nerve. Moreover, if one of the two motor inputs failed to provide re-innervation, at least the other one should fulfill it. At the same time, 15% of failures of the sample suggests that this mechanism is theoretical, unless we justify all of them by vascular impairments of the free flaps. On the contrary, there is no reason to hypothesize that double innervation is implied into worsening the rate of failures. Nonetheless, this high percentage of failures corresponds to two patients only, and larger numbers of cases are necessary to fully appreciate the true success rate of the technique.

Voluntary maximum smiles performed without teeth clenching were also recorded: the relevant labial landmark movements clearly show that patients modified their smile after surgery. Overall, they “controlled” their smiles, with voluntary reductions of healthy side labial movement. As a result, the pulling effect on the paretic side towards the healthy side decreased, and this contributed to the increased labial symmetry and activity ratio[10]. Reductions of healthy side labial movement are due only to the teaching of a dedicated physiotherapist and not to any loss of power loss related to the sacrifice of healthy facial nerve branches.

Previous investigations using quantitative assessment of surgical techniques did not rehabilitate the patients with the current double innervation, and our data can only be partially compared with literature data, even if similar measurement instruments and methods were used. Frey et al.[11] measured a group of patients who received a free gracilis muscle transplant powered by a facial nerve cross face graft. On average, in their patient series the labial commissure of the paretic side had a significant reduction of dynamic asymmetry, with values that became approximately one third of those recorded before surgery. The mean difference in motion was nearly 1 cm.

Hontanilla et al.[10] studied two groups of patients, who received either a cross-face facial nerve graft or an ipsilateral masseteric nerve innervation. Two years after surgery, on average the patients rehabilitated with the contralateral facial nerve had a difference between the healthy and paretic labial commissurae of 3.3 mm, while those rehabilitated with the masseteric nerve had a difference of 1.4 mm (in both cases, the larger movement was on the healthy side). Both values are very similar to those obtained in the current group of patients: average differences between the lateral displacement of landmarks ch: 2.4 mm for smile with teeth clenching (that is, use of masseter nerve neural input), and 3.1 mm for smile without teeth clenching (that is, contralateral facial nerve activation). In the masseteric nerve group, Hountanilla et al. report ratio of paretic to healthy side movement identical to the current one obtained with teeth clenching (91%), while in the facial nerve group it was smaller than the current one recorded for voluntary smile without teeth clenching (61% vs. 75%)[10].

These data show that our surgical protocol can enable better percentage of recovery than single nerve techniques using a one-stage technique that has limited adjunctive donor site morbidity[6]. Indeed, Hontanilla et al.[10] remarked that surgery using a cross-face facial nerve graft should be performed in two stages to avoid leaving the transplanted muscle without innervation for several months: the surgical approach used in the current group of patients well responds to this critical approach. In fact neurotization by the masseteric nerve is surely quicker than cross-face one as the axonal ingrowth must travel a shorter distance to reach the gracilis muscle flap.

The spontaneous smile was assessed because of its different neural pathways: the emotional contraction of the mimetic muscles is centrally controlled with excitatory stimuli on the facial nerve nucleus in the brainstem[10,17]. The recording of emotional smiles is more challenging than that of voluntary ones. Indeed, the recording apparatus and experimental set up may impair the patients, and the use of minimally disturbing systems is mandatory[12,18]. We included the vision of a funny spot, that participants can enjoy while sitting inside the working volume and wearing the facial landmarks[8]. Comparing the before and after surgery spontaneous smiles, we observed a reduction in the total healthy side movements, and a modifications in the movement of the paretic side labial commissura. A recent study[17] determined the presence of spontaneous smiles after surgical rehabilitation by clinical observation only, but did not report quantitative data. Indeed, we report quantitative data for this movement in nine patients only, since four patients performed intangible spontaneous smiles in either or both the sessions, according to the exclusion criteria introduced to prevent from considering indices too sensitive to limited movements of the healthy, reference side. Therefore, the current results should be taken with caution until a larger sample would be measured and cannot be directly compared to those obtained by clinical observation only.

