Tendon transfers to restore elbow flexion after traumatic paralysis of the brachial plexus in adults

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Summary. *Loss of elbow flexion after traumatic brachial palsy produces significant functional and cosmetic problems. Although a direct approach to the neurological lesion with an attempt to reinnervate the biceps has given some encouraging results, these can be incomplete and for this reason tendon transfers still have an important role. We report the results of our series of 60 patients (54 men and 6 women) who have undergone tendon transfer between 1984 and 1994. The transfers were performed during or after nerve surgery, and we used the muscles arising from the medial epicondyle, the pectoralis minor and the triceps. Our results were judged on any improvement in shoulder stability and in the power of lateral rotation, together with the power and range of active and passive flexion of the elbow. Good results were achieved in 74% of the patients in our study, with more than 120° of elbow flexion and an ability to support at least 1 kg with the elbow flexed to 90°.*

Résumé. *La perte de la flexion du coude, au cours des paralysies traumatiques du plexus brachial représente un handicap fonctionnel et esthétique majeur. 60 patients répartis en 54 hommes et 6 femmes d'âge moyen 31 ans ont eu un traitement palliatif entre 1984 et 1994 pour réanimer la flexion du coude. Le développement du traitement direct des lésions nerveuses a donné un nouvel espoir et permet d'obtenir dans un pourcentage important de cas, une réinnervation du biceps. Cependant, le résultat de ce traitement peut être incomplet, et dans d'autres cas les lésions sont trop anciennes pour en bénéficier. L'utilisation de transferts musculaires est alors indiquée. Nous avons essentiellement utilisé 3 trans-*

ferts réalisés d'emblée ou secondairement: le transfert des épitrochléens selon Steindler, le transfert du petit pectoral selon Pol Le Coeur et le transfert du triceps sur le biceps selon Bunnel. Le caractère instable, stable ou mobile en rotation externe de l'épaule ainsi que la flexion active et passive du coude et sa force ont été nos critères d'appréciation des résultats qui sont satisfaisants puisque 74% des patients ont récupéré une force de flexion correspondant à plus d'1kg, coude fléchi à 90° ainsi qu'une amplitude de flexion supérieure à 120°.

Introduction

When there is paralysis involving the upper roots C5–C6 and C5–C6–C7, useful hand function will depend on restoring active elbow flexion. With more severe nerve damage, the ability to flex the elbow allows the arm to be put into more acceptable positions. Surgical repair of the primary lesions restores function to the biceps in 60% of patients [1]. Originally, tendon and muscle transfers were an integral part of the overall therapeutic plan when nerve roots had been avulsed. Other transfers were performed when direct nerve surgery had failed, or in very old lesions. Several muscle transfers have been described, and we have usually used the Steindler technique [19, 20], transfer of the pectoralis minor (Pol le Coeur [11]) and Bunnell's transfer of the triceps [6].

Patients and methods

We report the results of muscle transfers to restore elbow function in 60 adults with post-traumatic brachial plexus lesions. Our results have been analysed in respect of the severity of the

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plexus injury and any previous surgery including neurolysis, direct repair with nerve grafting or neurotization. Our aim was to establish the place of muscle transfers in restoring function following brachial plexus lesions. The research involved a study of the records of 60 patients (54 men, 6 women) with an average age of 31 years (range: 22–64). Of these, motor cycle or scooter accidents, or previous surgical exploration accounted for 19 patients suffering lesions to C5–C6, 25 from lesions to C5–C6–C7, 10 from complete plexus lesions and 6 from sub-clavicular lesions.

Operative technique

Muscle transfer operations were performed without plexus exploration as the lesions were too old to allow improvement after direct nerve surgery in 6 patients. Transfers to restore elbow flexion at the same time as the plexus was explored were performed in 15, and nerve surgery on the shoulder was also undertaken in 10; this included 9 direct sutures of the spinal accessory to the subscapular nerve, 1 nerve graft between C5 and the subscapular nerve, and a neurolysis of lesions in continuity in 5. Muscle transfers were performed in 39 patients after nerve surgery (Tables 1–4).

