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Double innervation in free-flap surgery for long-standing facial paralysis

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Summary *Objective:* One-stage free-flap facial reanimation may be accomplished by using a gracilis transfer innervated by the masseteric nerve, but this technique does not restore the patient's ability to smile spontaneously. By contrast, the transfer of the *latissimus dorsi* innervated by the contralateral facial nerve provides the correct nerve stimulus but is limited by variation in the quantity of contraction. The authors propose a new one-stage facial reanimation technique using dual innervation; a gracilis muscle flap is innervated by the masseteric nerve, and supplementary nerve input is provided by a cross-face sural nerve graft anastomosed to the contralateral facial nerve branch.

Methods: Between October 2009 and March 2010, four patients affected by long-standing unilateral facial paralysis received gracilis muscle transfers innervated by both the masseteric nerve and the contralateral facial nerve.

Results: All patients recovered voluntary and spontaneous smiling abilities. The recovery time to voluntary flap contraction was 3.8 months, and spontaneous flap contraction was achieved within 7.2 months after surgery. According to Terzis and Noah's five-stage classification of reanimation outcomes, two patients had excellent outcomes and two had good outcomes.

Conclusions: In this preliminary study, the devised double-innervation technique allows to achieve a good grade of flap contraction as well as emotional smiling ability. A wider number of operated patients are needed to confirm those initial findings.

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Currently, the surgical treatment of long-standing paralysis in the central third of the face is achieved primarily by free-flap surgery.[1–3] Harii[4] first reported facial reanimation by gracilis transposition innervated by the deep temporalis nerve, a branch of the trigeminal nerve. This technique has been considered a great improvement in terms of the vector of contraction, quantity of smiling and aesthetic appearance of the face. The main drawback is the type of contraction stimulus provided, which is related to the voluntary clenching of the teeth, and its imperfect coordination with smiling on the healthy side of the face. To overcome this problem, O'Brien et al.[5] and Vedung et al.[6] achieved the correct stimulus by anastomosing the sural nerve on the contralateral facial nerve. After 10–12 months, when the regenerated axons in the nerve graft had reached the tragus on the paralysed side, they transposed a free gracilis flap and performed a second anastomosis to the free end of the sural graft. Among the various muscle flap techniques proposed, this technique has been the standard procedure since the mid-1990s in most reconstructive centres. To overcome the problem of the length of time required for a two-stage facial reanimation while maintaining the advantage of using the contralateral facial nerve as a nerve source, in 1994, Koshima[7] reported a one-stage facial reanimation technique using the rectus femoris. The quantity of contraction achieved with this method was adequate and the type of neural stimulus was correct, but the bulk of the flap was unacceptable. This idea was refined in 1998, when Harii[8] proposed the use of a *latissimus dorsi* flap harvested with a 15-cm length of the thoracodorsal nerve to be anastomosed immediately to a contralateral facial nerve branch. That flap was thinner and the aesthetic results were improved.[9] Percentages of positive results were close to 90% in most of series.[9–11] The main drawback was the quantity of contraction, which was not always guaranteed.[10,11] This problem may be due to the length of the thoracodorsal nerve and the unavoidable loss of axons when the collateral nerve branches are severed to prepare a 15-cm length.

Zuker et al.[12] proposed the use of a gracilis muscle flap anastomosed to the masseteric nerve to achieve reanimation in Möbius patients affected by bilateral facial paralysis with 100% positive results. Based on the positive experience with this technique, it has gained great popularity and has also been used in adults and in patients with unilateral paralysis, with similar results.[13,14] This technique guarantees the rapid reinnervation of the flap (within 2.5–4 months) and successful contraction. Although Manktelow et al.[15] hypothesised that the conversion to spontaneous nerve stimuli was a type of cerebral adaptation, this has not been observed clinically by Faria[10] or by the authors of the present study. Thus, the primary issue consists of the surgeon's choice between a technique that ensures the reliable recovery of function using a flap directly innervated by the masseteric nerve, and one that ensures the recovery of correct stimulus using the contralateral facial nerve.

In an attempt to obtain guaranteed voluntary contraction as well as spontaneous smiling ability with a single surgery, Watanabe et al.[16] used the method of Harii[8] to create a *latissimus dorsi* flap innervated directly by the contralateral facial nerve, and then created a second neurotisation through close contact with an area of the masseteric muscle.