As previously suggested[11], we analyzed in detail the lateral displacement of the labial landmarks. Before rehabilitation, all six analyzed labial landmarks (paretic and healthy side cph, ch, li) had considerable lateral movements, all in the healthy side direction (Fig. 4, 5). After treatment, smiles were performed with more correct lateral displacements. The best pre-post surgery result was obtained by the labial commissurae (Fig. 10). When smiling with teeth clenching (ipsilateral masseteric nerve stimulus), the healthy side reduced its lateral mobility of 1 mm on average, while the paretic (rehabilitated) side regained 5.3 mm in the correct direction. The other two labial landmarks (cph and li) had less satisfactory results; for instance, for crista philtri about half of the patients did not have a correct movement, and the result was even worse for the lower lip midpoint. A good result was also obtained when smiling without teeth clenching (contralateral facial nerve stimulus plus cerebral adaptation of the masseteric stimulus).

In conclusion, the quantitative method used in the present study permitted to detect both the alterations in 3D facial movements in patients with long standing unilateral palsy, and their rehabilitation after surgical treatment. We focused our analysis to the perioral region and to smile animations, those most commonly used to assess surgical results[10,18]. Indeed, all patients received other treatments to reanimate other parts of the face, but in the current study we concentrated our measurements on smile function. The significant asymmetry in the magnitude of labial movements that characterized the patients analyzed before surgery reduced after surgery, at least in those facial areas interested by the gracilis muscle free flap. The use of a double donor neural input enabled both movements that were of force similar to those of the healthy side, and spontaneous movements elicited by emotional triggering, maintaining a correct dimension of the muscular free flaps, tailored according to the specific anatomy of the patients.

Funding: None

Conflicts of interest: None declared

Ethical approval: ethical committee of the University of Milan Medical School

REFERENCES

1. Hadlock TA, Malo JS, Cheney ML, Henstrom DK. Free gracilis transfer for smile in children: the Massachusetts Eye and Ear Infirmary Experience in excursion and quality-of-life changes. Arch Facial Plast Surg 2011;13;190-194.
2. Manktelow RT, Tomat LR, Zuker RM, Chang M. Smile reconstruction in adults with free muscle transfer innervated by the masseter motor nerve: effectiveness and cerebral adaptation. Plast Reconstr Surg 2006;118;885-899.
3. Faria JC, Scopel GP, Busnardo FF, Ferreira MC. Nerve sources for facial reanimation with muscle transplant in patients with unilateral facial palsy: Clinical analysis of 3 techniques. Ann Plast Surg 2007;59;87–91.
4. Biglioli F, Colombo V, Tarabbia F, et al. Recovery of emotional smiling function in free-flap facial reanimation. J Oral Maxillofac Surg 2012;70;2413-2418.
5. Watanabe Y, Akizuki T, Ozawa T, Yoshimura K, Agawa K, Ota T. Dual innervation method using one-stage reconstruction with free latissimus dorsi muscle for reanimation of established facial paralysis: simultaneous reinnervation of the ipsilateral masseter motor nerve and the contralateral facial nerve to improve the quality of smile and emotional facial expressions. J Plast Reconstr Aesth Surg 2009;62;1589-1597.
6. Biglioli F, Colombo V, Tarabbia F, et al. Double innervation in free-flap surgery for long-standing facial paralysis. J Plast Reconstr Aesth Surg 2012;65;1343-1349.
7. Sforza C, Frigerio A, Mapelli A, et al. Facial movement before and after masseteric-facial nerves anastomosis: a three-dimensional optoelectronic pilot study. J Craniomaxillofac Surg 2012;40;473-479.

8. Sforza C, Tarabbia F, Mapelli A, et al., Facial reanimation with masseteric to facial nerve transfer: a three-dimensional longitudinal quantitative evaluation. J Plast Reconstr Aesth Surg 2014;67:1378-86.

9. Hontanilla B, Marré D. Comparison of hemihypoglossal nerve versus masseteric nerve transpositions in the rehabilitation of short-term facial paralysis using the Facial Clima evaluating system. Plast Reconstr Surg 2012;130;662e-672e.

10. Hontanilla B, Marre D, Cabello A. Facial reanimation with gracilis muscle transfer neurotized to cross-facial nerve graft versus masseteric nerve: a comparative study using the FACIAL CLIMA evaluating system. Plast Reconstr Surg 2013;131;1241-1252.

11. Frey M, Michaelidou M, Tzou CH, et al. Three-dimensional video analysis of the paralyzed face reanimated by cross-face nerve grafting and free gracilis muscle transplantation: quantification of the functional outcome. Plast Reconstr Surg 2008;122;1709-1722.