The reasons for failure of direct surgery on the nerves of the plexus is not clear, but double lesions were never found; Simultaneous contraction of the biceps and triceps after nerve

grafting may have resulted from a problem in the axons, or from inadequate alignment during suture. The failure of attempts to join the spinal accessory to the musculo-cutaneous nerve can be explained by the length of the grafts, 2 failures were more than 15 cm in length, the average length being 11.5 cm. A graft taken from the ulnar nerve to reinnervate the biceps in lesions of C5–C6–C7 was not considered, as C7 forms part of this major nerve [15]. Poor peroperative assessment of the continuity of the plexus roots using the Sunderland system [21] is a probable cause of the failure of neurolysis.

In our study group of 60 patients, 66 transfers were performed (15 pectoralis minor, 26 triceps, 25 Steindler's). Only one procedure was required to restore elbow flexion in 54 patients, and 6 underwent transfer of the pectoralis minor and a Steindler. Other operations were necessary to improve elbow flexion including 2 shoulder arthrodeses, 9 soft tissue procedures using the acromioclavicular ligament [16], and 18 humeral derotation osteotomies. Following 5 wrist arthrodeses, 7 tendon transfers of radial palsy type, and 2 transfers of flexor carpi ulnaris to extensor carpi radialis brevis were performed; wrist and hand function were improved.

Criteria for assessment

Two principal criteria for assessment were used: muscle power and the range of elbow flexion. At least 120° of active flexion with at least muscle power 4 was considered a very good re-

Table 1. C5–C6 lesions: 21 transfers, 19 patients (*abd* abduction; *bic* biceps; *coracobrach* coracobrachialis; *cub* cubital; *derotation* humeral derotation osteotomy; *ligamento* ligamen-

tous repair; *MC* musculo-cutaneous nerve; *neurot* neurotization; *pect* pectoralis; *SS* supra-scapular nerve; *XI* accessory nerve)

	Initial transfer	Nerve surgery & subsequent transfer	Elbow result	Shoulder	Shoulder result
C5–C6 avulsed 7 cases	4 pectoralis minor		2 VG +2 G	+6 XI–SS neurotization +1 ligamentous repair	1 VG +3 fair
			1 G		1 G
			1 VG		1 VG
		1 cub-bic neurotiz +1 secondary Steindler	1 VG	+1 XI–SS neurotization	1 VG
C5 graftable 3 cases	1 pectoralis minor +1 Steindler		1 VG	+1 graft C5- (Ax nerve+SS nerve)	1 failure
			1 VG	+1 derotation +1 graft C5–SS	1 failure
		1 graft C5–MC nerve +1 secondary Steindler	1 VG	+1 graft C5–SS	1 failure
		1 graft C5- anterior part of first trunk +1 secondary Steindler	1 VG	+1 derotation	1 failure
C5, C6 graftable 1 case		1 graft C5C6-first trunk +1 secondary Steindler	1 G	+1 graft C5–SS +1 derotation	1 fair
C5, C6 in continuity 6 cases	2 neurolyses +2 pectoralis minor at the same time		2 G	+2 derotation	2 fair
		4 neurolyses +1 pectoralis minor	1 VG		1 fair
		+1 secondary triceps +2 secondary Steindler	1 VG 2 G		1 G 2 VG
Specific cases 2 cases	2 isolated transfers for old injuries 1 triceps 1 Steindler		1 VG		1 VG
			1 G	+1 shoulder arthrodesis	1 fair

