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Cross-facial nerve transplants: why are spontaneous smiles not restored?

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Summary—The technique of cross-facial nerve transplantation (CFNT), with or without the addition of vascularised muscle, has made it possible to achieve some voluntary movement of the paralysed side of the face in patients with unrecovered facial palsy.

If normal faces are studied during conversation, it can be seen that there are two types of movement of the lips—those of emotional expression and those involved in the formation of vowel sounds and labial consonants. Smiles themselves can be classified roughly according to their length of muscle contraction—the longer "definitive" smile, and the shorter "flash" smile.

It is the synergistic facial movement of the unpremeditated "flash" smile and the small movements in the formation of the vowel sounds and labial consonants which fail to occur in patients reanimated by revascularised, reinnervated muscle, despite the return of voluntary contraction and resting facial tone.

This study was undertaken to try to determine why these synergistic facial movements of short duration are so difficult to achieve.

Eight patients who had unrecoverable unilateral facial palsy and who had undergone cross-facial nerve transplantation with and without vascularised muscle transplant, at Oxford, were traced and studied (Table 1).

The technique used was similar to that described by Smith (1971) and by Anderl (1973) but was performed in two stages. The proximal anastomosis of the sural nerve graft was placed just anterior to the parotid gland on the normal side of the face as described by Gary-Bobo *et al.* (1980). In some cases, two cable grafts were used, in others only one. The grafts were tunnelled across high in the upper lip. The donor branches of normal facial nerve were identified by electrical nerve stimulation and those which caused good upward and outward movement of the angle of the mouth, the upper lip and alar base were used. The distal end of the sural nerve graft was marked with a suture and placed just in front of the ear on the paralysed side of the face. A Tinel's sign indicating growth of axons across the nerve graft to its end was awaited before proceeding to the second operation.

At the second stage, in two of the patients, the distal end of the nerve graft was sutured directly to distal branches of facial nerve on the paralysed side. In five patients who had facial palsies of long standing, free vascularised gracilis muscle was used to provide movement of the corner of the mouth (Harii *et al.*, 1976, O'Brien *et al.*, 1980). In one

Table 1 Details of the 8 patients involved in the study

Name	*Age in years at onset of palsy*	*Aetiology of palsy*	*Surgical technique*	*Timing of 2nd stage after onset of palsy*
CD	1	Fracture skull	EDB transfer	15 years
CB	3	Bell's palsy	Gracilis transfer	2 years 3 months
PD	34	Acoustic neuroma	Gracilis transfer	9 months
AB	34	Acoustic neuroma	Gracilis transfer	2 years 5 months
DF	35	Acoustic neuroma	Direct CFNT	8 months
RV	40	Acoustic neuroma	Gracilis transfer	1 year 8 months
JB	45	Recurrent cholesteatoma	Gracilis transfer	2 years 3 months
BH	62	Acoustic neuroma	Direct CFNT	11 months

patient, vascularised extensor digitorum brevis was used as the free muscle graft with a long segment of the anterior tibial nerve acting as the cross-facial nerve graft as a one-stage operation—the muscle having been denervated 10 days prior to transfer to lessen the effect of ischaemia (Thompson, 1971; Mayou *et al.*, 1981) (Table 1).

Method

The study of these eight patients involved a full electromyographic examination. A co-axial needle electrode was inserted into the transplanted muscle on the paralysed side of the face or directly into a reinnervated facial muscle in the cases of direct CFNT. The normal facial nerve was then electrically stimulated with a surface electrode (2 mm diameter, 1 cm separation, cathode distal) in front of the ear and between the nasolabial fold and the anterior border of the parotid, *i.e.* near the presumed position of the proximal nerve graft anastomosis (Fig. 1A). The EMG response of the muscle was recorded simultaneously with a 1 msec time scale, on photographic film (Fig. 1B).

The transit time across the nerve graft from the donor facial nerve to reinnervated muscle could then be calculated. The nerve transit time across the normal facial nerve was also measured between the normal facial nerve trunk and the buccal and zygomatic branches by measuring the latency of the response in the elevators of the upper lip in response to electrical stimulation of the normal (ipsilateral) facial nerve.

Further studies were undertaken to confirm the lack of spontaneous reinnervation of the paralysed facial muscles by inserting electrodes into the orbicularis oculi on the paralysed side of the face and looking for a response to voluntary effort and to supramaximal electrical stimulation of the abnormal facial nerve. A blink reflex to stimulation of the supraorbital nerve was also sought.