12. Al-Anezi T, Khambay B, Peng MJ, O'Leary E, Ju X, Ayoub A. A new method for automatic tracking of facial landmarks in 3D motion captured images (4D). Int J Oral Maxillofac Surg 2013;42;9-18.

13. Sforza C, Guzzo M, Mapelli A, Ibba TM, Scaramellini G, Ferrario VF. Facial mimicry after conservative parotidectomy: a three-dimensional optoelectronic study. Int J Oral Maxillofac Surg 2012;41:986-993.

14. Trotman CA. Faces in 4 dimensions: Why do we care, and why the fourth dimension? Am J Orthod Dentofacial Orthop. 2011;140:895-899.

15. Sforza C, Mapelli A, Galante D, et al. The effect of age and sex on facial mimicry: a three-dimensional study in healthy adults. Int J Oral Maxillofac Surg 2010;39;990-999.

16. Sidequersky FV, Verzé L, Mapelli A, Ramieri GA, Sforza C. Quantification of facial movements by optical instruments: surface laser scanning and optoelectronic three-dimensional motion analyzer. J Craniofac Surg. 2014;25;e65-70.

17. Hontanilla B, Marre D. Differences between sexes in dissociation and spontaneity of smile in facial paralysis reanimation with the masseteric nerve. Head Neck 2014;36:1176-1180.

18. Bray D, Henstrom DK, Cheney ML, Hadlock TA. Assessing outcomes in facial reanimation: evaluation and validation of the SMILE system for measuring lip excursion during smiling. Arch Facial Plast Surg 2010;12;352-354.

FIGURE LEGENDS

Figure 1. Soft tissue landmarks: n, nasion; ft, right and left frontotemporale; ng, right and left naso-genian; cph, right and left crista philtri; ch, right and left cheilion; li, right and left lower lip midpoints.

Figure 2. Reference frames for the assessment of labial mobility in a pre-surgery example (A, rest condition; B, maximum smile). In B, the black arrows represent the labial marker displacements (where tangible) of both facial sides (right, paretic; left, healthy), used for the calculation of the paretic to healthy side movement ratio and the asymmetry index.

Figure 3. Reference frames for the assessment of labial mobility in a post-surgery example (A, rest condition; B, maximum smile with teeth clenching). In B, the black arrows represent the labial marker displacements of both facial sides (right, paretic; left, healthy), used for the calculation of the paretic to healthy side movement ratio and the asymmetry index.

Figure 4. Maximum smile animation: lateral displacement (right-left direction, mm) of labial landmarks before and after surgery without and with teeth clenching (mean ± 1 SD). Positive displacements: healthy side direction; negative displacements: paretic side direction. Before vs after comparisons: 1-way ANOVA: all significant ($p < 0.01$) except ch landmark of the healthy side.

Figure 5. Spontaneous smile animation: lateral displacement (right-left direction, mm) of labial landmarks before and after surgery (mean ± 1 SD). Positive displacements: healthy side direction; negative displacements: paretic side direction. Significant differences before vs. after (Wilcoxon test) ch paretic side, $p = 0.012$; li paretic side, $p = 0.02$; li healthy side, $p = 0.05$).

Figure 6. Patient affected by a long standing right side facial paralysis with a high degree of soft tissues ptosis.

Figure 7. Worsening of the asymmetry while smiling associated by contralateral deviation of right side facial soft tissues.

Figure 8. Twelve month post-surgical reconstruction via a double powered free gracilis muscle transfer: good correction of facial asymmetry at rest.

Figure 9. High grade of symmetry during smiling 12 months post- surgical reconstruction.

Figure 10. Smile with/ without teeth clenching animation: schematic illustration of mean lateral displacements (right-left direction, mm) of cheilion landmarks before and after surgery.

SUPPLEMENTAL DIGITAL CONTENT

All videos were recorded by FB; written consent was obtained from the patient.

Movie 1: Preoperative evidence of complete right side face paralysis (duration:11 s; 1075 Kb)

Movie 2: Good degree of intentional smiling 18 months postoperatively (duration: 9 s; 899Kb)

Movie 3: 18 months post-operatively: evidence of emotional smiling while watching a funny movie (duration: 15 s; 1519 Kb).

