One-Stage Reanimation of the Paralyzed Face Using the Rectus Abdominis Neurovascular Free Flap

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Background: Functional free muscle transfer for the surgical correction of long-standing facial paralysis has gained validity over the past three decades. These traditionally multistep reconstructions often achieve clinical success, but at the cost of significant morbidity and lengthy recovery periods. To address this dilemma, the authors propose reconstruction using the rectus abdominis and accompanying intercostal nerve in a one-stage neurovascular free flap reanimation procedure.
Methods: Between 1998 and 2001, five patients with long-standing unilateral facial paralysis at the University of Pittsburgh Facial Nerve Center underwent reanimation using the authors' protocol. Preoperative and postoperative assessments included clinical evaluation using the Facial Grading System and electromyography. The patients were followed for a mean of 16 months.
Results: At the final postoperative visit, all five patients demonstrated improved levator electromyographic potential, with a median 67 percent improvement. All five patients further demonstrated an increase in zygomaticus electromyographic potential, with a median 225 percent improvement. All five patients demonstrated increased Facial Grading System score at most recent follow-up.
Conclusions: The one-step reanimation using free rectus abdominis neurovascular free flap demonstrated a consistent positive outcome in electromyographic and clinical assessments. The additional benefits of reduced recovery time and anatomical reliability of the flap render the authors' method preferable to other traditional methods of surgical reanimation of the paralyzed face. (*Plast. Reconstr. Surg.* 117: 1553, 2006.)

The treatment algorithm of long-standing facial paralysis has undergone a major revolution in the past three decades with the advent of free tissue transfer techniques for facial reanimation. In 1976, a report of the reconstruction of two patients with long-standing Bell's palsy by Harii et al.[1] described a vascularized gracilis free muscle transfer, neurally anastomosed to the trigeminal nerve. The procedure enabled these patients to exert a measure of control over a previously nonfunctional facial hemisphere. Since then, several protocols have been described and successfully applied to a variety of facial paralysis patients.

Reanimation is classically performed in two stages. The first stage consists of nerve transfer and/or nerve graft followed by an 8- to 12-month axonal regeneration period. In the second stage, free muscle is transferred, and its neural component is anastomosed to the regenerating nerve in the recipient site. In one-stage reanimation, donor nerve and muscle are simultaneously transferred during a single procedure. One-stage reanimation has shown potential to significantly reduce recovery time.[2]

Surgeons who prefer the traditional two-stage method may state that staging reanimation obviates the need for dissection of the donor nerve at the time of muscle transfer and eliminates an incision on the cheek.[3] However, the two-stage process necessitates a lengthy waiting period in between two operations, in addition to the inconvenience of recovering from two separate procedures. In addition, a 4- to 8-month postop-

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erative period is needed for reinnervation of the transferred muscle.[4] From the initial operation, the time to recovery in a two-stage reanimation procedure can approach 20 months.

This article reports the application of the rectus abdominis neurovascular free flap in a one-step reanimation procedure. This procedure was adapted from a single prior report of rectus abdominis single-stage reanimation from Koshima and colleagues.[5] This approach is designed to reduce the morbidity and shorten the recovery time of previously described two-stage reconstructions. In addition, this technique uses a donor muscle that has highly desirable intrinsic harvesting and transfer characteristics.

PATIENTS AND METHODS

Patient Selection

Between April of 1998 and August of 2001, five patients with long-standing unilateral facial paralysis underwent one-stage reanimation with a rectus abdominis neurovascular free flap. The patients' ages ranged from 11 to 64 years. The causes of paralyses were as follows: posttraumatic ($n = 1$), postinfectious ($n = 1$), postoncologic ($n = 2$), and congenital seventh and eighth nerve palsy ($n = 1$). Excluding one international patient, all patients received neuromuscular reeducation before receiving free flap reanimation. Patients were then offered free flap reanimation to improve their volitional smile if continued improvement had not been made with physical therapy after a 6-month period.

Clinical Evaluation

The Facial Grading System is a 100-point evaluation that assesses impairments in resting symmetry, symmetry during voluntary movement, and synkinesis of voluntary movement. The Facial Grading System score was obtained at initial visit and at each of the follow-up visits by a trained physical therapist (J.V.S. or T.C.H.).

