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Magnetic resonance imaging of microneurovascular free muscle flaps in facial reanimation☆

T.M. Ylä-Kotola*, **M.S.C. Kauhanen, S.K. Koskinen, S.L. Asko-Seljavaara**

Department of Plastic Surgery and Department of Radiology, Helsinki University Hospital, P.O. Box 266, 00290 HUS, Helsinki, Finland

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Summary The purpose of this study was to describe the survival and volume of microneurovascular muscle flaps at different times after two-stage facial reanimation procedure by using magnetic resonance imaging (MRI) and to compare the functional outcome with MRI findings.

Fifteen patients with a mean age of 36 years (range 7–63 years) operated on between 1988 and 1999 were available for this study. The muscles used for functional reconstruction were the latissimus dorsi (eight patients), gracilis (six patients) and serratus anterior (one patient). Hospital charts were reviewed and the clinical outcome of facial reanimation was graded on a scale from 1 to 6 according to House. The mean postoperative follow-up time was 7 years (range 3–14 years). Clinical grading and 1.5 T unit MRI of patients were performed concomitantly. The MR images were evaluated semi-quantitatively so that the muscle structure of the free flaps was graded on a scale from 1 to 4. The free flap area of each slice was defined and the volume of the free flap was calculated. Data were analysed statistically.

The long-term functional outcome of the facial reanimation was regarded as good in 10 patients, which means they had only mild or moderate dysfunction of facial movements. In MR images, six free flaps displayed normal muscle structure, another six had a fatty appearance and two displayed severe muscle atrophy; in one patient the muscle tissue could not be identified. The volume of the free flap clearly declined in the course of the follow-up. A correlation was found between good functional outcome and normal muscle structure of the free flap in MRI, $p = 0.020$. The longer the follow-up time after muscle transplantation the poorer the functional result. A similar correlation was found between abnormal muscle structure in MRI and a long follow-up time.

Magnetic resonance imaging can be used to assess the muscle structure of free microneurovascular flaps. Normal findings in MRI seem to correlate with a good clinical outcome in facial reanimation. A good functional result correlates with a shorter follow-up time and normal muscle structure in MRI.

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* Corresponding author. Tel.: +358-9-47187217; fax: +358-9-47187570.
E-mail address: tuijaylakotola@hotmail.com

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Long-standing facial paralysis is a serious functional and aesthetic problem for the patient, and treatment often requires multiple surgical procedures.[1] The two-stage method to reanimate long-standing facial paralysis by cross-facial nerve grafting and later free microneurovascular muscle transfer has been the standard treatment of choice for over 20 years.[2] Despite long experience, however, the functional outcome of reanimation is still to some extent unpredictable.[3–5]

Magnetic resonance imaging (MRI) is an effective method for investigating changes in skeletal muscles after operation and trauma and also in muscular diseases.[6–8] Many studies have been conducted on the MRI appearance of denervated skeletal muscles.[6,9–11]

In a clinical denervation study paralyzed muscles of the upper extremities showed high signal intensity on T2-weighted images. This was observed 15 or more days after the denervation.[11] In another clinical study, muscles denervated because of traumatic lesions of peripheral nerves showed marked atrophy and fatty infiltration on T1-weighted images.[6] In three patients, MRI findings became normal after relief of the paralysis and thus denervation.[6,11] One of the patients received a nerve graft after median and ulnar nerve transsection; 15 months later this muscle was clinically reinnervated and the MRI findings appeared normal.[6]

In a recent study describing MRI findings in two patients with perineural spread of tumours, T2 prolongation was seen in facial muscles, suggesting denervation changes.[10] Microvascular free flaps have been subjected to MRI before,[12–15] but no study has previously been published to follow-up free microneurovascular flaps in MRI. In microvascular flaps, the nerve supply to the flap is often surgically interrupted, leading to muscle atrophy, which results in a predominantly fatty appearance of the flap on MR images.[15] In our earlier studies, microvascular flaps showed less intramuscular oedema and more fat degeneration 6 months postoperatively than in MRI right after the operation.[14] Furthermore, the volume of the flap increased at 2 weeks after the operation but returned to its initial volume at 6 months postoperatively.[14]

Our aim here was to describe the maintenance of muscular structure and volume of microneurovascular flaps at different time periods after facial reanimation by using MRI. We had earlier recorded the clinical functional outcome by using the standard House scale.[16] The present study compares the clinical outcome and patient data with MRI findings.