Table 1. Total three-dimensional labial mobility during smile movements before (A) and after surgery (B: without teeth clenching; C: with teeth clenching) in 13 patients.

Examination		Max smile before surgery (A)	Max smile after surgery (B)	Max clenching smile after surgery (C)	ANOVA	Post hoc comparisons		
					P value	A vs B	A vs C	B vs C
Healthy side (mm)	Mean	41.7	32.4	35.9	0.036			
	SD	9.7	8.8	11.3				
Paretic side (mm)	Mean	21.9	23.1	29.9	0.012			0.001
	SD	7.3	7.9	9.6				
Ratio (%)	Mean	52.18	74.95	91.18	0.002		0.006	
	SD	10.69	30.72	41.41				
Asymmetry index (%)	Mean	32.27	17.15	8.48	0.001		0.003	
	SD	8.74	18.22	22.13				

Comparisons are made by 1-way ANOVA for repeated measurements; post hoc test are made by paired Student’s test; significant values for ANOVA, $p < 0.05$; significant values for post hoc test, $p < 0.017$).

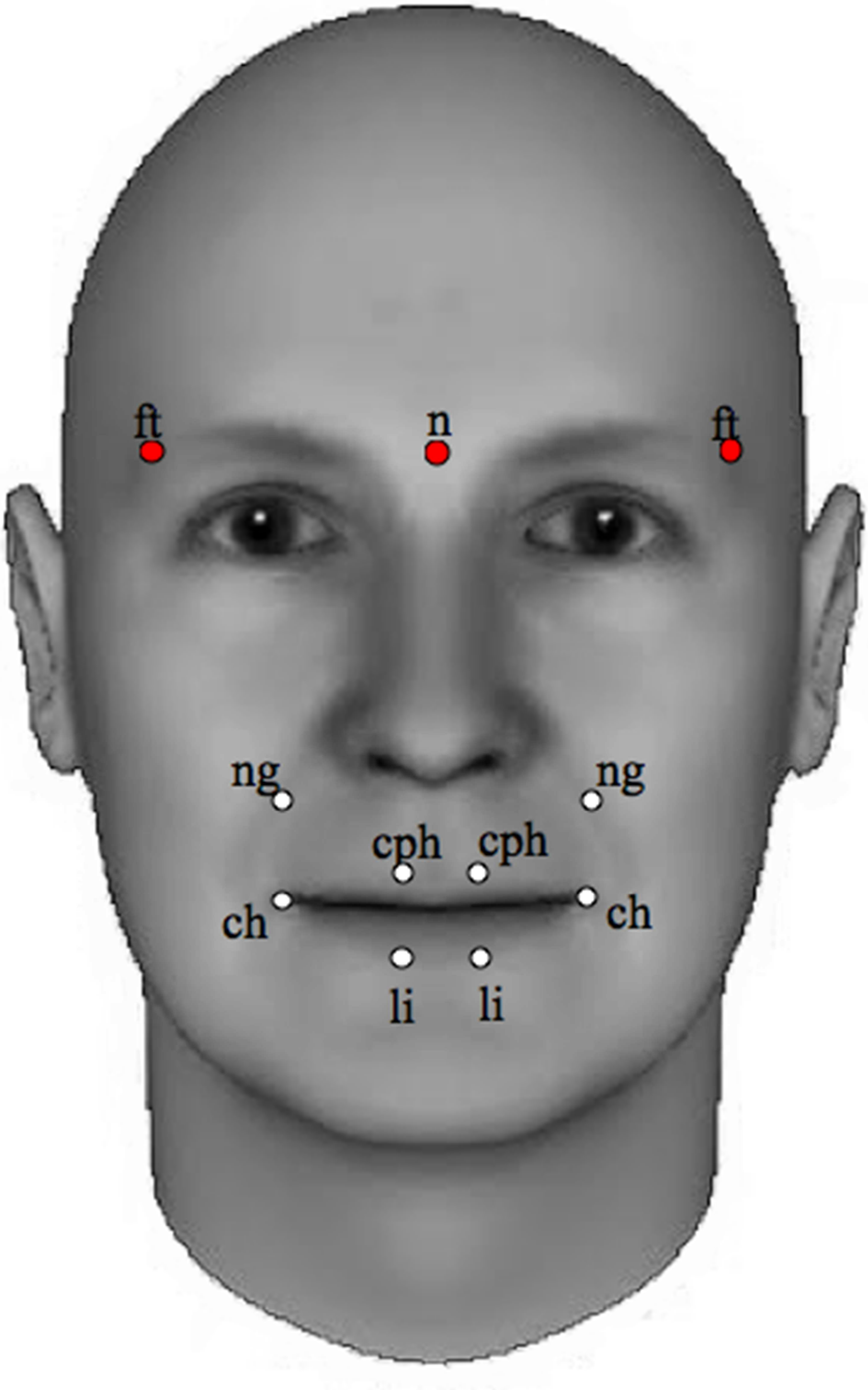
Ratio: paretic/healthy side %

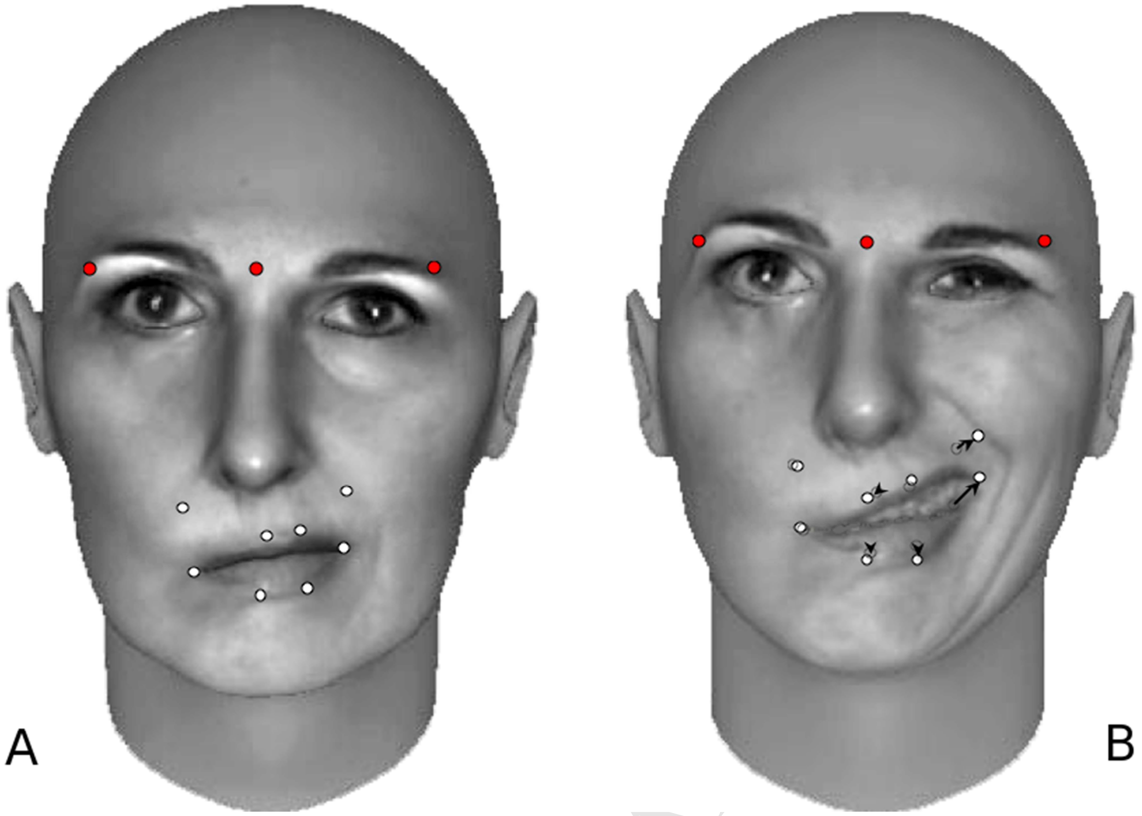
Asymmetry index: percentage ratio between the difference and the sum of the healthy/ paretic displacements