Table 2. C5–C6–C7 lesions: 27 transfers in 25 patients

	Initial transfer	Nerve surgery & subsequent transfer	Elbow result	Shoulder	Shoulder result
C5–C6–C7 avulsed 9 cases	3 triceps		3 G	+3 XI–SS +1 ligamentous repair +1 derotation	1 VG 1 fair 1 fair
		6 neurotizations XI+SCP- MC +5 secondary Steindler	1G+2 fair+2 failure	+2 derotation +1 ligamentous repair	3 fair+2 failure
		+1 triceps	1 G		1 fair
C5 graftable 5 cases		1 graft C5–MC nerve +1 secondary triceps 4 grafts C5- anterior part of first trunk +2 secondary Steindler	1 G	+1 graft C5–SS nerve	1 VG
		+2 secondary triceps	1 VG+ 1 fair	+1 derotation	2 fair
		+2 secondary triceps	1 VG+ 1 G		1G +1 fair
C5, C6 graftable 3 cases		3 grafts C5C6- first trunk +2 secondary triceps	2 VG	+1 derotation	1 VG+1 failure
		+1 pectoralis minor+ Steindler	1 VG	+1 derotation	1 failure
C5, C6, C7 in continuity 4 cases	3 neurolyses +3 pectoralis minor +1 secondary Steindler		1 G+1 fair+1 failure	+1 derotation	3 fair
		1 neurolyse +1 secondary triceps	1 G		1 VG
Specific cases 4 cases	4 isolated transfers for old injuries 2 triceps		1 VG +	+1 ligamentous repair +1 shoulder arthrodesis	1 fair 1 fair
	2 Steindler		1 VG+1 1 fair	+1 derotation	1 VG 1 fair

Table 3. Complete plexus lesion: 10 transfers in 10 patients

	Initial Transfer	Nerve surgery & subsequent transfer	Elbow result	Shoulder	Shoulder result
Avulsion C5 to T1 0 case					
C5 Graftable avulsion C6C7C8T1 0 case					
C5,C6 Graftable avulsion C7C8T1 7 cases		*7 grafts C5C6-first primary trunk +7 secondary triceps	3 VG+2G +2 fair	+3 neurot XI–SS +4 grafts C5–SS +4 ligamento. +3 derotation	3TB 3 fair+1 failure
C5–T1 IN Continuity 3 cases		*3 neurolyses +3 Steindler	2 fair+1 failure	+2 derotation +1 ligamento	2 fair+1 failure

Table 4. Subclavicular plexus lesions: 8 transfers in 6 patients

	Initial transfer	Nerve surgery & subsequent transfer	Elbow result	Shoulder
2 posterior trunk and lateral anterior trunk injuries		Grafts +2 pectoralis minor +2 steindler	2 fair	SS intact
2 musculo-cutaneous+ median injuries		Grafts +2 triceps	2 VG	SS intact
2 injuries of 3 trunks		Grafts +2 triceps	1 G+1 fair	SS intact

sult; patients who achieved less than 120° flexion but also achieved flexion against gravity were considered to have a good result; those who had more than 80° flexion but muscle power of only 3 were considered to have a fair result, and those who achieved less than muscle power 2, or power 3 where the transfer was of no practical value, were considered failures.

Lack of 20–25° elbow extension was considered to be useful, and might help to increase lever function of the limb.

Shoulder stability and function also have a role in the success of the transfer as unless this joint is stable, and external rotation is possible, the forearm may strike the chest during flexion of the elbow.

It is therefore important to assess both shoulder function and elbow flexion when considering nerve and palliative surgery.

Results

Our results were recorded at an average of 26 months after operation but a stable condition had been reached by 6 months. Very good results were recorded in 22 patients (37%), good results in 22 (37%), fair results in 11 (18%), and poor results in 5 (8%). Thus 74% of our patients achieved a good or very good results.