Patients and methods

Patients

A total of 15 out of 35 patients operated on at Helsinki University Hospital between 1988 and 1999 were available for both late clinical grading and MRI. All the patients had complete, unilateral, long-lasting facial paralysis. The aetiology of the facial paralysis was removal of acoustic neuroma (5), parotidectomy (3), removal of intracranial tumours (1), trauma (1), congenital (2), cholesteatoma (1) and not known (2). The two-stage method was used to reanimate the paralysed face. A single senior surgeon operated on all the patients. The surgical method is described in our earlier work.[16] The muscles used were the latissimus dorsi in eight, the gracilis in six patients and the serratus anterior was used in one.

Haematomata were found in three patients after the muscle transplantation. Secondary procedures after the muscle transplantation were needed 26 times in 10 patients. These included tarsorrhapies ($n = 9$) and forehead procedures ($n = 2$). Secondary procedures involving only the transplanted muscle were needed 15 times during the follow-up, ranging from zero to three facial lifts per patient.

From 6 to 8 months later, patients started to train the transplanted muscle function. They were advised to train the mimic muscles in front of the mirror several times a day. Hospital charts were reviewed to collect the clinical data related to the patients and the operations (Table 1). At the time of the free muscle transfer, the age of the patients ranged from 7 to 63 years, mean 36 years. The mean follow-up time was 7 years, ranging from 3 to 14 years, after the free muscle transfer. The clinical grading and MRI were done concomitantly.

Magnetic resonance imaging

Patients underwent MRI with a 1.5 T unit (Signa LX, General Electric Medical Systems, Milwaukee, WI) using a standard head coil. The sequences used in this study were axial T2-weighted fast spin echo, coronal and oblique coronal T1-weighted spin echo, and oblique coronal T2 weighted fast spin echo with fat saturation. Axial and coronal images, the oblique coronal images and coronal T1-weighted spin echo images (TR 440 ms/TE 21 ms, matrix 256×224, field-of view 18 cm, slice thickness 3 mm) were used to align with the expected course of the free flap, i.e. from the junction of the zygomatic bone and arch to the corner of the mouth. Owing to the small cross-sectional area of

Table 1 Clinical data

A. Patients	
Sex	Female 11, male 4
Duration of paralysis	1–41 years, mean 10 years
Side of paralysis	8 right-sided, 7 left-sided
Age at time of free muscle transfer	7–63 years; <20 years, $n=3$; >60 years, $n=1$
Body mass index (BMI) at time of free muscle transfer	18–31
B. Operations	
Time between nerve cross-over and microneurovascular muscle transplantation	4–19 months, mean 8 months
Muscle	8 latissimus dorsi, 6 gracilis, 1 serratus anterior
Weight of muscle ($n=10$)	20–75 g, mean 47 g
Intraoperative ischaemia time of free muscle	59–109 min, mean 82 min
Number of primary complications (heamatomas)	3 in 15 patients
Number of secondary procedures	0–8 per patient, mean 1.7
Length of follow-up	3–14 years, mean 7 years

the flaps, images perpendicular to the long axis of the flap were not useful in the analysis. Images paralleling the flaps were therefore used in the analysis.

The MR images were viewed on a PACS workstation and evaluated by two investigators blinded to the clinical results. The free flap area of each slice was defined manually (region-of-interest method) from the oblique coronal T1-weighted images, and the area was calculated using the software (AGFA Impax 4.1) provided with the workstation. The volume of the free flap was then calculated from the formula:

Volume = (Area $1 \times$ thickness of a MRI slice 1) + (area $2 \times$ thickness of a slice 2) + ... + (area $n \times$ thickness of a slice n), where n is the last slice to be calculated.

The maximum thickness of the muscle was also marked. The muscle structure of the free flaps was semi-quantitatively assessed on a scale from 1 to 4 by judging the appearance of the muscle. The muscle grades are listed in Table 2.

The initial weight of the muscle flap (available in 10 patients) ranged from 20 to 75 g. The original volume of these free flaps was calculated from the formula:

Original volume = original weight of the flap (g)/muscle density (g/cm^3), assuming the muscle density of 1.056 g/cm^3 used for mammalian muscles.[17]

Clinical evaluation

The patients were videoed at rest, while speaking and while performing a number of voluntary movements to show mimic muscle function. They were also interviewed by a single medical doctor. The functional outcome of the facial reanimation was graded on a scale from 1 to 6 according to House.[18] The House grades are presented in Table 3. The final clinical grades combined the interview results and the grades achieved from the videotapes.