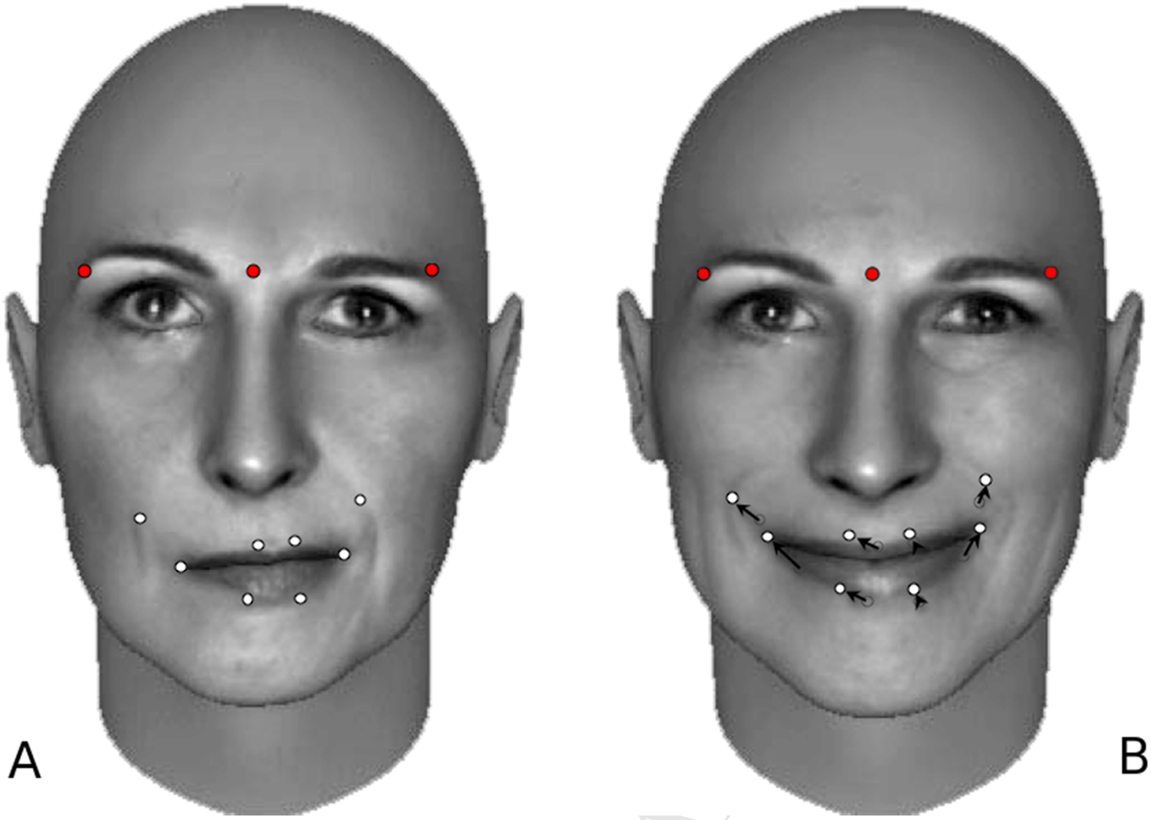
Table 2. Total three-dimensional labial mobility during spontaneous smile movements before and after surgery in nine out of 13 patients.