Based on the observation that a one-stage gracilis transfer innervated by the masseteric nerve achieves a higher percentages of positive results than a one-stage transfer using the *latissimus dorsi*, and given the advantages of the synchronicity and spontaneity of stimuli provided by the contralateral facial nerve, the authors have devised a new one-stage reanimation technique with dual innervation: a gracilis muscle flap innervated by the masseteric nerve receives a second nerve input with a cross-face sural nerve graft anastomosed to a contralateral facial nerve branch. In this article, the technical details and preliminary results of this technique are described.

Materials and methods

Surgical technique (Figures 1 and 2)

This incision begins in the temporal region, passes hidden behind the tragus and under the earlobe, and extends 6–8 cm into the cervical region along a skin crease 2 cm caudal to the inferior mandibular border. An anterior skin flap is elevated to access the lower two-thirds of the face.

To ensure the correct formation of the nasolabial fold, the dissection of the skin flap is extended 1.5–2 cm medially to the ideal fold position. When the flap subsequently contracts, the natural skin crease will form a new nasolabial fold that is as symmetrical as possible to that on the contralateral side. To achieve the best aesthetic results, four to six 2/0 polyethylene sutures are positioned across the residual fibres of the orbicularis oris muscle. If this is not visible, the sutures are passed through the deep subcutaneous tissue. One U-stitch may capture the inner musculature of the philtrum if it deviates from the midline.

The masseteric motor nerve is identified within the muscle parenchyma. The zygomatic arch and the posterior border of the masseter muscle serve as surgical landmarks. One need not detach the muscle insertion from the zygomatic arch because the masseteric nerve is deep in this area. The best approach is to enter the muscle 1 cm below the zygomatic arch and 1 cm medial to its posterior border. The nerve lies 1.5–2 cm beneath the muscle surface and can be readily visualised by gently dissecting the muscle fibres along their nearly vertical axis. The fibres divide readily to reveal the nerve.

One or two small collateral branches of the masseteric nerve may be cut in the craniocaudal direction to harvest 2.5–3 cm of the nerve trunk. The nerve is severed at this level and turned superficially to facilitate anastomosis.

A 10 $\times$ 6-cm gracilis muscle flap is simultaneously harvested from the medial thigh following the standard procedure. The flap is transferred into the face pocket and stabilised using only the medial attachment defined by the previously placed sutures. End-to-end vascular anastomosis is performed between the flap and facial vessels. Then, end-to-end neural anastomosis is carried out between the anterior branch of the obturator nerve and the masseteric nerve using 10/0 epineural sutures surrounded by fibrin glue.

On the healthy side of the face, a facelift-type incision is traced posteriorly into the mastoid region with no cervical

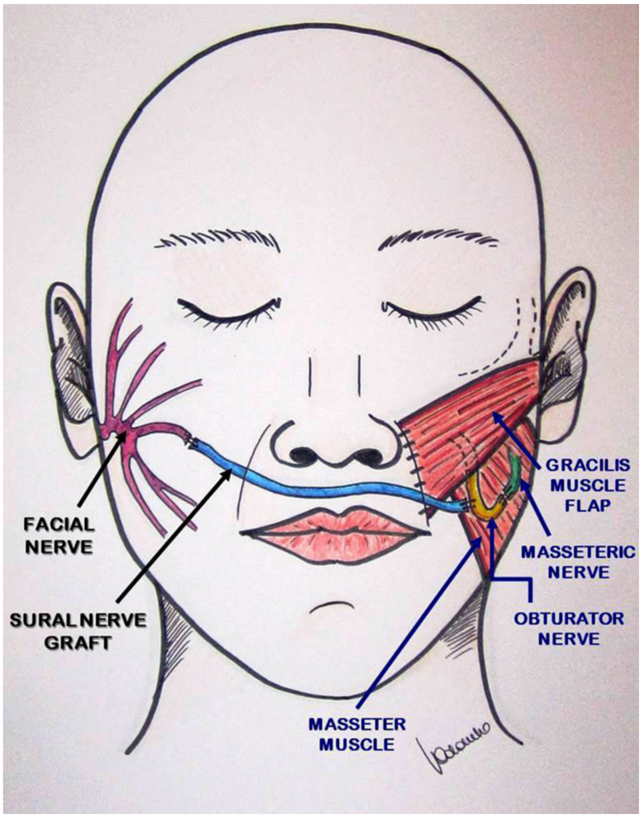

Figure 1 Scheme of surgery. The transposed gracilis muscle flap is innervated by masseteric nerve (end-to-end anastomosis) and contralateral facial nerve (end-to-side anastomosis) through an interpositional sural nerve graft.