Results for each type of transfer

Transfer of the pectoralis minor (15 cases). Preoperative examination (Tables 5 and 6) revealed that the pectoralis major and minor muscles had a combined strength of power 4 or 5 in 70% of C5–C6 lesions, but only in 32% of C5–C6–C7 lesions. Transfer of the pectoralis minor was usually done with a good result in C5–C6 plexus lesions (9 out of 15 cases), notably when only these 2 roots had been avulsed (Table 7). Transfer of the pectoralis minor gave less good results in more extensive plexus damage and, when C5, C6, C7 were involved, a Steindler transfer was also required, except in one instance where a neurolysis was done at the same time as the transfer. Solitary transfer of the pectoralis minor gave good or very good results in 53% of cases. Six failures were salvaged by a secondary Steindler procedure, and this increased the results by 2 very good, 2 good and 2 fair, thereby improving the overall good results from 53% to 80%.

Steindler's procedure (Table 8). Transfer of the muscles arising from the medial epicondyle of the humerus has been done in the following patients: 9 with le-

Table 5. C5–C6 lesions: muscle testing before transfer in 27 patients

Power	0	1	2	3	4	5	Transferable in
Pectoralis major	2	2	1	3	4	15	70% of cases
Triceps	2	0	0	4	5	16	78% of cases
Flexor carpi radialis	0	0	0	2	6	19	93% of cases
Pronator teres	0	0	0	2	5	20	93% of cases

Table 6. C5–C6–C7 lesions: muscle testing before transfer in 43 patients

Power	0	1	2	3	4	5	Transferable in
Pectoralis major	13	3	5	8	13	1	32% of cases
Triceps	22	0	2	5	10	4	32% of cases
Flexor carpi radialis	10	2	3	11	9	8	40% of cases
Pronator teres	5	0	6	14	13	5	41% of cases

Table 7. Pectoralis minor transfer

	Very good	Good	Fair	Failure	Total
C5–C6	3	4	0	2	9
C5–C6–C7	0	1	0	3	4
Complete lesions	0	0	0	0	0
Subclavicular	0	0	0	2	2
Total	3	5	0	7	15

Table 8. Steindler muscle transfer

	Very good	Good	Fair	Failure	Total
C5–C6	4	5	0	0	9
C5–C6–C7	3	2	4	2	11
Complete lesions	0	0	2	1	3
Subclavicular	0	0	2	0	2
Total	7	7	8	3	25

Table 9. Triceps muscle transfer

	Very good	Good	Fair	Failure	Total
C5–C6	3	0	0	0	3
C5–C6–C7	4	7	0	1	12
Complete lesions	3	2	2	0	7
Subclavicular	2	1	1	0	4
Total	12	10	3	1	26

sions of C5–C6 including 2 following a pectoralis minor transfer; 11 with lesions of C5–C6–C7 including 2 following a pectoralis minor transfer; 3 with complete lesions and 2 with plexus lesions in the subclavicular region. Steindler's procedure was performed following a pectoralis minor transfer in 6 patients and the results were good in 3 cases (2 lesions of C5–C6, 1 lesion of C5–C6–C7), and fair in 3 cases (1 case of neurolysis and 2 subclavicular lesions). In our series the average transfer was 3.8 cms. The transfer, including the bone origin, was fixed with a screw and washer, and no problems arose. These procedures were followed by an average loss of 24° elbow extension which in practice improves the lever action of the limb. Solitary Steindler procedures have shown good results in 53%, but when performed after a pectoralis minor transfer this increased to 66%.

Transfer of the triceps (Table 9). Of the 26 cases, 11 simultaneous contractions of the biceps and triceps occurred after nerve surgery and this was a strong in-

Table 10. Results depending on degree of plexus injury

	Very good	Good	Fair	Failure	Total
C5–C6	10	9	0	0	19
C5–C6–C7	7	11	4	5	27
Complete lesions	3	0	5	0	8
Subclavicular	2	2	2	0	6
Total	22	22	11	5	60

Table 11. Results depending on primary or secondary transfer

	Very good	Good	Fair	Failure	Total
Initial transfer	7	12	1	1	21
Secondary transfer	15	10	10	4	39

dication for triceps transfer. There were 2 lesions of C5–C6–C7, 7 total lesions, and 2 subclavicular with involvement of all 3 trunks. Nerve grafting was also performed on the complete upper trunk in all the subclavicular lesions. The results were either good or very good in 85% of cases.