The patients were asked to estimate how much time they spent actively practicing facial movements after they had been asked to train their mimic function. The amount of practice was graded on a scale from 1 (none) to 4 (several times a day). For this study, the personal written consent of each patient was obtained and the study was approved by the Ethics Committee of Helsinki University Hospital.

Table 2 Grading of muscle structure in MRI

Grade	Number of patients
I. Normal or almost normal muscle structure	6 (40%)
II. Muscle infiltrated with fat	6 (40%)
III. Severe muscle atrophy and fibrosis	2 (13%)
IV. Muscle could not be identified	1 (7%)
	15

Table 3 Functional outcome graded according to *House*

Grade	Number of patients
I. Normal	0 (0%)
II. Mild dysfunction	4 (27%)
III. Moderate dysfunction	6 (40%)
IV. Moderately severe dysfunction	5 (33%)
V. Severe dysfunction	0 (0%)
VI. Total paralysis	0 (0%)
	15

Statistical analysis

The data were statistically analysed by an ordinal regression model with the SPSS Polymatous Universal Model (PLUM). In univariate analysis Pearson and Spearmans correlation tests and the Kruskal–Wallis test were used. In multivariate analysis both the complementary log–log function and the negative log–log function were used. A p-value less than 0.05 was considered statistically significant.

Results

The long-term functional outcome of the facial reanimation is presented in Table 3. The muscle function was regarded as good in 10 patients comprising mild or moderate dysfunction of facial movements. Five patients had moderately severe dysfunction and none had severe dysfunction or total paralysis after reanimation.

The results of the semi-quantitative grading of MR images are presented in Table 2. In the images, the muscle structure appeared normal in six patients (Fig. 1) and fatty in another six (Fig. 2). Severe muscle atrophy was noticed in two out of 15 patients. In one patient the muscle flap could not be identified, probably due to the originally small size of the flap (20 g at transfer).

The maximum thickness of the muscle flap ranged from 0.47 to 1.79 cm, average 0.95 cm. At the time of muscle transfer, the calculated volumes of the flaps (could be calculated in 10 patients) ranged from 18.9 to 71.0 ml, average 44.9 ml. At the time of evaluation the volumes of the flaps (could be calculated in nine patients) ranged from 5.8 to 18.8 ml, average 10.2 ml.

In seven patients, data on muscle volume both at the time of muscle transfer and at the time of MRI evaluation were available; the average loss of volume was 38.1 ml, ranging from 22.0 to 54.7 ml. In these patients, approximately 20% (range 13–23%) of the original volume of the muscle flap was seen in MRI, which means 80% loss of muscle volume. The average follow-up period for these patients was 3.9 years.

Normal muscle structure of the microneurovascular flap in MRI correlated with good mimic function after reanimation (correlation coefficient 0.59, $p = 0.019$). The time period elapsing between facial reanimation and evaluation was associated with the final functional outcome and the MRI grade; the longer the follow-up time after the muscle transplantation the weaker was the muscle function ($p = 0.023$) and the poorer was the muscle structure in MRI ($p = 0.019$).