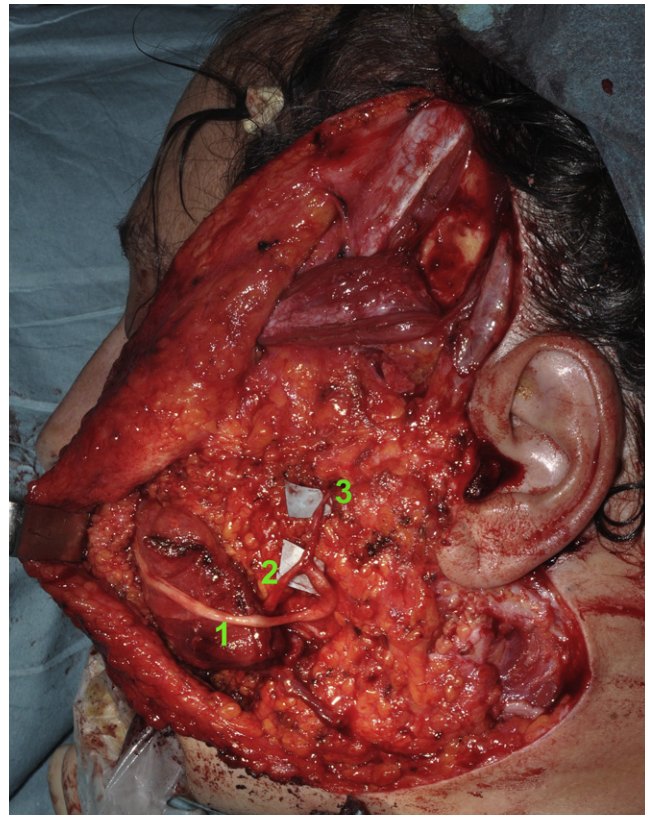

Figure 2 Intraoperative view before setting the masseter muscle over nerve anastomoses. (1) Sural nerve. (2) Anterior branch of the obturator nerve. (3) Masseteric nerve. The intraoperative photograph shows that the patient also underwent the mini-temporalis technique for reanimation of lower eyelid.

extension. Anterior skin flap dissection allows the identification of a middle branch of the facial nerve just medial to the anterior margin of the parotid gland. The involvement of this nerve in a smiling movement is tested with an electrostimulator. A 20–25-cm portion of the sural nerve is then grafted across the face in a reverse manner. The distal end is anastomosed end-to-end with the branch of the facial nerve previously identified. On the paralysed side of the face, the proximal end of the sural nerve is anastomosed end-to-side to the anterior obturator branch, between the hilum of the flap and the anastomosis to the masseteric nerve. An epineural window is opened to allow the end-to-side anastomosis. The inner fascicles and fibres of the receiving nerve are not severed.

Finally, the lateral side of the flap is anchored to the periosteum overlying the zygomatic arch and lateral zygomatic bone. Care must be taken to achieve correct flap tension; insufficient tension will result in inadequate flap contraction, and excessive tension may lead to subsequent spasm of the gracilis.

Patients

Between October 2009 and March 2010, four patients (one man and three women) aged 46–53 years (mean, 49.4 years) with long-standing unilateral facial paralysis received gracilis muscle transfers innervated by the homolateral masseteric nerve and the contralateral facial nerve. Our senior surgeon (FB) performed all the operations. All patients had complete homolateral facial paralysis (House–Brackman stage VI), confirmed by preoperative electromyographic evaluation of the mimetic musculature. The suitability of the masseteric nerve as a donor nerve was also assessed.

Postoperative clinical examinations were performed at 3, 6, 9 and 12 months after surgery. At each office visit, facial objectivity was evaluated at rest and during activation of the mimetic musculature.

Patients were asked to contact the surgical team for an immediate examination when the first voluntary movement of the commissure occurred, or when a relative or friend observed spontaneous activation of the flap during smiling. The patients and people close to them were asked to pay close attention to these types of movement. As soon as voluntary muscle functioning began, the patients were referred to our team's physiotherapist for instruction in physical exercises to be performed in front of a mirror and, later, without a mirror.

