Neurotizations in Brachial Plexus Injuries: New Approaches

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Restoration of extremity function after nerve injury is often unpredictable. If management is based on a thorough knowledge of nerve physiology and the basic principles of nerve regeneration, however, excellent function is achievable.

Nerve transfer has been developed and refined to attain the best possible results, and the technique offers reconstructive possibilities limited only by our imagination.

9.1 Principle of Nerve Transfer

The procedure, while considered innovative, dates from the turn of the century, as Harrys and Low proposed it in 1903, followed by Tuttle, who in 1913 proposed the use of the spinal accessory nerve. The first work existing in the literature was published by Tsuyama in 1972 [36], who analysed the concept of neurotization of intercostal nerves. Almost at the same time, in 1971 Kotani [16] proposed the possibility of taking the spinal accessory nerve to reinnervate the biceps, and this was repeated by Allieu in 1982 [2].

The theoretical basis for nerve transfers is similar to that for tendon transfer: it is possible to sacrifice a redundant motor unit, as is done with muscular units, to restore a critical lost function, not reparable by direct suture or by interposed graft. In cases of neurotization sensitive recovery is also possible.

The indications for this kind of procedure include severe lesions of the brachial plexus, with root avulsion, and elderly nerve lesions with considerable nerve tissue defect.

It is evident that these situations are quite rare, fortunately, in current daily practice, but when encountered generally present many reconstructive problems for the surgeon.

The control mechanisms that allow reprogramming of previously antagonistic actions into complex smoothly integrated extremity movements are unknown, but they are evident in each patient and presumably involve cerebral plasticity.

The technical aim of this treatment is evidently to recover a nerve function which is otherwise not possible, while also introducing the concept of converting a high level nerve injury into a low level one. In fact the problem with high level nerve injuries is that generally after 15 – 18 months of denervation, skeletal muscles become refractory to reinnervation. That is why motor nerves are transected as distally as possible so as to be connected as closely as feasible to the denervated muscle. The prerequisite for a neurotization is to have a muscle still alive. This is not easy to determine and in longstanding paralysis the only objective EMG test is the presence of **spontaneous fibrillations**, which is an acceptable indication (of denervation but also of the vitality of the muscle fibres).

Neurotization has been described as the transfer of a functional but less important nerve to a denervated more important nerve.

Evidently it is not that easy. The transfer of a nerve to the distal part of a denervated nerve stump requires some characteristics that often reduce the indication or render the procedure more complex, and ultimately reduce the possible option of nerve transfer.

At first the most important factor is the **number of fibres** in the donor nerve compared with the receiving one. Unfortunately brachial plexus primary, secondary and terminal branches have many nerve fibres (see Ta-

Table 9.1. Average number of nerve fibres in roots of brachial plexus, terminal branches, and nerves utilized for transfers

C5	16,472	Suprascapular nerve	3,500	Intercostal nerves	1,200
C6	27,421	Axillary nerve	6,500	Cervical plexus	7,000
C7	23,781	Musculocutaneous nerve	6,000	Spinal accessory nerve	1,600
C8	30,626	Median nerve	18,000	Charles Bell nerve	1,600
T1	19,747	Ulnar nerve Radial nerve	16,000 19,000	Nerve to latissimus dorsi	500

ble 9.1) on their inside. On the contrary close nerves which could act as donor present a really low number of fibres, which reduce their restoring potential. That is why, as we see below, some authors suggest, especially for the restoration of critical function (such as elbow flexion), to utilize at least two donor nerves, to be sure that the number of fibres can at least be sufficient to restore a valid function (considered as M3 or M3+, on the modified scale).

One more thing to remember, if it is evident, is to try to restore a motor unit with an **agonist nerve**, which would facilitate the cortical recovery, and eventually would not create co-contraction. In any case this condition is considered preferable, but not necessary [23]. Another condition to consider is the **sensitive motor composition** of the donor nerve compared to the receiving one. Normally the aim is to restore motor function, due to the fact that generally this procedure is used in really dramatic cases in which the arm control and its basic motion are the primary achievable aim; in any case sometimes also sensibility can be restored, as we see below. So it is important to utilize a pure motor nerve. For the receiving nerve the problem is similar; it is advisable to go a little further distally to identify the precise motor branch, to neurotize only that, minimizing the donor nerve drop into sensitive distal fibre. Sometimes the surgeon is faced with the problem of having to do a pure motor neurotization, but which requires a graft interposition, or having to do a neurotization by direct suture, in which an imprecise amount of fibres could be lost.

Finally it is important to make a wise **choice of the donor nerve or of a specific part of it**, as we see there are not many usable nerves. In some cases it would be possible to take an entire nerve denervating the original target to reinnervate another muscle. In other cases, it would not be feasible, so an option is to choose the distal component of the donor nerve, which has already reached a portion of its target muscle, and to reroute only the distal part, reducing the normal innervation only partially. Another alternative is to take only a fascicle of the donor nerve (usually a fifth or a quarter part of it) taking care to outline, by intraoperative electrical stimulation, the specific action of the rerouted fascicle, and not to remove a relevant part of the entire nerve.