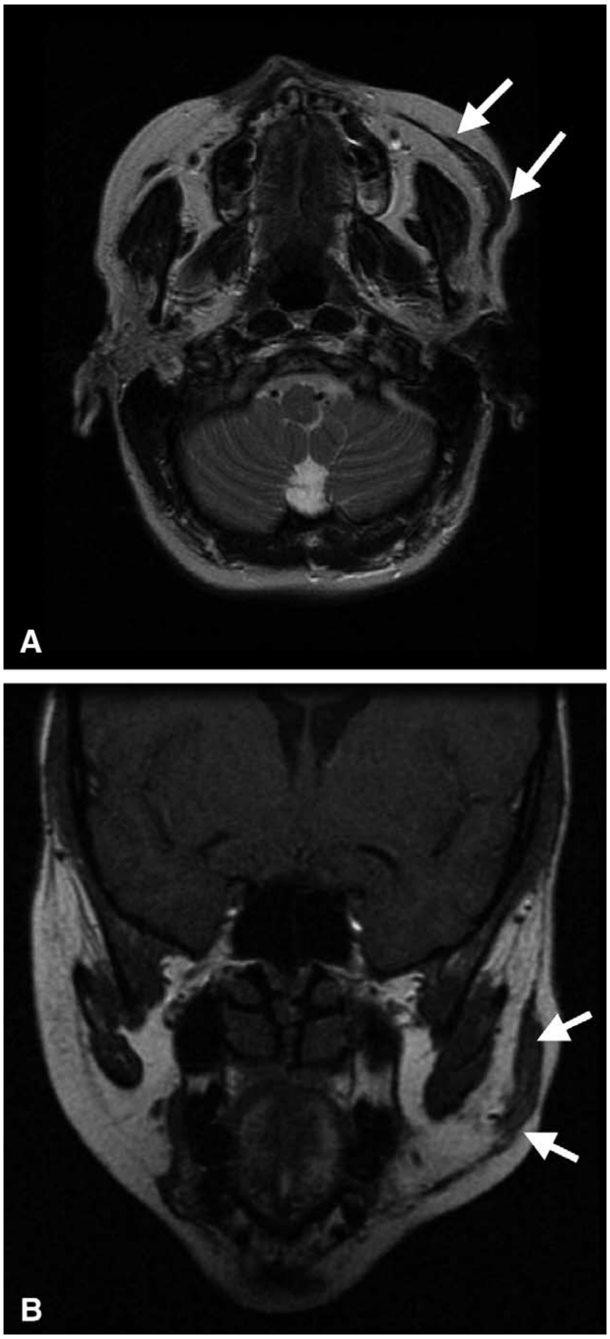

Figure 1 MRI appearance of microneurovascular muscle flap in a 38-year-old woman with congenital left-sided facial paralysis. Free muscle transfer with the gracilis was done 2 years before MRI. This flap has almost normal muscle structure (grade 1 in present study) and the patient's mimic function is good (mild dysfunction). (A) In an axial T2-weighted MR image and (B) in an oblique coronal T1-weighted MR image, the free muscle flap is indicated with a white arrow.

The patients estimated the amount of time they had spent on mimic practice after the muscle