A normal subject was also studied electromyographically and two other normal subjects were recorded on video in order to determine the lengths

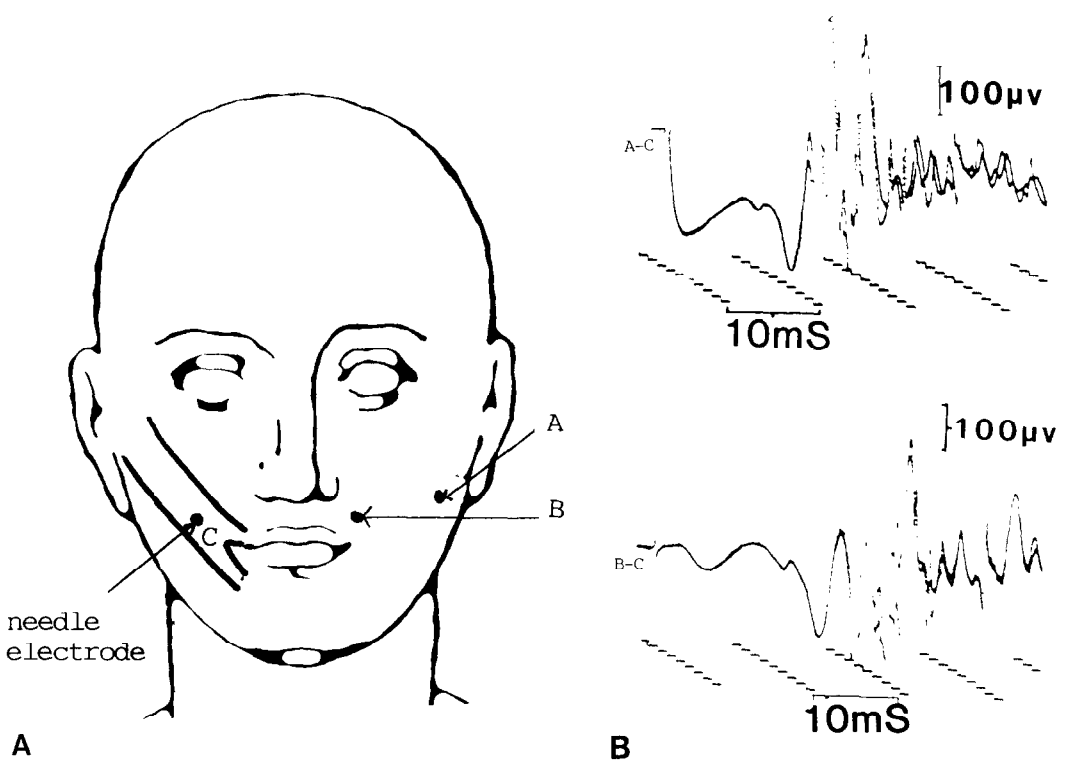

Fig. 1

Figure 1—(A) Electrode positions: A and B = stimulating electrodes. C = needle electrode in reinnervated muscle. (B) Measurement of latency.

of facial muscle contractions during smiles. (To achieve this, a digital clock was displayed alongside the normal subject during filming.) Video recordings of some of the patients were also made in order to study the results more closely.

Results

The velocity of the nerve impulses across the sural nerve graft was calculated from the latency and an estimation of the distances (Fig. 1B). The average velocity in the eight patients studied was found to be 18.75 metres/sec, *i.e.* about half the normal velocity of facial nerve, which was confirmed as being greater than 35 metres/sec (Table 2).

The numbers of reinnervated motor units were assessed by counting individual motor units seen on the photographic records of the EMG tracings. Each motor unit was identified by its unique size, shape and duration (Fig. 2A). In the normal subject, motor units were so numerous as to be uncountable (Fig. 2B).

The largest motor unit potential achieved on maximal voluntary muscle contraction (*i.e.* on instruction to smile broadly) was measured (Table 2).

In some patients it was noted both clinically and on EMG that there was a definite contraction of the reinnervated muscle in response to blinking or to deep respiration.

Table 2 Results of treatment.