Five standard facial expressions were used to assess voluntary movement and synkinesis. They included forehead wrinkle, eye closure, open-mouth smile, snarl, and lip pucker. A score of 100 on the Facial Grading System indicated normal facial movement, and 0 indicated complete facial paralysis.[6] In our assessment, we used the Facial Grading System at most recent follow-up.

Surgical Technique

The procedure is initiated by making an incision in the midline below the umbilicus and then across the lower abdomen in a gently sweeping curve. This allows access to the rectus fascia and muscle. Before mobilizing and dissecting the muscle, a 10- to 15-cm of rectus fascia can be harvested that can be used as a fascial sling.

Next, the rectus muscle is harvested along with the intercostal nerve. The deep inferior epigastric artery and vein are identified. After obtaining an adequate length of pedicle, the muscle flap is raised. With the rectus sheet being retracted to the sides, the intercostal nerve is located. The nerve is stimulated and contraction of the muscle segment to be harvested is confirmed. By lateral dissection toward the lateral axillary line, a 12- to 15-cm length of the intercostal nerve can be isolated.

After this, an appropriate size rectus muscle, the inferior epigastric vascular bundle, and the contributing intercostal nerve are harvested. Typically, a 4 × 5-cm segment of muscle is obtained.

The recipient site preparation is done by first identifying the buccal branch of the facial nerve on the nonparalyzed site. This branch is identified by making an incision halfway between the tragus and the lateral oral commissure. This branch is then encircled with a vascular loop.

Next, an incision is made in the region of the nasolabial fold and the dissection is continued toward the zygoma superiorly and the orbicularis oris inferiorly. After this, the highest crease within the neck is identified and a 4-cm incision is made and, through it, the facial artery and vein are identified and encircled with vascular loops.

As part of the preparation, four 4-0 Prolene sutures are placed into the deep tissues of the zygoma. Similarly, five 4-0 Prolene sutures are placed around the orbicularis oris muscle inferiorly. These sutures are used to parachute the muscle to the area superiorly and inferiorly, respectively.

Next, the Prolene sutures are placed as looped stitches with two passes through the muscle and tied in place, setting the muscle from lateral to medial direction. The vascular pedicle is positioned in a subcutaneous tunnel toward the neck in the region of the facial artery and vein.

Using the same technique, sutures are passed through and back through to encircle the muscle. In this way, the muscle is secured into position inferiorly.

Electromyography

Electrophysiologic testing is a useful adjunct to clinical observation in patients with facial palsy. Electromyography detects electrical activity at rest and the depolarization and repolarization of the peripheral nerve that occurs during voluntary muscle contraction.[7] Electromyographic surface electrodes were placed on the skin overlying the muscle groups under investigation. We performed preoperative and serial postoperative electromyography to measure the volitional responses of the facial musculature.

Various muscles of facial expression were tested, including orbicularis oris, buccinator, and risorius. Two muscle groups that were consistently tested were the zygomaticus and levator groups. Specifically, we tested the zygomaticus during open-mouthed smiling and the levators during puckering motion. Peak muscle activity from each muscle group during maximal exertion voluntary movement was recorded by a trained physical therapist (Fig. 1).

RESULTS

Patients received preoperative assessment at the University of Pittsburgh Facial Nerve Center. All patients underwent clinical evaluation and preoperative and postoperative electromyographic testing. Each patient was followed postoperatively with electromyographic testing for an average of 16 months (range, 6 to 44 months). There were no postoperative complications reported in the five patients. All five patients self-reported subjective improvement in facial movement at their final postoperative visit (Fig. 2).

The median preoperative electromyographic potential for the levators during voluntary movement was 6 μV (range, 3 to 20 μV). At most recent follow-up, the median electromyographic potential for the levators during voluntary movement was 20 μV (range, 9 to 24 μV). All five patients displayed increased electromyographic potential at the levator muscle site, with a median 67 percent improvement (range, 10 to 400 percent).