9.2 Technique

When considering a brachial plexus reconstruction, the surgeon must identify the entity of the lesion and immediately afterwards the possible reconstructive strategy depending on the available donor nerves.

Normally even in the better cases there is a discrepancy between the donor nerve and the function to be restored. Therefore the surgeon must prioritize the function that he aims to restore in the injured limb, as considered essential, when compared to the rest.

In complete brachial plexus palsy the first aim, evidently, is elbow flexion, followed by or at the same level as shoulder stability and abduction. Wrist extension-finger flexion and wrist flexion-finger extension follow next. Intrinsic hand function, due to the large distance from the denervated muscle to the possible donor nerve, is the last priority. Recent advances even offer some concrete hope for this distal target.

The possible donor nerve could come from the plexus itself (and is then called intraplexal neurotization) or from elsewhere (then called extraplexal neurotization).

Evidently when available the most suitable donor nerves for distal branch repair are the plexus roots themselves, and clearly this is not a neurotization but a direct reconstruction.

Obviously when we speak about intraplexal neurotization we are dealing with incomplete brachial plexus palsies, where a branch or a fascicule of a nerve could be used to reanimate another function.

When direct reconstruction is not possible and we are faced with a complete paralysis, we must look for a neighbouring expendable nerve to reconstruct lost function.

Next we present the technical alternatives for reconstruction based on the possible donor nerve.

9.3 Extraplexal Donor Nerve

9.3.1 Spinal Accessory Nerve

The use of this nerve as a donor nerve was first described by Kotani in 1972 and was later introduced in Europe by Allieu in 1982 [2]. This is the XI cranial nerve, which innervates the sternocleidomastoid and the trapezius muscles. Due to its intracranial course,

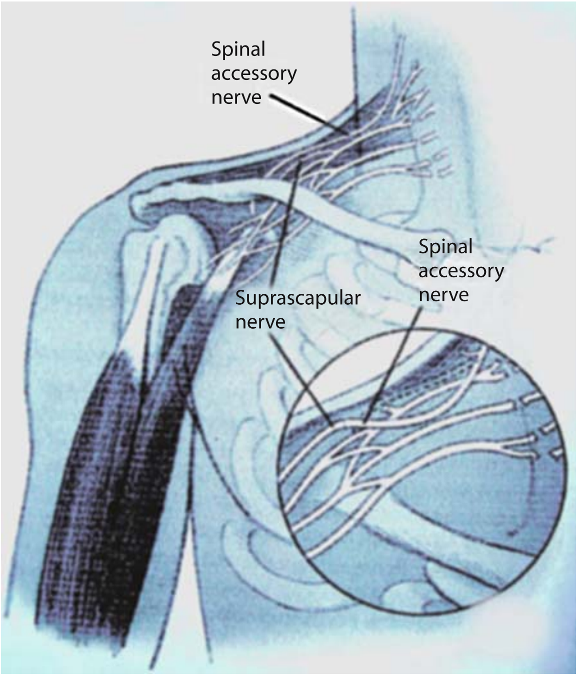

Fig. 9.1. Neurotization of spinal accessory nerve on suprascapular nerve

the spinal nerve is usually protected during traumatic stretching of the brachial plexus, and so it is usually available to perform neurotization. Moreover, it is a pure motor nerve, and it contains approximately 1,700 myelinated motor fibres. This makes this nerve even more suitable for pure muscular neurotization.

Harvesting this donor nerve, we encounter the advantage that it lies in the operative fields, so it is not necessary to use another surgical approach to obtain the nerve. The precise anatomy of the nerve has been studied to a large extent, in order to reduce the damage at the denervated trapezius muscle. Moreover, accurate anatomical study could also provide precise landmarks to reduce the frequent iatrogenic nerve lesions associated with several lymph node related procedures.

The spinal accessory nerve supplies the sternocleidomastoid and trapezius muscles. In the posterior triangle of the neck, this gives off two to three branches for the upper trapezius muscle, and then passes under and supplies the middle and lower portion of the muscle [9].

Anatomical study [9] shows that the outcome of neurotization procedures and their consequences on the trapezius and sternocleidomastoid function depend on the level of division of the spinal accessory nerve. Preservation of function of the primary target muscle (sternocleidomastoid and the upper trapezius) is possible when the spinal accessory nerve is used as a donor nerve and divided in the posterior triangle, just distal to the point where the branches for the upper trapezius are given off.

This nerve is generally used for suprascapular nerve reconstruction (Fig. 9.1), usually in cases when one root judged as being of good quality is found and the direct reconstruction is performed to prioritize musculocutaneous reconstruction with the aim of elbow flexion recovery. In this case it is advisable to try to achieve some shoulder abduction and extrarotation by restoring the supraspinatus and infraspinatus muscles, through suprascapular neurotization. Normally, due to the similar size of the two nerves and due to their proximity, no interposed nerve graft is needed. For this reason, which reduces recovery time and reduces the axonal sprout lost at the suture line, this procedure is considered somewhat safe. A recent literature review reported that 98% of patients recover $< M3$ strength in shoulder abduction [20], while another series reported an 80% rate of success (muscle strength $< M3$) after this procedure [30].

