PATTERNS OF INJURY TO THE TERMINAL BRANCHES OF THE BRACHIAL PLEXUS

THE PLACE FOR EARLY EXPLORATION

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Non-operative management has frequently been adopted for closed injuries of the infraclavicular brachial plexus and its branches in the belief that spontaneous recovery is likely to occur, and surgical exploration is performed only if recovery has not occurred in the expected time. This paper correlates the clinical and electrophysiological features with the operative findings in six patients with such injuries.

The axillary nerve was ruptured in all six patients, the musculocutaneous nerve in two and the radial nerve in two. When the muscles supplied by a branch of the plexus were denervated, the differentiation between rupture of that branch and a lesion in continuity could only be made by surgical exploration, which should be performed as soon as other injuries permit.

Closed infraclavicular injuries of the brachial plexus and its terminal branches are less common than injuries to the plexus above the clavicle and are often accompanied by skeletal injuries around the shoulder. Leffert and Seddon (1965) reported a good prognosis for recovery of infraclavicular lesions and recommended non-operative management, advising surgical exploration if recovery failed to occur in the expected time (Seddon 1975). This policy has been widely adopted. Although a number of surgeons now explore the plexus early in certain circumstances, the published reports refer mainly to supraclavicular lesions (Narakas 1981; Millesi 1977; Sedel 1982).

Failure of spontaneous recovery within the expected time (6 to 12 months after injury) indicates either considerable internal disruption with fibrosis or nerve rupture, but at this stage the chance of useful recovery from nerve grafting is poor (Sunderland 1978). If exploration is required, it should ideally be undertaken as soon as possible, preferably before evidence of re-innervation can be expected. When making this decision, the surgeon must be familiar with the common patterns of injury; he must also take into account the violence of the injury, as well as the clinical and neurophysiological findings.

In this paper we describe the clinical and operative findings in six patients with injuries to the infraclavicular brachial plexus and its terminal branches, and attempt to define the indications for early surgical exploration.

PATIENTS AND METHODS

Six patients with injuries of the infraclavicular brachial plexus or its terminal branches were seen over a 17-month period. All except one (Case 1, who was referred from another hospital three years after injury) were admitted to our hospital and examined on the day of injury (Table I). The clinical findings were recorded on the chart designed by Merle d'Aubigné and Deburge (1967) and modified by Narakas (1981). Features suggesting a supraclavicular lesion were sought, including supraclavicular bruising, reduced tone in the paracervical muscles, paralysis of the scapulothoracic muscles or diaphragm and Horner's syndrome. Since there was clear evidence of the infraclavicular site of the injury in all six patients, myelography was not performed. From the physical findings, an attempt was made to identify which branches of the plexus were affected. Lesions were recorded as complete if there was no activity in muscles supplied by each nerve with anaesthesia in the appropriate area. Lesions were recorded as incomplete if some function was present in the muscles supplied by each nerve.

Two patients each had a rupture of the axillary artery which was repaired on the day of injury. One of the authors was present at this stage to define the nerve lesions as far as possible, and it was found that an electrical nerve stimulator was helpful for identifying the distal stumps. The ends of the disrupted nerves were marked

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Table I. Details of patients showing the extent of the neurological lesion diagnosed by each procedure

Case	Age (years)	Sex	Injury type	Clinical findings		EMG findings		Operative findings		Procedure (time after injury)	Comments
				Complete	Incomplete	Complete	Incomplete	Rupture	Continuity		
1	24	M	*Motorcycle	Axillary Musc-cut.	Radial Ulnar Suprascap.	Axillary Musc-cut.	Radial Ulnar Suprascap.	Axillary	Musc-cut. Radial Ulnar Suprascap.	Axillary graft 6 cm Musc-cut. neurolysis (10 weeks)	Rapid ulnar nerve recovery
2	18	M	*Motorcycle	Axillary Musc-cut. Suprascap.	Radial	Axillary Musc-cut. Suprascap.	Radial	Axillary	Musc-cut. Radial Suprascap.	Axillary graft 4 cm Musc-cut. neurolysis (3 weeks)	
3	20	M	*Bicycle	Axillary Musc-cut.	Suprascap. Radial Ulnar	Axillary Musc-cut.	Radial Ulnar Suprascap.	Axillary Musc-cut.	Radial Ulnar Suprascap.	Axillary graft 5 cm Musc-cut. graft 10 cm (10 weeks)	Axillary artery repair Day 1
4	27	M	*Motorcycle	Axillary Musc-cut. Radial	Suprascap.	Axillary Musc-cut. Radial	nerve to latissimus dorsi	Axillary Radial	Musc-cut. Suprascap.	Axillary graft 5 cm Radial graft 9 cm Musc-cut. neurolysis (3 months)	
5	18	M	*Motorcycle	Axillary Musc-cut. Radial Med.cut. (f)	Ulnar Median (lateral root)	(Not performed)		Axillary Musc-cut. Radial Med. cut. (f)	Median Ulnar Lateral cord	Axillary graft 5 cm Radial graft 9 cm Musc-cut. graft 8 cm (3 months)	Axillary artery repair Day 1; median, ulnar recovery
6	13	M	Motorcycle	Axillary		Axillary		Axillary		Axillary graft 8 cm (3 years)	

* Collision with a car
Musc-cut., musculocutaneous nerve
Suprascap., suprascapular nerve
Med. cut. (f), medial cutaneous nerve of forearm.

with coloured sutures and wrapped in small pieces of silicon sheet to facilitate later identification. An attempt was then made to place the nerves away from the vascular graft in order to reduce the risk of further vascular damage at the second procedure. Nerve grafting was not performed at the time of vascular repair because of other severe injuries and because of the difficulty of estimating at this stage the amount of damaged nerve requiring excision.