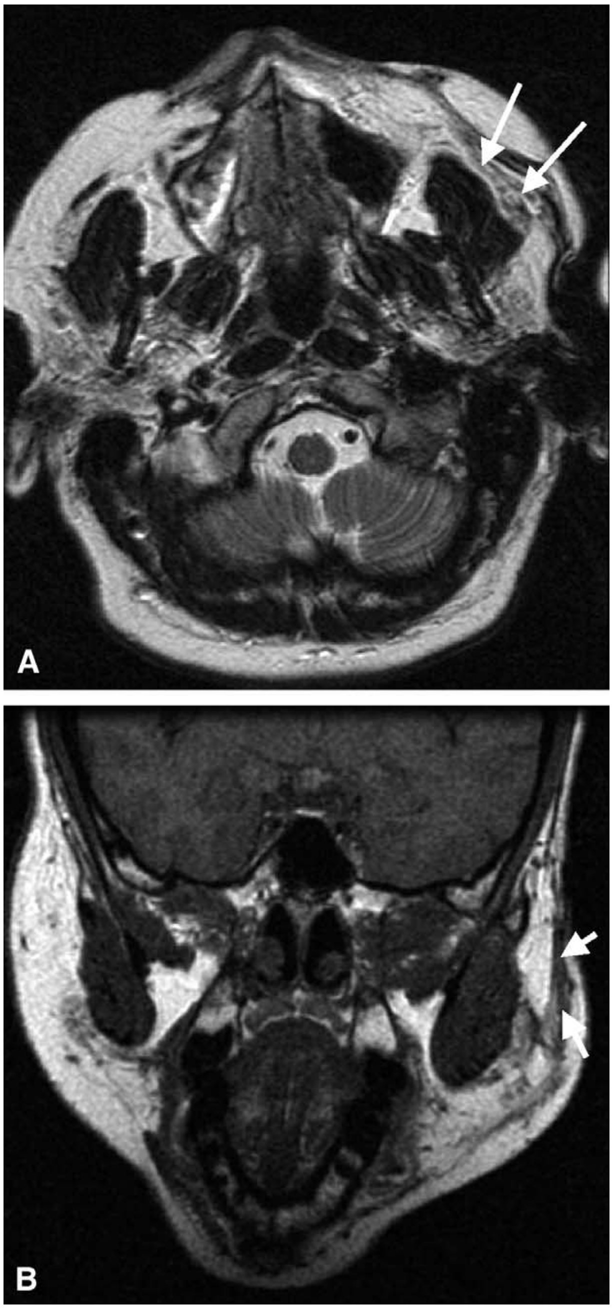

Figure 2 MRI appearance of microneurovascular muscle flap in a 54-year-old woman with left-sided facial paralysis after cranial base fracture. Free muscle transfer with the latissimus dorsi was done 10 years before MRI. This flap has a fatty appearance (grade 2 in present study) and patient's mimic function is quite good (mild dysfunction). (A) In an axial T2-weighted MR image and (B) in an oblique coronal T1-weighted MR image the free muscle flap is indicated with a white arrow.

transplantation. Frequent practice was associated with higher muscle volume measured in MRI. Practice, however, did not influence the MRI grade of muscle structure or the functional outcome. Correlation studies were performed between the MRI grading of muscle structure and the muscle volume both at the time of the transplantation and at the time of evaluation, the patients' age and sex, BMI, intraoperative ischaemia and the number of secondary procedures. None of the above-mentioned factors correlated with the MRI grade or the long-term result of facial reanimation. The effect of different donor muscles was also studied statistically and no differences between the muscles were found in this patient series.

Discussion

In this study two thirds of patients with permanent facial paralysis achieved sufficient mimic function after microneurovascular reconstruction. In MRI, almost half of the patients had a normal muscle structure in the microneurovascular muscle flap. Good mimic function correlated with a normal muscle structure in MRI. The longer the duration of follow-up, the poorer were the mimic function and the muscle structure. Several follow-up studies on facial reanimation have been published.[3-5] Comparisons of the results show that factors such as follow-up time and grading system vary greatly. In most of the studies, the follow-up period has been considerably shorter than in our study, average times ranging from 2 to 4 years.[3-5]

We measured the functional outcome after facial reanimation by the well-established, standard grading system of House.[18] Although the grading methods vary considerably between studies, our patients' mimic function was similar to that described in the other studies.[4,5]

Nevertheless, an additional structural parameter is warranted and MRI was chosen. Earlier studies have shown that denervation causes the fatty change or atrophy seen in MRI and that reinnervation can return the muscle structure to normal.[11,16] To our knowledge, no report has previously been published on the appearance of microneurovascular flaps in MRI. When the flap is reinnervated by nerve coaptation, the muscle structure is presumed to be restored. In our study, 40% of the flaps displayed unaltered muscle structure (grade 1) and another 40% had a fatty appearance. The longer follow-up period correlated with abnormal muscle structure in the flap. In our study, the average follow-up time was 7 years but in the reinnervation studies with denervated skeletal muscles it was from 3 to 15 months.[6,11] In those studies, the MRI appearance returned to normal after relief of paralysis or nerve grafting.[6,11] We suggest that the great variation in muscular structure in our microneurovascular flaps in MRI may be due to the difference in follow-up periods.

Furthermore, we noticed a marked loss of volume in microneurovascular muscle flaps. After the 7-year follow-up, only one-fifth of the original volume remained. Earlier Salmi had observed that the microvascular flap volume was the same as the original volume 6 months postoperatively.[14] This difference in remaining flap volume may also be due to the longer follow-up period in our study.

Another interesting feature was that frequent mimic practice increased flap volume but did not influence the muscle structure of the flap. On the basis of the result for 15 patients, we hypothesise that a patient cannot influence the structure of the flap by exercising. However, owing to the rather small size of the flaps and the use of long-axis images, the volume measurements in our study are suggestive only, and further studies are needed to confirm the relationship between exercise and flap volume.

The correlation between functional outcome and the MRI grading of muscle structure was good. Also, the longer follow up time after facial reanimation was associated with poorer functional outcome and abnormal muscle structure in MRI. We suggest that in cases of poor mimic function after facial reanimation, MRI could be used in clinical practice to investigate any changes in muscle structure.

In summary, MRI can be used to assess the muscular structure of microneurovascular flaps. Normal findings in MRI seem to correlate with a good clinical outcome in facial reanimation. The better functional result correlates with a shorter follow-up time and with normal muscle structure in MRI. Work is in progress to delineate the long-term histology of microneurovascular flaps after facial reanimation.

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