	EMG				*Functional Result*		
Name	*Time of study after 2nd stage*	*Velocity of sural nerve graft in metres/sec*	*Maximum no. of motor units*	*Maximum amplitude in UV*	*Tone*	*Voluntary movement*	*"Flash" smiles and fast synergistic movements*
CD	7½ years	16	2	50	+	+	−
CB	5 years	27	4	150	+	++	+
PD	10 months	10	4	1500	+	+	−
AB	2 years	19	6	1500	+	++	+
DF	4½ years	20	2	1250	+	+	−
RV	1½ years	30	6	2000	+	++	+
JB	1 year	13	5	500	+	++	−
BH	3 years	15	3	2700	+	++	−

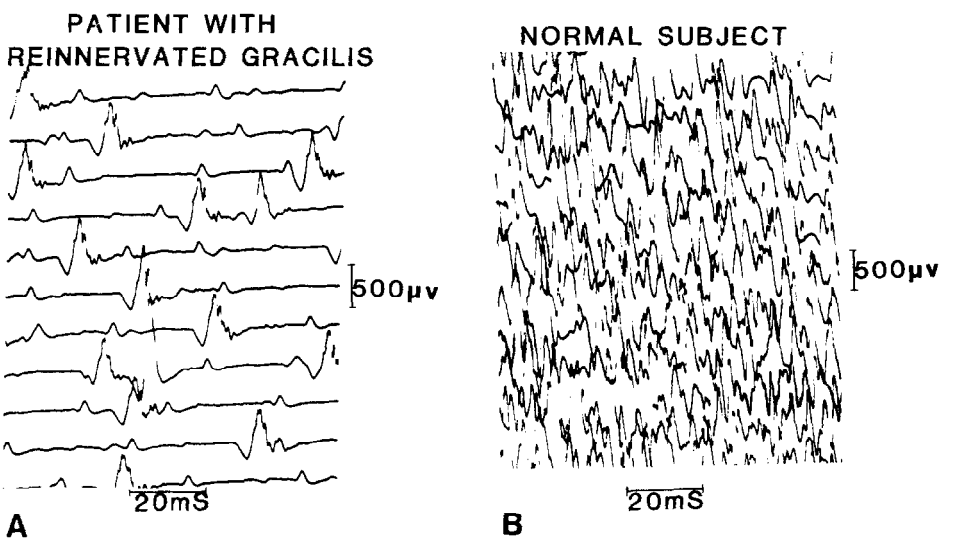

Fig. 2

Figure 2—Actual EMG recordings.

Clinical results of surgery were assessed on the basis of return of tone, voluntary contraction on demand and those small synergistic facial movements which constitute the "flash" smiles (Table 2). All patients achieved some degree of return of tone to the paralysed side of the face, *i.e.* the mouth had become level at rest.

Voluntary movement of the reinnervated muscle was also achieved by all patients to a greater or lesser extent, *i.e.* all patients were able deliberately to contract the muscle on demand. However, the small synergistic facial movements accompanying speech were partially achieved by only three patients.

Attempts to demonstrate spontaneous reinnervation from the ipsilateral facial nerve did not show any evidence that it had taken place.

The video assessments of normal subjects during conversation showed that synergistic "flash" movements last in the order of 30–60 milliseconds. Similar timing was seen in patients who were videoed but synergistic movements were mostly absent and "definitive" movements were slow to develop.

Discussion

It is, of course, simplistic to use one reinnervated muscle acting along only one vector to reanimate the corner of the mouth and lateral upper lip—an area which has normally about 10 muscles acting on it along different vectors. However, even with just one vector patients do actually learn to produce a long "definitive" smile by voluntarily contracting the reinnervated muscle at the appropriate time. After a lot of practice this smile will begin to look fairly natural. The ability to produce the shorter "flash" smile hardly ever returns so that a supposedly good clinical result is marred by an asymmetrical face during most of speech. The question arises whether there is delay in the transmission of the nerve impulses across the nerve graft, resulting in a delay in the production of the "flash" smiles—there certainly does appear to be some delay in production of even the "definitive" movements.

This study demonstrated some increase of transit time of impulses across the sural nerve graft—a phenomenon which has previously been noted in relation to cross-facial nerve grafts (Mayou *et al.*, 1981). This delay is a few milliseconds and is related to the relatively poor myelination and small diameter of the regenerating axons, but it cannot have a significant effect on the summation of individual twitch contractions which have contraction times in the order of 50 milliseconds or more. At a velocity of 18 metres/sec, nerve impulses could still cross the nerve graft in time to produce even the shortest "flash" smile. The delay across the nerve graft cannot therefore be responsible for the noticeable absence of these "flash" smiles and other synergistic movements or for the delay in the development of the longer "definitive" smile which is so often seen.

It appears that the more motor units that were identifiable in the vascularised reinnervated muscle graft or facial muscle, the better the clinical result in terms of the reproduction of synergistic facial movements. These results do not correlate with the maximum amplitude of the voluntarily evoked motor unit potential as was described by Tolhurst, but both series involved only small numbers of patients (Tolhurst, 1980).