Some authors [35] consider this procedure even more infallible and successful than suprascapular direct reconstruction by the C5 or C6 roots. This could be explained by the absence of an interposed nerve graft in the proposed neurotization and by the fact that the plexus roots are defined as “in the sphere of lesion” and so they could be somehow compromised.

In other cases the spinal accessory nerve could also be transferred to the musculocutaneous biceps branches, or to the axillary nerve by a sural nerve graft.

New possibilities for using this assured donor nerve include the free functioning muscle flaps that are transferred to restore elbow function or other function (such as wrist extension or finger flexion) [5, 8]. In this situation, if the spinal accessory has not been used in primary reconstruction, it is possible to use it in a “one time free functioning muscular flap” neurotizing the branch of the obturator nerve in a free gracilis muscle transfer.

9.3.2 Intercostal Nerves

The use of these nerves was first described by Seddon in 1963 [37] to restore musculocutaneous nerve by the interposition of an ulnar nerve graft. The technique was later modified by Hara and Tsuyama by elimination of the interposed nerve graft [36].

Since these first descriptions many other utilities for this nerve transfer have been described, but elbow flexion remains the most achievable goal.

Intercostal nerves are the ventral primary rami of the spinal nerves. The ventral primary ramus of the T12 spinal nerve is the subcostal nerve. T1 contributes to the brachial plexus, and T12 does not actually occupy an intercostal space. Therefore ten thoracic nerves (T2–T11) make up the anterior branch of the intercos-

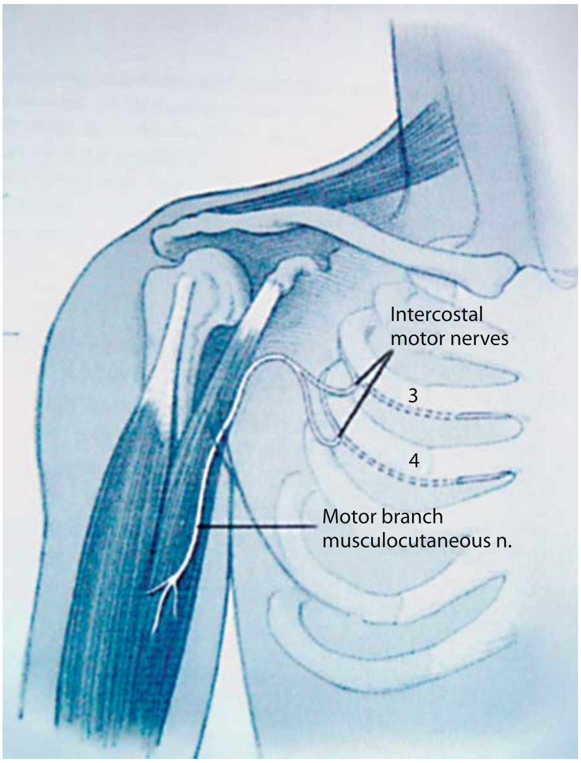

Fig. 9.2. Neurotization of intercostal nerves to motor branch of musculocutaneous nerve

tal nerves. The second intercostal nerve, due to its high location, is not accessible for neurotization.

Intercostal nerves provide segmental cutaneous sensation as well as motor power for intercostal subcostal, serratus posterior superior and transversus thoracic muscles. The nerves are located on the caudal undersurface of each rib. Generally three or four intercostal nerves are harvested and used for neurotization, and commonly these are the third, fourth, fifth and sixth intercostal nerves. Both the lateral cutaneous branch and the anterior motor branch are of use. Due to their small calibre, and reduced number of nerve fibres (about 1,200), at least two intercostal nerves are used for each nerve transfer.

Contraindications for the use of these nerves include, evidently, important chest trauma, associated with rib fractures. In women patients it is correct to consider the use of these donor nerves. In fact, due to the scar for the surgical approach, if there are other feasible solutions, maybe these could be more cosmetically appealing. It is important, regardless of the sex of the patient, to spare, whenever possible, the cutaneous branch of the fourth intercostal nerve, which possesses substantial sensory components which supply the nipple areolar complex.

As already mentioned the primary goal of intercostal reconstruction is elbow flexion by direct musculocutaneous neurotization (Figs. 9.2, 9.3). Recent studies have shown the evident superiority of results in direct intercostal nerve neurotization, when compared to interposed graft repair. That is also why the 3rd to the 6th intercostal nerves are chosen, due to their proximity to the recipient nerve, as the pivot point is at the axilla.

Nevertheless the decision is between a direct neurotization, without graft nerve interposition, from the intercostal nerves to the entire musculocutaneous nerve, versus a punctual neurotization connecting the donor nerves directly to the bicipital rami of the musculocutaneous nerve.

Intercostal nerves have also been used with an interposed nerve graft to restore triceps function and to neurotize the axillary nerve [22]; other authors [35] referred to the use of the 6th, 7th and 8th intercostals to perform a direct neurotization to the axillary nerve.

A recent series of elbow flexion repair by the intercostal nerve [4] showed that 67 % of patients recovered a biceps flexion of M4 or more. The same authors outlined the most important factors of success as early exploration, use of at least three intercostal nerves, nerve repair without graft and under no tension and of course shoulder stability.