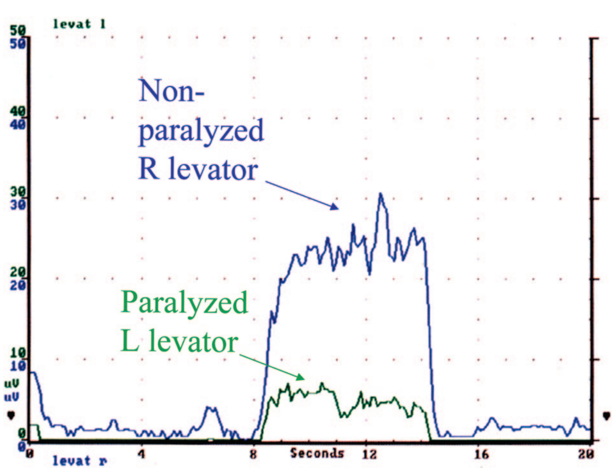

Fig. 1. Electromyographic reading of the levators of a patient with left facial paralysis. This electromyographic reading was performed during voluntary movement. The higher peak represents the nonparalyzed, right levator electrical activity. The lower peak represents the paralyzed, left levator electrical activity.

The preoperative electromyographic potential for the zygomaticus muscle group ranged from 0 to 30 μV, with a median of 4 μV. All five patients had increased electromyographic potential at their final postoperative visit, with a final median potential of 20 μV (range, 13 to 50 μV) and a median 225 percent improvement (Fig. 3).

With a normal Facial Grading System score being 100 and a score of 0 signifying a complete unilateral palsy, baseline Facial Grading System score was established for the patients. All five patients in the series showed an improvement in Facial Grading System score at most recent follow-up, with the median score improving from 16 to 38 (Fig. 4). The most pertinent portion of the Facial Grading System was the subscore for voluntary movement, which assessed the five standardized facial expressions. In correlating clinical assessment to the electromyographically tested muscle groups, four of five patients had clinically detectable improvement in their open-mouth smile, and all five patients had improved movement during a closed-mouth pucker.

DISCUSSION

Since Harii et al.[1] described a vascularized gracilis free muscle transfer, plastic surgeons have regarded dynamic reanimation as the treatment goal in facial nerve paralysis. This innovation has prompted others to expand on the idea of using an autologous neurovascular muscle transfer for facial reanimation and led to the development of systematic protocols.

Even though the original technique presented by Harii et al.[1] was a one-stage operation, it was functionally limited because the gracilis muscle was anastomosed to the temporal branch of the trigeminal nerve. Facial movements had to be methodically reinstated, lacked spontaneity, and were elicited at inappropriate times, such as when the jaws were clenched.

The logical alternative to this technique was the anastomosis of a neural graft to the ipsilateral facial nerve, which is generally atrophied in longstanding facial paralysis, or more suitably to a branch of the unaffected contralateral facial nerve. In 1980, O'Brien et al.[8] described a two-stage operation using a cross-face nerve graft act-

Fig. 2. Preoperative and 15-month postoperative photographs of a patient after left facial reanimation with free rectus flap and fascial sling placement. (*Above*) The patient at rest, during open-mouth smile, and during pucker. (*Below*) The patient at rest, during open-mouth smile, and during pucker.

ing as a conduit between the contralateral facial nerve and the transferred neurovascular graft.

In the first stage, a donor nerve, usually the sural, is excised and anastomosed to the facial nerve on the side contralateral to the deficit. This is done to provide a much-desired coordinated spontaneity to the reconstructed side. The nerve is tunneled subcutaneously across the upper lip to the melolabial region of the dysfunctional side, the operative site is closed, and the nerve is permitted to undergo axonal regeneration. After a period of approximately 1 year, when the grafted nerve has demonstrated sufficient axonal growth as evidenced by a positive Tinel sign, the second part of the reanimation procedure takes place.

A donor muscle, complete with a neurovascular pedicle, is harvested. The previously grafted nerve is exposed through an incision in the melolabial fold and a preauricular incision is used to gain access to the recipient site. A skin flap is elevated and the muscle is inserted into the resulting pocket. The motor nerve of the muscle is anastomosed to the crossed donor nerve and vascular anastomoses are completed, generally using either the facial or superficial temporal vessels. The muscle is positioned and trimmed so that it comes to lie over the zygomaticus major muscle. Muscular attachments are made superolaterally to the zygoma and then medially to the area or areas in which reanimation and support are desired.