Eighteen months after surgery, facial reanimation was assessed in all patients. Standardised photographs were taken and analysed by a team of three persons not involved in the surgery (one physician, one physiotherapist and one nurse). The results were classified according to the system developed by Terzis and Noah.[17]

Electromyography (EMG) and electroneurography were used to assess reinnervation from contralateral facial nerve, through the grafted cross-face suralis nerve.

The EMG coaxial needle electrode was inserted into the gracilis muscle to verify the voluntary recruitment of motor unit action potentials during smiling without clenching the teeth.

Electrical stimulation of the contralateral facial nerve was applied inferiorly and caudally to the contralateral tragus; motor potentials were recorded using the coaxial needle electrode inserted into the gracilis muscle.

Masseteric innervation of the grafted muscle was tested recording voluntary activity asking the patients to clench their teeth and by direct electrical stimulation of the masseteric nerve: motor potentials were recorded using the coaxial needle electrode inserted into the gracilis muscle.

The spontaneity of contraction could be observed readily by talking with patients during examination, when they were relaxed and smiled involuntarily. The spontaneity of flap contraction in response to emotional stimuli was also evaluated as suggested by Terzis and Noah.[17] The patient was left alone in a room to watch a comedic movie for 10 min. To avoid embarrassing the patient or inhibiting his or her spontaneity, no other person was present at this time.

Results

The average duration of surgery was 5.4 h (range, 5–6.1 h). Clinical examination and colour Doppler images confirmed the complete survival of all microvascular flaps. All patients were available for follow-up and recovered partial facial mimetic function.

All patients also recovered voluntary (video 1) and spontaneous (videos 2 and 3) smiling abilities. Voluntary flap contraction was achieved within a mean of 3.8 months (range, 2–4.8 months) and spontaneous flap activation within a mean of 7.2 months (range, 6–8.8 months) post-surgery. The patients also recovered the ability to smile only on the operated side by voluntarily activating the flap, although bilateral symmetric smiling was the goal.

Supplementary video related to this article can be found at doi:10.1016/j.bjps.2012.04.030.

The quantity of contractions improved within 12 months of the initial flap movement. According to the five-stage classification of reanimation results developed by Terzis and Noah,[17] two patients had excellent outcomes (symmetrical smile with teeth showing, full contraction) (Figures 3–6) and two patients had good outcomes (symmetry, nearly full contraction) at 18 months after surgery.

The EMG coaxial needle electrode inserted into the gracilis during smiling without clenching the teeth showed process of reinnervation led by the contralateral facial nerve (Figure 7).

Motor potentials were recorded during electrical stimulation of the contralateral facial nerve using the coaxial needle electrode inserted into the gracilis muscle, showing

Figure 3 Preoperative view at rest of the patient with a complete long-standing left facial paralysis. Ptosis of facial tissues and asymmetry of the face.

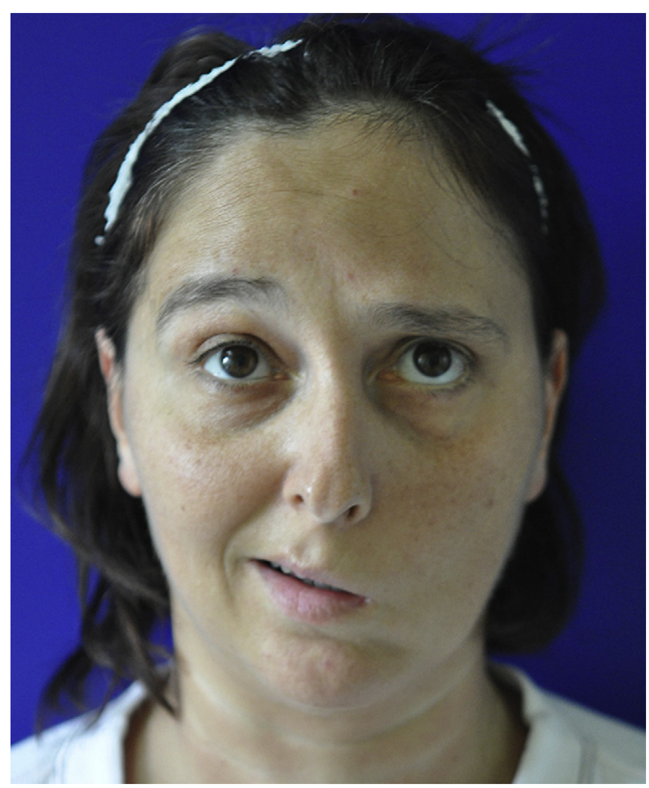

Figure 4 Preoperative view while smiling: note worsening of facial asymmetry.