New proposals of use of the intercostal nerve include the mixed-to-mixed transfer, in which the intercostal nerves are transferred as the main motor branch and its sensitive accessory branch together to the musculocutaneous nerve, in an attempt to orient the branches of the donor nerve to the fascicle of the recipient nerve, to improve the sensibility.

Another innovative use of the intercostal nerve is the transfer to the free muscular transfer, as already seen for the spinal accessory nerve. A recently proposed technique [15] used in adults and also anticipated in children with non-obstetrical brachial plexus palsy, suggests the use of a double free muscle transfer, to restore the elbow flexion and finger flexion, by using both the spinal nerve and the intercostal nerve as donor nerves for the transferred functioning muscle (the technique and detail are explained below).

9.3.3 Phrenic Nerve

The use of the phrenic nerve was first proposed by Gu [12]. It originates from the C4 cervical nerve root with some contribution also from C3 and C5. It can easily be identified in the same surgical field, as it lies on the anterior surface of the scalenus anterior muscle.

Despite its proven clinical consistency, some authors are still in doubt about its use due to the functional pulmonary compromise resulting from its section for transfer. Several studies [13, 32] have shown that unilateral phrenic nerve sacrifice in patients with an adequate reserve is safe and well tolerated.

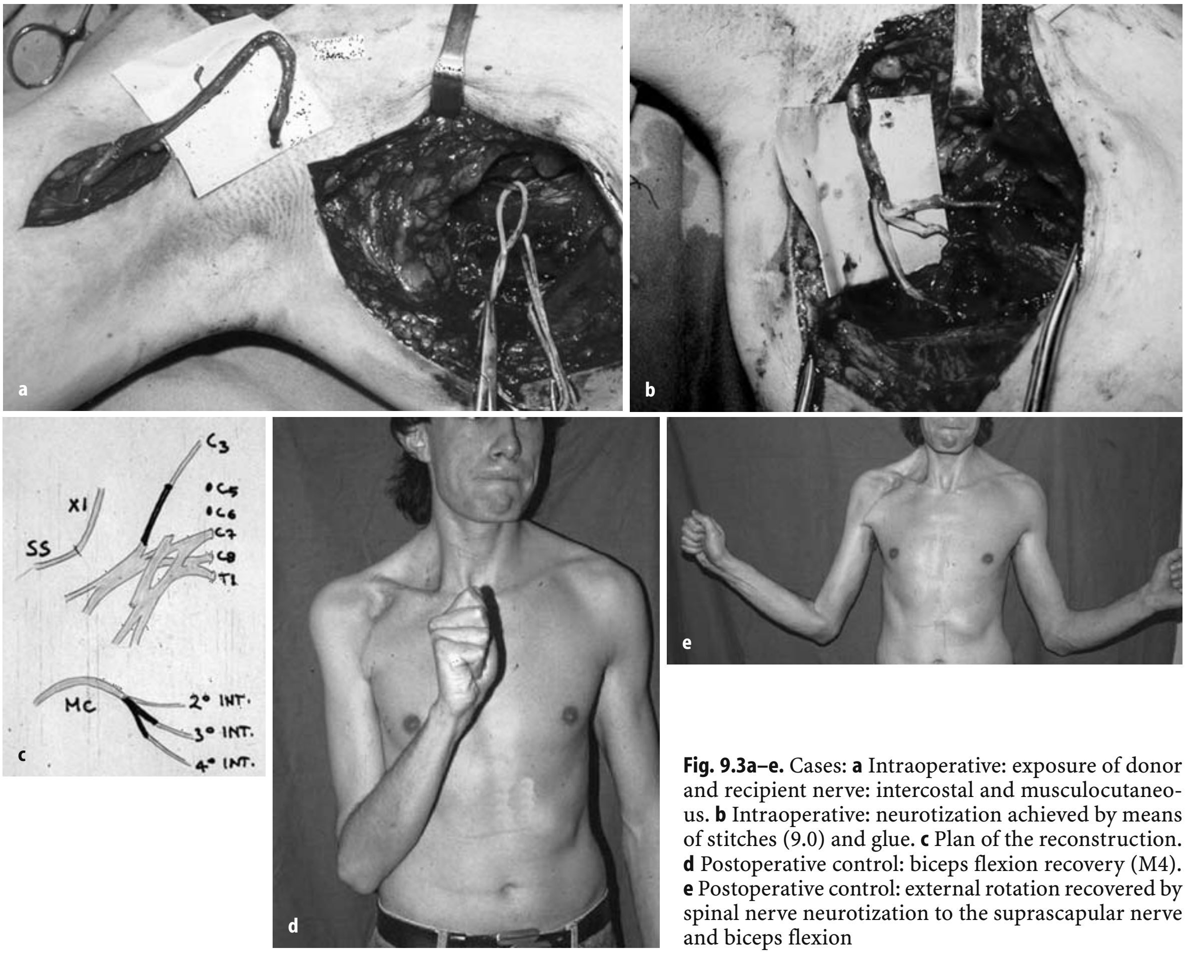

Fig. 9.3a–e. Cases: **a** Intraoperative: exposure of donor and recipient nerve: intercostal and musculocutaneous. **b** Intraoperative: neurotization achieved by means of stitches (9.0) and glue. **c** Plan of the reconstruction. **d** Postoperative control: biceps flexion recovery (M4). **e** Postoperative control: external rotation recovered by spinal nerve neurotization to the suprascapular nerve and biceps flexion