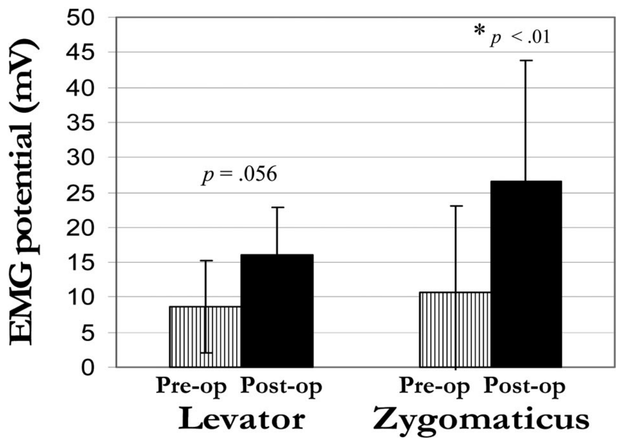

Fig. 3. Preoperative and postoperative electromyographic readings from levator and zygomatic muscle groups from the paralyzed side. The left set of graphs show a mean increase of 145 percent in levator electromyographic activity ($p = 0.056$). The right set of graphs show a significant mean increase of 218 percent in zygomaticus electromyographic activity ($p < 0.01$).

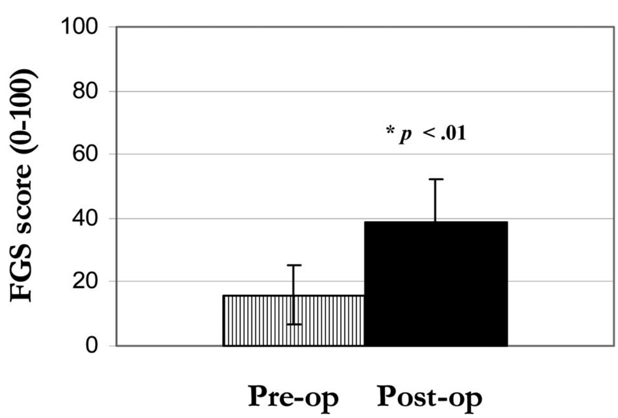

Fig. 4. Preoperative and postoperative Facial Grading System score. A score of 100 indicates normal facial function and a score of 0 indicates complete facial dysfunction. With free rectus reanimation, Facial Grading System score improved from a mean of 16 ± 9 to a mean score of 39 ± 16 (range, 25 to 55), with an average improvement of 186 percent ($n = 5$) ($p < 0.01$).

The two-stage technique became the standard of care for a number of years, yet it has been associated with a number of drawbacks. It can be argued that with two suture sites within the nerve, there is a higher potential for restriction of axonal development. Furthermore, the disadvantage of a two-stage approach is that the harvesting of a bridging nerve invariably leaves the patient with a sensory deficit. This deficit may discourage a patient from attempting the procedure using a sural nerve harvest because of the resulting foot hypesthesia or paresthesia. Primarily, though, the criticism of the two-stage procedure is that the interoperative period between stages adds nearly 12 months to an already significant rehabilitative period.

To overcome these obstacles, Nakajima[9] advocated using a single-stage reconstruction. Kiang and Kuo,[2] Wang et al.,[10,11] O'Brien,[12] Koshima et al.,[5,13] Harii et al.,[14] Wei et al.,[15] and Kumar[16] each proposed single-stage procedures using a variety of muscle donors. In 1995, Kumar[16] presented the results of the single-stage reanimation procedure, in which the gracilis muscle was transferred without having to use an intervening donor nerve. The key to the success of this procedure relied on reversing the muscle orientation in the recipient site and keeping the neural pedicle of the gracilis long enough to traverse the distance to the contralateral facial nerve. Thus, single neural anastomosis was made concomitantly with the vascularized muscle transfer. This allowed shortening of the long interoperative period, reducing the functional deficits associated with the harvesting and grafting of a bridging nerve. A comparative study of single-stage versus two-stage procedures by Kumar and Hassan[17] revealed fewer complications in patients who undergo a single-stage procedure, with good to fair results in 90 percent of these patients.

In 1990, Hata et al.[18] reported the use of the rectus abdominis muscle in a two-stage repair of facial paralysis, with satisfactory results. The rectus abdominis muscle graft was first successfully applied in a single-stage reanimation procedure by Koshima and colleagues in 1997.[5] Incorporating the principles of the single-stage repair, and expanding on the use of the rectus abdominis muscle, we present here the first case series of single-stage rectus abdominis free muscle transfers. We propose that this method holds certain advantages over the two-stage treatment modality.