Figure 5 The same patient at rest 18 months after surgery: no gross asymmetry of the face is noticeable.

Figure 6 Nice smile of the patient 18 months after surgery.

the excitability of the grafted (crossed) facial nerve fibres (Figure 8).

Masseteric innervation of the grafted muscle could not be ascertained by electrical stimulation due to artefacts because of direct muscle stimulation while attempting to stimulate masseteric nerve; the presence of motor reinnervation was assessed by EMG voluntary activity recording obtained by clenching the teeth.

Discussion

Most authors agree that the contralateral side of the face provides the correct stimulus for unilateral facial palsy reanimation.[1,4,18] Both two-stage procedures and one-stage transfers based on contralateral facial nerve innervation aim to rehabilitate natural smiling ability, but the efficacy of these techniques is partially impaired by reduced contraction or complete failure in a significant proportion of patients. Negative outcomes are due to several reasons: one is the major length of the flap nerve, known to be an obstacle to nerve regeneration. Another reason may be axonal loss; two anastomoses are created in two-stage procedures reducing the in-growth of regenerated axons, while the collateral thoracodorsal nerve branches are severed in the widely used one-stage *latissimus dorsi*. This technique is also burdened by a long denervation time that leads to muscle atrophy.[10,11]

By contrast, a gracilis transfer with coaptation of the masseteric nerve leads to almost total functional recovery of flap contraction.[14,19] Although a few reports[13,14,20] have

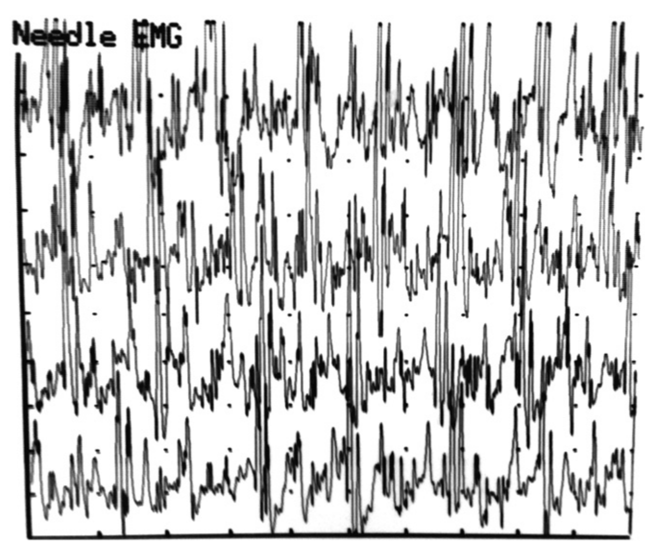

Figure 7 Recruitment of motor unit in gracilis muscle during smiling, without clenching of the teeth.

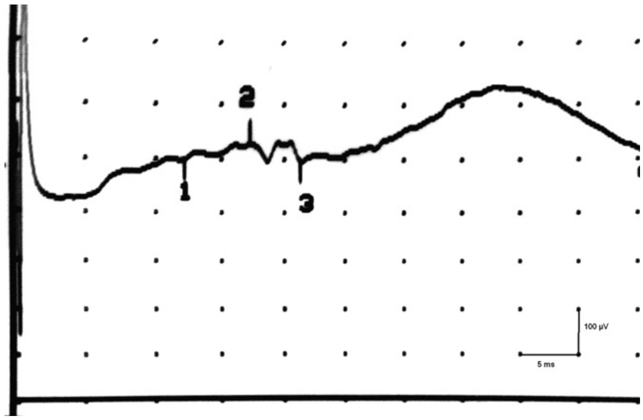

Figure 8 Motor potential recorded into the gracilis muscle while stimulating the contralateral facial nerve.

assessed the recovery of spontaneous smiling, such abilities have not been observed by others[10] or by the authors in clinical practice. As a proof of this, between October 2005 and November 2010, in our Surgical Unit, 11 patients were operated on for long-standing facial palsy by transposition of a gracilis muscle flap innervated only by the masseteric nerve. Follow-up time of all patients was at least 1 year. These patients were examined postoperatively through clinical evaluation and recorded while watching funny videos to check any spontaneity of flap contraction, like the current study. The quantity of contraction was satisfactory in all patients, with achievement of good symmetry at rest and during smile. However, none of the 11 patients recovered the ability to smile spontaneously.