Nevertheless its use is contraindicated in patients with pulmonary compromise; additionally it should not be harvested in patients in whom the intercostal nerves have also been used for reconstruction. In similar cases an end-to-side coaptation could be carried out with the phrenic nerve, without complete transection. When a rupture of the phrenic nerve is encountered, based on clinical and instrumental evidence, and in the case of the impossibility of direct phrenic repair, it could then be used entirely for neurotization.

With regard to children its use has unanimously been ruled out. Nevertheless it has been shown [38] that in children younger than 3 years phrenic transfer has some consequences regarding the respiratory system, thorax, and digestive system, and the younger the patients, the more severe the cost is. In children older than 3 years this kind of procedure could be better tolerated.

The phrenic nerve contains about 1,000 – 1,500 myelinated fibres. Before its use diaphragmatic and pulmonary function must be tested clinically preoperatively, and documented by X-ray, which shows a normally mobile diaphragm at the affected side. Intraoperative electrical stimulation is also advised. The phrenic nerve, due to its size and location, could be a suitable match with the suprascapular nerve as well the axillary. Better results are obtained when it is used for neurotization of the suprascapular nerve, and some authors [6] have reported an increase of up to 40° of shoulder abduction, while others [30] have reported 75 % of patients with more than M3 recovery in the shoulder muscle.

9.3.4 Cervical Plexus Motor Donor

There are four motor branches available lying in the same surgical fields, despite the fact that they do not offer a really large number of myelinated nerve fibres.

These are the accessory branches of motor nerves for the sternocleidomastoid, trapezius, levator scapulae and rhomboid muscles. They are located between the C5 spinal nerve and the spinal accessory nerve. These must be considered in cases of multiple root avulsion, even if outcomes are controversial. Brunelli [3] popularized their use with satisfactory results for suprascapular neurotization. Other authors still regard this solution as being unreliable [6, 30]. Nevertheless it is important to remember to consider carefully the association of cervical plexus donor nerve with accessory spinal nerve, due to the possibility of developing shoulder instability as a result of the complete denervation of the scapulothoracic muscle.

9.3.5 Contralateral C7

In the years 1986–1989 Gu [10] developed this new technique of extraplexal neurotization, distressing the brachial healthy side roots to provide a new donor nerve in patients affected by complete brachial plexus lesion. Since then many authors have supported this technique and have recorded little if any donor site morbidity.

The advantages of the use of this donor nerve are evident: first of all the large number of myelinated fibres it contains (~27,000), which makes it possible to achieve a target, until then regarded as unachievable, such as hand function. All the muscles which have a C7 contribution do not have the C7 root as the only source of fibres, but, on the contrary, they receive cross innervation mainly from C6 and C8. This anatomical data forms the basis for the possibility of sectioning a portion or the whole of C7 healthy roots, without a significant loss of specific muscle function. The specific documented outcomes after this kind of surgery are a temporary paresthesia of the first three fingers, or of the palm, or of the anterolateral arm. These sensory findings were or were not associated with weakness of the triceps or of the extensor digitorum communis. All the series reported a spontaneous recovery of the temporary sensory abnormalities within 3 months, and a normalization of the muscular strength at long-term follow-up. Other studies have also assessed the limited donor morbidity with clinical [7] and electrophysiological study [11].

There are several proposed techniques such as complete or partial C7 transfer, generally using a vascularized ulnar nerve graft. Partial C7 transfer has been proposed [31] due to the already huge amount of fibre available, in order to minimize the risk at the uninjured arm. When only half of the healthy C7 is used, intraoperative stimulation must identify the C7 component which predominantly stimulates for the pectoralis major, and this would be chosen. In cases of each half of the nerve producing wrist and finger contraction, some authors [29] suggested abandoning the procedure because of the considerable risk of jeopardizing the hand.

In cases of complete root avulsion, the use of the contralateral C7 rather has the aim of restoring the **median** nerve, while dedicating the other available motor nerve sources (such as spinal accessory and intercostal) to elbow and shoulder.

Despite the low rate of donor site morbidity associated with the satisfactory sensitive results encouraging the use of this new technique, motor outcomes are far from optimal. With regard to sensibility recovery in Songcharoen's [31] series, 48 % of the patients obtained S3 function and 33 % obtained S2 function. On the contrary regarding wrist and finger flexion only 29 % of the patients obtained good finger flexion; the same mediocre results are documented in all the large series. Gu [14] reported slightly better results in 63 % of his patients, using the whole contralateral C7.

The author concluded that even though the results of contralateral C7 to median nerve are better if compared to other donor nerves, the success rate of this procedure is still far too low. The best outcomes are seen in individuals younger than 18 years.