Results in relation to the degree of injury to the plexus (Table 10). Transfers for C5–C6 lesions were a little more successful than those for lesions of C5–C6–C7. With diffuse plexus damage, the results were variable but should be considered in relation to any recovery which had already occurred, and which itself influences the choice of procedure, which was usually a triceps transfer, but occasionally Steindler's procedure.

The place of direct nerve surgery

Nerve surgery without muscle transfer restored elbow flexion in 60% of our patients. Muscle transfers were performed in two situations (Table 11):

1. Immediately with nerve surgery to the shoulder, and in the majority of cases a good result was obtained. This was probably due to the fact that these transfers were performed for lesions which were neither very extensive nor severe (C5–C6 and C5–C6–C7 lesions). Reinnervated muscles were never transferred.

2. Muscle transfer is usually necessary for very severe primary lesions in patients who have already undergone nerve repair. Even if the nerve repair has not restored active flexion to the elbow, it will occasionally have produced power 2 in the biceps and this can be reinforced by Steindler's procedure. Apart from the elbow flexors, nerve surgery will have reinnervated other muscles, most notably the triceps. Tri-

Table 12. Shoulder results

	External rotation & flexion	External rotation	Abd.	Flexion	Stabilised	Unstable
C5–C6 19 cases	6	2	1	1	14	5
C5–C6–C7 25 cases	4	1	1	1	17	8
Complete lesions 10 cases	2	1	2		5	5
Subclavicular 6 cases	6				6	
Total 60 cases	18	4	2	2	42	18

ceps transfer can occasionally restore elbow flexion even when the elbow flexors have been totally paralysed.

The shoulder (Table 12)

Stability. Good elbow flexion requires a stable shoulder, and this depends directly on the recovery of power in the shoulder muscles, especially the supraspinatus and the deltoid. The long head of the biceps provides active stability and prevents the shoulder from dropping. When the shoulder remains paralysed it is often stabilised by joint stiffness which itself can follow fractures of the shoulder girdle.

In our series, 42 patients required shoulder stabilisation; 19 after surgery on the subscapular nerve, the posterior part of the superior trunk, or directly on the axillary nerve; 6 after a biceps had recovered to power 2 (3 avulsions C5–C6–C7 treated by anastomosing the spinal accessory and the musculo-cutaneous nerves, and 3 old lesions); 11 after neurolysis of the plexus for lesions in continuity, and in 6 with a subclavicular lesion and an intact subscapular nerve.

Arthrodesis was performed in 2 of the 18 unstable shoulders, and 8 were repaired by using the acromioclavicular ligament [16]. In 2 with no recovery of elbow flexion, the shoulders were left alone. The need for surgical stabilisation was avoided in 6 patients where associated fractures of the shoulder girdle developed sufficient stiffness.

Active external rotation. Recovery of active external rotation of the shoulder considerably improves elbow flexion as it avoids contact between the forearm and the thorax and allows the arm to adopt a better position. External rotation has been restored in 30% of the patients in this series following direct surgery on the subscapular nerve. Anastomosis between the spinal accessory and the subscapular nerve has allowed active external rotation in 9 of 17 cases (53%), whereas grafting between C5 and the subscapular nerve has only succeeded in 2 of 12 (17%). Direct su-

ture of the spinal accessory to the subscapular nerve has produced 9 good results in 14 cases (64%).

Diaphyseal derotation of the humerus where there has been no recovery of active external rotation, or in the presence of fixed internal rotation, allows better positioning of the arm. It also prevents contact between the limb and the chest, and improves grip. There were 18 osteotomies in this series. They were performed under the insertion of pectoralis major and were fixed with an 8-hole cortical plate.