Our idea to combine the use of facial nerve stimulus (to ensure spontaneity) with a masseteric nerve source (to guarantee the quantity of contraction) was borrowed from Yamamoto et al.[21] They introduced the concept of neural supercharge in recent paralysis and demonstrated the effectiveness of using a hypoglossal input in combination with facial nerve stimulus to guarantee an adequate quantity of contraction and the correct facial nerve stimulus. Their concept was based on the observation of reanimation procedures for long-standing paralysis, in which a reduced number of axons reached the muscle as compared to the physiological situation. A double axonal input yields a number of reinnervated fibres that is closer to the normal situation.

Watanabe et al.[16] first reported the use of one-stage free-flap surgery with double innervation for the reanimation of long-standing facial paralysis. They improved *latissimus dorsi* contraction by placing the hilum of the flap in contact with a part of the denuded masseter on the paralysed side. Trigeminal and facial innervation was assessed clinically and by needle electromyography. The authors of the present study devised a similar technique using the gracilis muscle, which has several advantages over the *latissimus dorsi* flap. First, the thickness of the flap is constant, whereas the *latissimus dorsi* is thicker near the hilum and thins distally. Thus, visible bulk may present a problem in the lateral region of the face with the use of Watanabe's technique.[4] Debulking only partly resolves this problem and risks the reduction of contraction. The second advantage of our approach is that all axons passing through the anastomosis between the masseteric and anterior obturator nerves may reach the flap. This is not possible when the contralateral facial nerve branch is anastomosed to the thoracodorsal nerve, as in a one-stage *latissimus dorsi* transfer, because some axons get lost through the collateral branches previously severed to obtain the required 15-cm nerve length.

In a gracilis flap transfer, double innervation is obtained through two epineural anastomoses: an end-to-end anastomosis between the masseteric and anterior obturator nerves, and an end-to-side anastomosis between the distal end of a cross-face nerve graft and the anterior obturator nerve distal to the first anastomosis.

End-to-end anastomosis provides maximal axonal regeneration, but the efficacy of end-to-side neurorrhaphy has also been demonstrated by Viterbo et al.[22] Following their recommendation, we open an epineural window on the side of the nerve when making the end-to-side anastomosis, but do not sever the inner fibres of the receiving nerve.

A potential advantage of this neurotisation technique is that end-to-side neurorrhaphy without disruption of the inner fibres avoids wasting any regenerated axons from the masseteric nerve. Moreover, the masseteric nerve input remains guaranteed, even in case of the failure of axonal input from the cross-face nerve graft to reach clinical significance.[2,9] We did not observe this negative outcome in our patient sample, but many more cases must be studied to confirm our findings.

The favourable quantity of contraction during spontaneous smiling may occur because axons passing through the cross-face nerve graft also trigger the activation of masseteric nerve fibres. This mechanism has also been suggested by Labbè[23] in the double innervation of a lengthened temporalis muscle for facial reanimation.

All single-stage reanimations[24–27] with contralateral facial nerve innervation achieve initial functional recovery within 7–12 months. During the recovery time, muscle fibres are partially but irreversibly atrophied. A more rapid innervation procedure would reduce this phenomenon. This observation gave rise to the concept of babysitting used for recent paralyses.[28] This technique is based on the rapid innervation of the mimetic musculature by cranial nerve XII prior to the 'preferred' innervation by the contralateral facial nerve. Similarly, in case of free-flap transposition, minimisation of muscle atrophy should increase functional results; masseteric innervation may be helpful in reducing muscle flap atrophy during the denervation period because reanimation starts sooner than when cross-facial nerve grafts are used (within a mean of 3.8 months after surgery).[16]

Watanabe et al.[16] have emphasised the importance of a patient's ability to smile on the reconstructed side with or without smiling on the healthy side. Homolateral activation is due to masseteric innervation, as contralateral facial nerve input rarely allows the flap to function independently from the healthy side of the face.[9] Our observations confirmed this, but patients do not frequently use unilateral smiling and the predominant movement is a symmetrical smile.

In this preliminary study, the devised double-innervation technique allows to achieve a good grade of flap contraction as well as emotional smiling ability. A wider number of patients are needed to confirm these initial findings.

Conflict of interest statement

The authors have no financial interests or personal relationships with other people or organisations that may have inappropriately influenced the work presented here.

We have no funding and we have do not have any conflicts of interest to declare nor ethical approval.

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