The rectus abdominis has an anatomically reliable vascular supply from the deep inferior epigastric artery and vein. This vascular supply is not only relatively large in diameter but also can be appropriately matched to the size of the facial vasculature, thus facilitating anastomoses under microscopic technique. More importantly, though, is the pedicle length of this vascular supply, which averages between 6 and 10 cm. With such ample working distances, the inferior epigastric supplies the plastic surgeon with a number of insertion and anastomosis options within the facial and neck field.

In terms of neural supply, the rectus abdominis is segmentally innervated from the terminal branches of the lower six intercostals nerves, with a nerve length ranging from 3 to 15 cm. This allows the nerve to sufficiently traverse the distance to the contralateral facial nerve. Furthermore, the ability to anastomose the numerous segmental nerves to more than one branch of the contralateral facial nerve provides the surgeon with the potential for a greater array of innervation options. A recent study by Duchateau et al.[19] and the operative findings of Hata et al.[18] confirmed a consistent motor nerve topography penetrating the muscle approximately 3 cm from the lateral edge, ensuring the surgeon a consistent anatomical location.

As a technical consideration, the rectus abdominis can be harvested at the same time the donor site is being prepared, significantly decreasing the time spent in the operating room. Furthermore, there is no additional nerve or donor-site morbidity. The operative scar can be hidden within the waistline, and the flexion of the abdomen is sufficiently compensated for by the remaining musculature. The potential risk of abdominal wall instability and herniation is minimized by only harvesting a segment of the rectus muscle and by meticulous closing of the rectus sheath.

Although most donor muscles tend to be larger than the intrinsic muscles of the face, the rectus abdominis is a flat muscle that is appropriately sized for facial grafting and reanimation. In instances where excess tissue is present, the rectus abdominis, with its parallel muscle fibers and reliable vascular pedicle, can effectively be debulked in situ, allowing for precise sizing and hemostasis.

In terms of strength required for a donor muscle to be effective, it has been reported by Wei et al. that,[15] in single-stage latissimus dorsi flaps, only 25 percent of the strength of the muscle remains by the time the graft has become functional. This limits muscle choice to those that will sustain adequate contractile strength following atrophy. The main problem faced when using the extensor digitorum brevis muscle was that, by the time axonal regeneration had taken place, the muscle had atrophied beyond functional standards. The rectus abdominis, although small enough to be aesthetically incorporated into the face, has enough intrinsic mass to tolerate this loss of function and still provide adequate contractility. However, final results rest on the surgeon's discretion in debulking the muscle, hedging the appropriate aesthetic bulk against the functionality of the muscle. Specific protocols and standards have yet to be described.

One of our patients had a fascial sling placed for muscle suspension in addition to the free rectus reanimation. This particular patient had a 400 percent improvement in her levator electromyographic potential. Preoperatively, she had no discernible electromyographic reading from her zygomaticus muscle group but had a postoperative zygomatic electromyographic potential of 20 μV at most recent follow-up. She also demonstrated a 210 percent increase in Facial Grading System score, signifying that her recovery was functionally significant. Although our experience is limited, we believe that fascial sling placement in addition to free rectus reanimation can enhance clinical outcome.

Although we had at least some functional improvement in all five patients in the series, we do not suggest that this current procedure is a panacea. Although we saw improvement, some of the functional improvement could be explained by the continued physical therapy and the static support provided by the free flap. Static support could explain the large gains in function in the patient with the static sling. Aesthetic improvement was admittedly moderate. Although symmetry and voluntary movements were improved, these were not within the normal range. This case series provides great possibility for future treatment and is a step forward in the search for highly functional facial reanimation.

Above all, the rectus abdominis has the distinct advantage of having tendinous inscriptions down the length of the muscle, making it possible to have reliable points of insertion in the recipient site. Combined with the ability to separate the tissue into several distinct muscle bellies each with its own nerve fascicle, the rectus can be inserted reliably into a number of different structures to provide consistently firm support and dynamic movement. Given these considerations, we feel that the choice of the rectus abdominis muscle using a single-stage technique affords the surgeon several unique benefits not found with other types of procedures.