New Proposal. Other authors [15] suggested the use of contralateral C7 in a complex double free muscle transfer technique. They use the whole contralateral C7 to reconstruct shoulder and elbow extension in primary surgery: subdividing the ulnar nerve graft and directing it to the radial and to the suprascapular nerve. And more recently they have reconstructed elbow flexion with a free gracilis muscle transfer, neurotized to the spinal accessory; the third operatory procedure was directed to finger flexion recovery by a second free gracilis muscle transfer neurotized to the intercostal nerves. In their series, also including children with non-obstetrical brachial plexus palsies, they reported encouraging results.

Other uses of contralateral C7 include the reanimation of a single free muscle transfer to restore elbow flexion, as already described for the spinal accessory nerve and intercostal nerve.

9.4 Intraplexal Donor Nerve

In cases of incomplete brachial plexus palsy it could be possible to utilize a healthy expendable nerve or part of one to restore function.

9.4.1 Triceps Branch of Radial Nerve

Lesion of the upper roots of the brachial plexus results in loss of shoulder abduction and external rotation due to the paralysis of the supraspinatus and infraspinatus muscles and of the deltoid and teres minor muscles. The normal procedure usually prioritizes the suprascapular direct or selective reconstruction, rather than the axillary. Nevertheless it is known that all the muscles of the glenohumeral joint contribute to shoulder abduction and external rotation. Finally the reinnerva-

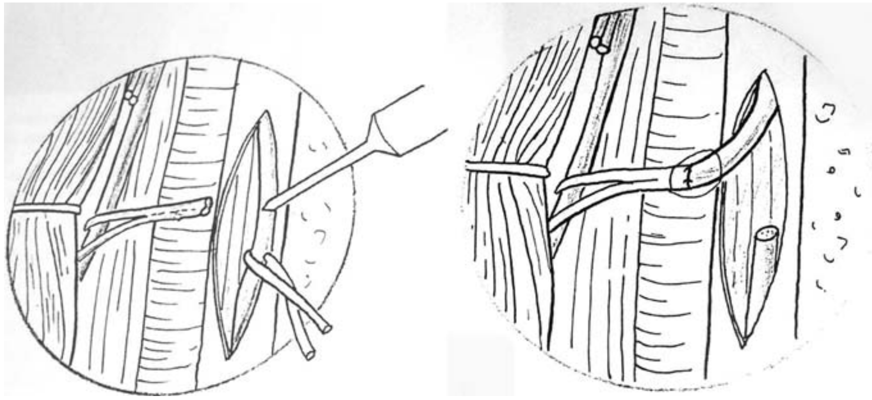

Fig. 9.4. Oberlin's procedure of biceps branches of musculocutaneous nerve neurotized by a fascicle of ulnar nerve

tion of both axillary and suprascapular nerves provides the best possible functional results in terms of shoulder abduction and external rotation.

We have already seen the possibility of neurotization of the suprascapular nerve, outlining that the gold standard procedure appears to be the use of the spinal accessory nerve as source of neurotization.

With regard always for the same principle of at the same time reducing the pathway the nerve has to run in recovery and the number of sutures it has to cross, a new kind of neurotization has been studied and proposed for reanimation of the axillary nerve.

Commonly the axillary nerve has been neurotized by the available roots of the plexus, through nerve graft, or by extraplexal donor nerve such as the phrenic nerve or the intercostal nerve. Recently some authors [37] have studied the anatomy of the long head of the triceps nerve to the axillary injured nerve. This *new procedure* uses a posterior approach centred over the quadrilateral space, which allows the exposure of both the radial nerve, with its branch to the long head of the triceps, and the axillary nerve; the nerves are then matched together directly.

This procedure offers the advantage of having the nerve in the same operative fields that are also far away from the original lesion, so dissection could be easier and faster. Moreover the proximity of the two nerves renders this procedure appealing for its shorter time of recovery, because it does not require a nerve graft.

Other studies [39] have been directed at the macroscopic and interfascicular anatomy of the axillary nerve, to render the neurotization even more efficient by focusing the reparation only on the deltoid branches.

9.4.2 Ulnar Nerve

We have already seen that the ulnar nerve has been used in cases of complete brachial plexus palsy, as a vascularized nerve graft, when the only possible donor was the contralateral C7, which lies far away from the receiving nerve target.

The ulnar nerve could also be a valuable donor nerve in cases of upper plexus palsy (C5, C6–C7 palsy).

This technique, first proposed by Oberlin in 1994 [25], explains completely what is meant by the use of the expendable nerve or part of it. He used a consumable part of the healthy ulnar nerve to restore the paralyzed elbow flexion, by a direct neurotization (Figs. 9.4, 9.5). In this way he transformed the high level lesion of the biceps branches of the musculocutaneous nerve into a low level injury, increasing the rate of success of the recovery and reducing the time of reinnervation, due to the proximity of the donor and the recipient nerve.

In his procedure the ulnar nerve is identified and dissected at the arm level; an intrafascicular dissection associated with an intraoperative stimulation allows a fascicle to be identified, with a size of 15–20% of the entire nerve, which stimulates mostly the wrist flexor rather than the intrinsic function. That fascicle is chosen for neurotization; so it would be freed proximally and divided distally. In the same operative field the musculocutaneous nerve is identified, in the belly of the biceps muscle; the muscular branches for the biceps are identified and divided proximally. So the donor ulnar fascicle and the recipient biceps branches are glued together, without any graft.