The adequacy of reinnervation of muscle is directly related to the numbers of axons which manage to cross the sural nerve graft and reach the muscle. Different muscles have different ratios of axons to muscle fibres—one motor unit being the sum of all those muscle fibres innervated by one axon from one motor neurone. Normal facial muscle and platysma have about 25 muscle fibres innervated by one axon (Feinstein *et al.*, 1955) and this type of muscle has been described by Terzis as being "intelligent" (Terzis, 1983). Gracilis and pectoralis minor, which are examples of proximal trunk muscles, have about 1500 to 2000 muscle fibres to each axon, and have been described as being "stupid". Extensor digitorum brevis, like all distal limb muscles, has in the order of 200 to 300 muscle fibres per axon and is thus neither "intelligent" nor "stupid". Obviously, muscles with many motor units but few muscle fibres per motor unit will be capable of producing a wide variety of finely tuned movements. Facial muscle is thus an "intelligent" muscle, being specifically adapted for its role as a muscle of facial expression.

After nerve anastomosis, the number of axons actually reaching these muscle fibres is very small. Even with the most meticulous technique, it is only possible to achieve growth of between 20% and 50% of total possible axons across a nerve graft (Harrison, 1985). If a muscle like gracilis is reinnervated there is much more chance of a greater number of muscle fibres being reinnervated than with the more "intelligent" muscles such as facial muscle. Because we can only achieve less than 50%

reinnervation of any muscle, it may be worth considering the use of a "stupid" muscle like gracilis or pectoralis minor in order to gain maximum numbers of reinnervated muscle fibres.

One other factor relevant to the quality of contraction produced by a reinnervated muscle is the proportion of slow or tonic motor units (Histochemical Type I, red muscle fibres) and fast or phasic motor units (Histochemical Type II, white muscle fibres). The former are responsible for tone and the relatively slow, long-lasting contractions and the latter are responsible for the short bursts of activity. It is tempting to speculate that in the normal subject "flash" smiles and fast synergistic movements are based on these fast twitch motor units. The ratio of fast and slow motor units is determined by individual motor neurones. Normal facial muscle has a large porportion of slow twitch motor units (Kidd, 1984) and so the facial motor neurone pool must contain large numbers of motor neurones determining slow twitch muscle fibres. Following denervation, all muscle fibres revert to the slow twitch type, and recovery of fast twitch function can only occur if reinnervation of the muscle fibres is produced by an axon originating in a fast twitch motor neurone. Regeneration of the facial nerve is therefore going to produce a predominance of slow twitch determining axons. Following CFNT, the fast twitch motor neurones which would innervate the fast twitch motor units to produce the "flash" smiles and fast synergistic movements will be in short supply. If gracilis muscle has a high proportion of fast twitch motor units, as it is known to have in the cat, it would be impossible for these motor units to recover their original physiological and biochemical characteristics following CFNT as they need innervation by special fast twitch motor neurones of which there are few in the facial motor neurone pool.

The incidental finding of marked muscle contraction in response to blinking and deep respiration has made us more aware of which donor nerve to use. These abnormal synergistic responses are quite noticeable and undesirable. The blink response is obtained when a donor nerve partly supplying orbicularis oculi has been used, and the contraction of the reinnervated muscle on deep respiration is related to a donor nerve which has supplied the muscles of the alar nasi. It is easier to identify appropriate donor nerves if the patient is anaesthetised in such a way that low current nerve stimulation can be used without causing mass contractions (Ward and Poole, 1983).

Conclusion

When trying to achieve natural facial movement of emotional expression there is no doubt that a cross-facial nerve transplant from branches of the normal facial nerve which supply the levators and retractors of the upper lip, will allow impulses from the best possible source to innervate a muscle used to reanimate the face. As it is not possible, at present, to achieve total facial reanimation; achievement of synergistic facial movement at the angle of the mouth is the main hope for patients who are distressed by the severe deformity resulting from hemifacial paralysis. There are several possible muscles which can be transplanted to do this but although they can be successfully reinnervated and revascularised, they cannot compare with the ability of normally innervated facial muscle to produce natural smiles.

In this paper we have attempted to identify the reasons for poor symmetry of synergistic facial movement which is noted in many patients following the apparently successful reinnervation of facial or transplanted muscle. This asymmetry is not the result of delay in the transit of nerve impulses across a graft, but it appears to be related to a paucity of actual numbers of motor units which are reinnervated.

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