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REFERENCES

1. Harii, K., Ohmori, K., and Torii, S. Free gracilis muscle transplantation with microneurovascular anastomosis for the treatment of facial paralysis: A preliminary report. *Plast. Reconstr. Surg.* 57: 133, 1976.
2. Kiang, H., and Kuo, E. T. One-stage reconstruction of facial paralysis using the abductor hallucis muscle. Presented at the Third Joint Meeting Between Chinese and Japanese Plastic and Reconstructive Surgery, Shanghai, China, in October of 1991.
3. Chuang, D. C. C. Technique evolution for facial paralysis reconstruction using functioning free muscle transplantation: Experience of Chang Gung Memorial Hospital. *Clin. Plast. Surg.* 29: 449, 2002.
4. Buncke, H. J., Buncke, G. M., Kind, G. M., Buntic, R. F., Brooks, D., and Chin, B. T. Cross-facial and functional microvascular transplantation for long-standing facial paralysis. *Clin. Plast. Surg.* 29: 551, 2002.
5. Koshima, I., Tsuda, K., Hamanaka, T., and Moriguchi, T. One-stage reanimation of established facial paralysis using a rectus abdominis muscle transfer. *Plast. Reconstr. Surg.* 99: 234, 1997.
6. Henkelmann, T. C., and May, M. Physical therapy and neuromuscular rehabilitation. In M. May and B. M. Schaitkin (Eds.), *The Facial Nerve*, May's Second Edition. New York: Thieme, 2000. Pp. 301–317.
7. Schaitkin, B. M., May, M., and Klein, S. R. Topographic, otovestibular and electrical testing: Diagnosis and prognosis. In M. May and B. M. Schaitkin (Eds.), *The Facial Nerve*, May's Second Edition. New York: Thieme, 2000. Pp. 213–228.
8. O'Brien, B. M., Franklin, J. D., and Morrison, W. A. Cross-facial nerve grafts and microneurovascular free muscle transfer for long established facial palsy. *Br. J. Plast. Surg.* 33: 202, 1980.
9. Nakajima, H. One-stage reconstruction of facial paralysis using the rhomboideus major muscle. Presented at the 126th Local Meeting of the Tokyo District of Japanese Society of Plastic and Reconstructive Surgery, Tokyo, Japan, in April of 1986.
10. Wang, W., Chang, T., Yang, C., et al. Ultra-long neurovascular latissimus dorsi for facial reanimating in one stage. *Chin. J. Microsurg.* 12: 155, 1989.
11. Wang, W., Chang, T., Yang, C., et al. Ultra-long neurovascular pedicle segmental muscle flap transfer for facial reanimation in one stage. *Chin. J. Med.* 72: 681, 1992.
12. O'Brien, B. M. One-stage reconstruction of facial paralysis using the gracilis muscle transfer. Presented at the 10th Symposium of the International Society of Reconstructive Microsurgery, Munich, Germany, in September of 1991.
13. Koshima, I., Moriguchi, T., Soeda, S., Hamanaka, T., Tanaka, H., and Ohata, S. Free rectus femoris muscle transfer for one-stage reconstruction of established facial paralysis. *Plast. Reconstr. Surg.* 94: 421, 1994.
14. Harii, K., Asato, H., Yoshimura, K., Sugawara, Y., Nakatsuka, T., and Ueda, K. One-stage transfer of the latissimus dorsi muscle for reanimation of a paralyzed face: A new alternative. *Plast. Reconstr. Surg.* 102: 941, 1998.
15. Wei, W., Zuoliang, Q., Xiaoxi, L., et al. Free split and segmental latissimus dorsi muscle transfer in one stage for facial reanimation. *Plast. Reconstr. Surg.* 103: 473, 1999.
16. Kumar, P. A. V. Cross-face reanimation of the paralyzed face, with a single stage microneurovascular gracilis transfer without nerve graft: A preliminary report. *Br. J. Plast. Surg.* 48: 83, 1995.
17. Kumar, P. A. V., and Hassan, K. M. Cross-face nerve graft with free-muscle transfer for reanimation of the paralyzed face: A comparative study of single-stage and two-stage procedures. *Plast. Reconstr. Surg.* 109: 451, 2002.
18. Hata, Y., Yano, K., Matsuka, K., Ito, O., Matsuda, H., and Hosokawa, K. Treatment of chronic facial palsy by transplantation of the neurovascularized free rectus abdominis muscle. *Plast. Reconstr. Surg.* 86: 1178, 1990.
19. Duchateau, J., Declety, A., and Lejour, M. Innervation of the rectus abdominis muscle: Implications for rectus flaps. *Plast. Reconstr. Surg.* 82: 223, 1988.