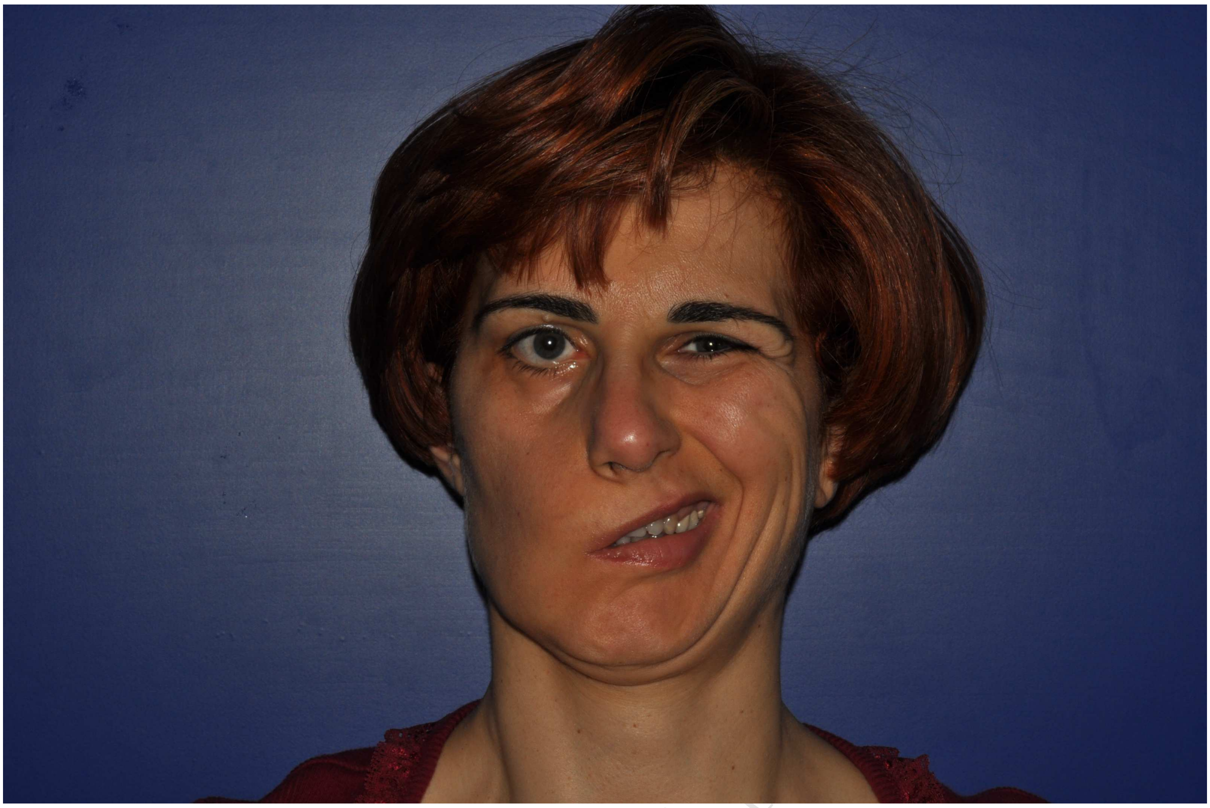
		Spontaneous smile before	Spontaneous smile after	Wilcoxon P value
Healthy side (mm)	Mean	46.5	32.7	0.05
	SD	14.7	11.0	
Paretic side (mm)	Mean	28.8	21.0	NS
	SD	10.2	10.4	
Ratio (%)	Mean	62.28	74.25	NS
	SD	12.75	6.180	
Asymmetry index (%)	Mean	23.52	21.43	NS
	SD	8.74	26.65	

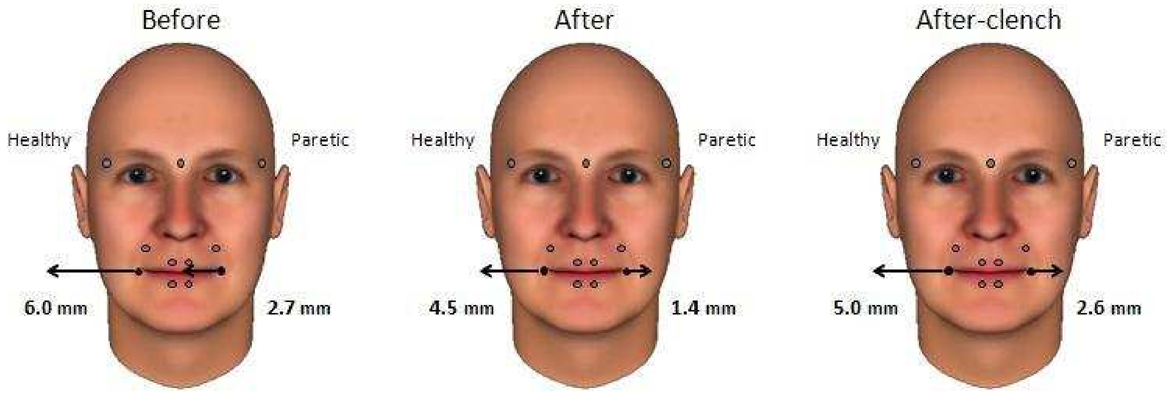
Comparisons are made by Wilcoxon test; NS: not significant, p > 0.05.


ft
n
ft
ng
ng
cph
cph
ch
ch
li
li


A
B


A
B




Before
After
After-clench
Healthy
Paretic
6.0 mm
2.7 mm
4.5 mm
1.4 mm
5.0 mm
2.6 mm