This technique provides a really high rate of success in elbow flexion recovery, such as 93% of < M3 recovery in elbow flexion in the series of Leechavengvongs [17], and the results were similar in the series of Sungpet [32].

No donor morbidity was recorded.

Other authors [34] proposed a slight modification of the technique using a fascicle of the median nerve, instead of the ulnar nerve, to neurotize the biceps branch of the musculocutaneous nerve, likewise reporting satisfactory results, without morbidity at the donor site.

Recently reanalysing the different series of the original procedure, Liverneaux [18] outlined some incomplete recovery or weakness of elbow flexion, in cases of

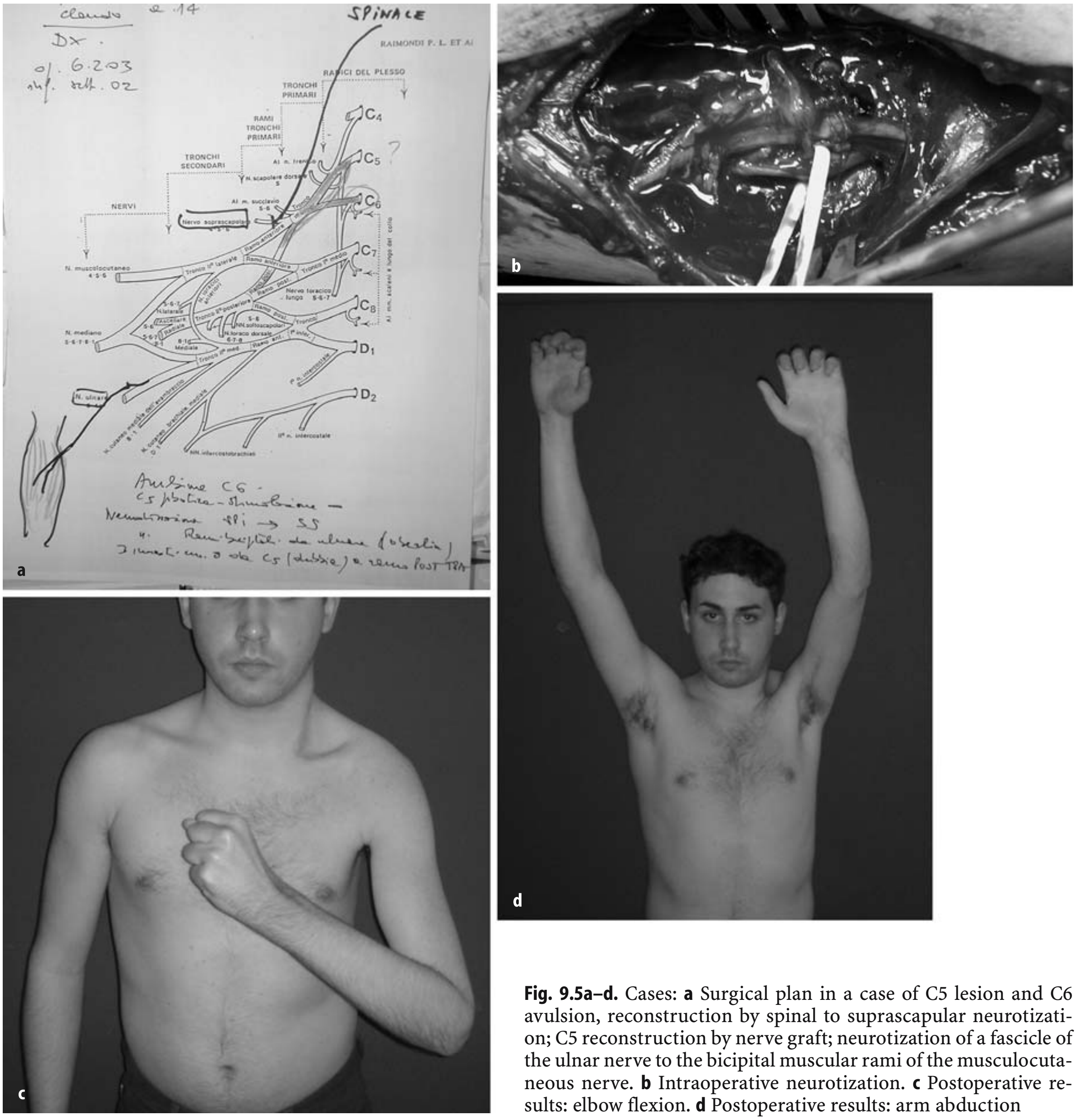

Fig. 9.5a–d. Cases: **a** Surgical plan in a case of C5 lesion and C6 avulsion, reconstruction by spinal to suprascapular neurotization; C5 reconstruction by nerve graft; neurotization of a fascicle of the ulnar nerve to the bicipital muscular rami of the musculocutaneous nerve. **b** Intraoperative neurotization. **c** Postoperative results: elbow flexion. **d** Postoperative results: arm abduction

Fig. 9.6. Intraoperative: double neurotization with one fascicle of the ulnar nerve directed to the bicipital rami of the musculocutaneous nerve, and a fascicle of the median nerve directed to the muscular rami of the brachial muscle

elderly patients and in those with long preoperative delays. So he proposed a new technique, to maximize the result of elbow flexion. The new procedure bases its rationale on the fact that the biceps is originally a forearm supinator, while the brachialis is the primary elbow flexor muscle. The new scheme associates the previous ulnar fascicle transfer with an additional transfer of a fascicle of the median nerve, chosen as a wrist flexor fascicle, to neurotize the brachialis branches of the musculocutaneous nerve, increasing the motors for elbow flexion (Fig. 9.6).