The hand

In supraclavicular plexus lesions, surgery on the wrist and hand was only helpful when the damage was limited to C5–C6–C7, and this was found in 30–40% of our cases. Typical radial palsy is amenable to tendon transfers, and this was undertaken in 7 of our patients. Two wrists were arthrodesed following Steindler's procedure thus enabling flexor carpi ulnaris to be used as an extensor of the fingers, and they were successful.

Transfer of flexor carpi ulnaris to extensor carpi radialis brevis was required to overcome a problem resulting from a Steindler procedure, and considerable improvement was obtained both in the hand and in the effect of the Steindler operation.

In complete or subclavicular lesions, when the hand was totally paralysed (3 cases in our series), wrist arthrodesis gave sufficient stability to allow the hand to be used as a 'paperweight'.

Discussion

To restore elbow flexion, muscle transfer must have similar biomechanical actions to those of the biceps and the brachialis. Lanz [22] was the first to estimate the power of flexion and extension of the elbow. Muscles producing flexion from 0°–145° develop a force of 14 kg/m to which the biceps contributes 4.8 kg/m and the brachialis 3.8 kg/m. The extensors pro-

Fig. 1. Relative force of the different transfers in relation to a reference group comprising 13 shoulder muscles (from Comtet and Herzberg): comparison with anatomical characteristics (Bonnel)

duce a total of 9.3 kg/m with the triceps providing 8.5 kg/m. Therefore the triceps develops a force double that of the biceps. Bonnel [3] describes the anatomy of each of the muscles studied (Fig. 1). Transfer of the pectoralis minor is designed to replace the coracobrachialis rather than the biceps, but its short length raises a problem. The pectoralis major, the latissimus dorsi and the triceps appear to have the necessary properties to restore elbow flexion.

The relative strengths as defined by Brandt [4] seem to be more important than the anatomical characteristics. Comtet and Herzberg [9] have studied the relative strengths of the muscle of the shoulder (Fig. 1).

The triceps transfer is more powerful than that of either the pectoralis major or latissimus dorsi, which are not so strong as a normal biceps. The pectoralis minor is a good deal weaker. The Steindler procedure is a powerful transfer, but its action is reduced owing to poor lever action.

The choice of which muscle to transfer depends on clinical and electromyographic (EMG) testing of the various muscles available. They must be of at least strength 4 and have an adequate EMG trace. The choice also depends on which muscles retain adequate innervation, and thus on the extent of the plexus lesion. The radicular composition of the nerves supplying relevant muscles is also an important factor when deciding which muscle to transfer (Table 11). Pectoralis minor and major are supplied from C5–T1, so that in lesions of C5–C6 both of these are transferable in 70% of cases (Table 5); When C7 is also involved, this falls to 30% (Table 6).

The triceps is innervated by C6–C7–C8, and can be used in 80% of cases when C5–C6 are damaged, but in only 30% if C7 is also involved. The triceps received its nerve supply from C8 in one third of the patients in this series.

Latissimus dorsi is innervated by C5–C6 and therefore cannot be used for subclavicular lesions. Muscles transferred in the Steindler procedure include the pronator teres and flexor carpi radialis (C6–C7), the palmaris longus (C7–C8) and the flexor carpi ulnaris (C7–C8–T1). The flexor carpi radialis and pronator teres are always transferable in C5–C6

lesions but when C7 is also damaged only 40% can be used. The strong flexor digitorum superficialis receives an important part of its innervation from C8–T1, and can therefore be used when the upper plexus roots are involved.

Transfer of the pectoralis minor [2, 11, 12, 18] only produces about 1 kg of power, and its short length makes the operation difficult. We overcame this problem by increasing the length of the 3 muscular sections using 3 non-absorbable sutures which were passed into the paralysed biceps muscle [2]. Use of this muscle did not produce any significant untoward effect. It was not used in lesions of C5–C6–C7, except where there was no significant loss of continuity, or when there was a possibility of restoration of biceps function following nerve surgery, because the pectoralis minor would have been 30% weaker than in lesions of C5–C6. In this situation we reinforced its action with a Steindler procedure thereby producing a combined power of between 2 and 3+. We found that the combination of these 2 transfers in C5–C6–C7 increased the likelihood of success.

Steindler's procedure has been described by other authors [2, 10, 13, 14, 16, 19, 20, 23]. Steindler's original idea was to move the origin of the muscles arising from the medial aspects of the distal part of the humerus proximally by about 6–7 cm in order to increase their effect upon the elbow joint. One problem that can occur is concurrent flexion of the wrist and fingers which could make the hand unusable. In order to avoid this complication, we reduced the length of the transfer to 3–4 cm, even though this reduced the power of elbow flexion. Therefore we used the Steindler procedure only in those cases where there was elbow flexion of power 2 following either nerve surgery or transfer of the pectoralis minor.

Failures in our series followed either poor preoperative assessment, clinically and by EMG, or when no better muscle was available to transfer. However in 2 patients who only had activity in flexor carpi ulnaris, wrist arthrodesis allowed us to transfer this muscle to the extensor of the fingers without any effect on elbow flexion.

In our experience, transfer of triceps to the biceps [2, 6, 7, 8, 17, 23] gives a powerful function. This can nearly always be used in C5–C6 lesions, and in 30% of C5–C6–C7 plexus lesions. It is the only transfer which is useful when active contractions of the biceps and triceps occur either spontaneously or after nerve surgery on the upper trunk. However, this technique does remove active extension of the elbow and this can only be partly replaced by gravity. Patients need this active movement when reaching for high objects so there must also be active shoulder abduction of at least 90°. We believe, therefore that it is helpful to exchange active elbow extension for active flexion of the elbow joint.

Transfer of pectoralis major and of latissimus dorsi have been proposed by other workers [5, 23]. We did not use the pectoralis major either alone or in conjunction with the pectoralis minor, for its use sig-

nificantly reduces the useful 'pinchgrip' between the arm and the thorax. As the latissimus dorsi is innervated by C5 and C6, it is rarely available for transfer in lesions of the plexus.

Nerve surgery to the shoulder gives external rotation in 60% of cases. When this fails, a transfer is only possible when the shoulder is stable and there is active elbow flexion of at least power 3. In practice, a transfer is rarely possible as both the latissimus dorsi and the teres major are paralysed in C5–C6 lesions, and this is why we prefer a derotation humeral osteotomy to avoid contact between the arm and the thorax during elbow flexion. Stabilisation using the acromioclavicular ligament is only needed for persistent instability. We rarely arthrodesis a shoulder as this removes all possibility of rotation.

Conclusion

As each patient poses a different set of problems, attempts to restore active elbow flexion depend on the active muscles available for transfer. In patients with C5–C6 lesions with no active elbow flexion and with the roots avulsed, we favour anastomosing the spinal accessory nerve to the subscapular nerve, to be followed either with a pectoralis minor transfer or a triceps transfer. In those patients with C5–C6–C7 lesions the problems are greater as there will be more widespread paralysis and therefore fewer muscles available for transfer. Where there is no elbow flexion, we favour triceps transfer, provided its main innervation is from C8. If this is not the case, we transfer the pectoralis minor and also perform a Steindler procedure. In cases of paralysis of C5–C6 and C5–C6–C7, with active elbow flexion of power 2, we use the Steindler procedure. In cases of complete brachial plexus palsy, we transfer a reinnervated triceps where possible. In subclavicular plexus lesions our operative plan depends on the residual function. In such cases, transfer of the pectoralis minor, the triceps and a Steindler procedure must be considered.

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