This technique, already shared by several authors [19], shows really encouraging results.

9.4.3 Median Nerve

Some authors [34] proposed a slight modification of the technique suggested by Oberlin, using a fascicle of the median nerve, instead of the ulnar nerve. They suggest using a small fascicle of the median nerve to neurotize the biceps branch of the musculocutaneous nerve and they likewise report satisfactory results. Moreover, the study shows that grip strength, pinch strength, moving two-point discrimination, and strength of wrist volar flexion on the unaffected side are not worse than before the operation in any patient. Other authors [19] use the median nerve as a donor site, but outline the possibility of using both the donor nerve, and median and ulnar nerves to revitalize two different targets, the biceps and the brachialis, to reach the strongest elbow flexion.

9.4.4 Brachialis Muscle Motor Nerve

Another recently described procedure refers to the rare cases of lower root avulsion with intact upper roots, the so-called Klumpke paralysis. These types of lesions involve C8–T1 ± C7 avulsion, and are somewhat rare: in the published series they range from 2% in the Narakas and Oberlin series [21, 24] to 10% in Seddon's [28] series.

This kind of lesion is characterized by a severely compromised hand which could be compared to some tetraplegic hands or cases of combined median and ulnar palsy. Commonly there is a complete absence of all the finger flexors, of the thumb flexor and of all the thenar and hypothenar intrinsic musculature. Recently Palazzi reevaluated the work of Accioli [1], who first described a technique of reanimation of the finger flexor by the use of an intraplexal donor, and particularly the brachialis motor branch.

The proposed technique [26] was developed in three different possible schemas, which share the common use of the brachialis motor branch as donor nerve, to neurotize different target muscles secndary to the paralyzed distal muscle.

The first schema foresees the use of the brachialis to reanimate the epitrochlear branch of the median nerve, with a direct suture due to the proximity of the donor and recipient nerve. The second option is exploited in cases of conserved epitrochlear muscle innervation, and utilizes the donor brachialis nerve in an end-to-side neurotization with the median nerve distally to the site of emergence of the epitrochlear branch, in order to reinnervate the finger and thumb flexor.

The third possibility is used for more complex lesions with avulsion of the C7, C8 and T1. In such cases most of the radial extensor function is lost. The reconstruction is conducted by an end-to-end suture from the donor motor branch of the brachialis to the posterior interosseous nerve with an interposed nerve graft; the aim evidently is to restore wrist and finger extension.

Even if conducted in a small series (due also to the fact that the original lesion is quite rare), results are quite encouraging, with motor and sensory recovery, and without any donor morbidity recorded.

9.5 Our Strategy in Using Nerve Transfers

The strategy depends on several factors: complete or incomplete palsy, adult or child, and duration of the paralysis.

9.5.1 Complete Paralysis

A maximum number of neurotizations is necessary, usually spinal accessory to suprascapular, intercostals on musculocutaneous. The use of phrenic nerve or contralateral C7 has been discussed. However, it may be possible after 1 year to use the contralateral pectoralis nerve with a long graft, to reinnervate a gracilis transplant.

Another possibility would be to reinnervate with one intercostal nerve the thoracodorsal nerve with the aim of restoring a latissimus dorsi which can be secondarily utilized for transfer.

9.5.2 Partial Paralysis

During the primary repair, if the upper roots are slightly scarred or one is avulsed, or there is a lack of grafts, a spinal accessory to suprascapular suture is done immediately and at the same time the upper trunk is grafted from the remaining root. If there is an avulsion of C5–C6, the double neurotization spinal accessory on suprascapular and ulnar to musculocutaneous is done immediately. It can be refined by a triceps to axillary nerve transfer. If C7 is also avulsed, the three branches to the triceps are neurotized with the median nerve. In non-operated patients (mostly children but even sometimes adults after a failed repair) who have not recovered external rotation, or a good biceps, or triceps, but have a reasonable recovery of the other muscles, an isolated nerve transfer can be of great help.

This use of isolated, on demand, neurotization, targeting one missing function is a recent and very useful development of this surgery.

As briefly seen, neurotization considerably changes the panorama of possible reconstruction in severe brachial plexus palsy, and allows us to imagine reconstructive options that were previously completely unachievable.

The strongest points of this innovative "way of thinking" include firstly the significant number of available donor nerves, secondly the possibility of precisely addressing the chosen target, and ultimately the advantage of transforming a high level nerve lesion into a lower level one, reducing the time of nerve recovery.

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