Electrophysiological studies were performed 10 days after injury, or as soon as the other injuries permitted, in five of the six patients. In Case 5, these studies were not performed because the lesions identified at the time of vascular repair corresponded exactly with the clinical picture. The electrophysiological studies were made with the Medelec MS6 and all nerve and muscle responses were suitably amplified, displayed and permanently recorded on photographic paper which was then conventionally processed. Electromyograms were recorded with co-axial needle electrodes from the paralysed or paretic muscles. Spontaneous muscle fibre activity (fibrillation) was sought at several sites within each muscle and, if present, recorded. Motor unit responses to voluntary effort were also sought.

The musculocutaneous and axillary nerves were electrically stimulated supramaximally (0.2 ms duration, with a voltage greater than 250 μ V if necessary) in the posterior axilla and supraclavicular fossa. Muscle responses, if any, were recorded simultaneously using a 2 or 5 ms/cm time scale. If no response could be evoked with high intensity stimulation and high recording amplification, the stimulating electrodes were moved to the motor point of the muscle and an attempt was made to

find the stimulation threshold in volts, at a stimulus duration of 0.2 ms.

Sensory nerve fibre action potentials were individually recorded in the radial, median and ulnar nerves just proximal to the wrist, in response to electrical stimulation of the digital nerves of the thumb, index, middle, ring and little fingers.

RESULTS

Clinical findings (Table I). In all six patients, our findings suggested lesions of the terminal branches of the infraclavicular brachial plexus. The nerves supplying proximal muscles were affected more often and more severely than those supplying the forearm and hand; nerves most often affected were the axillary, musculocutaneous, radial and suprascapular. The median and ulnar nerves, however, were either unaffected or exhibited partial lesions indicating nerve continuity. Partial lesions of the radial nerve involved the triceps and brachioradialis, but the more distal muscles were spared.

Careful consideration of the neurological deficit in relation to the anatomy of the plexus and its terminations led to a reasonably accurate pre-operative diagnosis. The clinical findings often resembled those of a rupture of the upper trunk (C5, C6 fibres). However, the presence of sensation in the C6 dermatome, together with the absence of supraclavicular swelling and tenderness, indicated that the lesion was more distal. The presence of activity in the latissimus dorsi and in the lateral root of the median nerve was helpful in confirming the integrity of the posterior and lateral cords respectively, and in localising the lesions to their branches. With the one exception of the C6 dermatome already mentioned,

clinical examination of sensibility was less helpful than was motor examination in localising the lesion.

Electrophysiological findings (Table I). In general, these studies were helpful in confirming the level of the nerve lesions. In every patient in whom muscle paralysis was complete clinically, electrophysiological evidence of wallerian degeneration of nerve fibres with complete axonal loss was found. When the lesion had been present for over 14 days, there was spontaneous activity of muscle fibres (fibrillation) and no response to maximum voluntary effort or to maximum electrical stimulation of the appropriate nerve in the axilla. Electrical stimulation with 0.2 ms pulses over the motor zone of the affected muscle also gave no response at less than 200 volts. Neurapraxia was thus not responsible for the muscle paralysis in any patient, and we surmised that the demonstrated complete axonal loss was the result of either nerve rupture (neurotmesis) or of severe nerve damage in continuity (axonotmesis). It was our inability to distinguish between these two alternatives that led us to perform early operative exploration.

The sensory nerve fibre action potentials in the median or ulnar nerves at the wrist helped to confirm the integrity of those fibres which arise in the dorsal root ganglia of C6, C7, and C8 and travel within the three main divisions of the brachial plexus to their respective nerves. Radial sensory nerve fibre action potentials were either greatly reduced or absent.

Operative findings (Table I). The infraclavicular plexus was exposed through an incision extending from the clavicle into the deltopectoral groove (Narakas 1981). To provide a wide enough exposure (essential if neural damage is to be avoided), both pectoralis major and minor were detached from the humerus and coracoid process. In the two patients who had previously undergone vascular repair, gross scarring was found; however, the marking sutures and silicon wrapping placed at the first procedure were helpful in avoiding damage to the vascular graft. In one patient (Case 2) with a complete suprascapular nerve lesion, the clavicle was retracted proximally and the nerve traced distally from its point of origin from the lateral cord to the suprascapular fossa. In those patients with only partial suprascapular nerve lesions the nerve was not exposed. The lateral, medial and posterior cords were identified and traced distally. We were aware of the possibility of a two-level lesion, and were prepared to explore the entire plexus; however, the lesions found distal to the clavicle accounted for the clinical findings in each case and supraclavicular exploration was thus unnecessary.

In all six cases, the axillary nerve was ruptured between its origin from the posterior cord and the quadrilateral space. The musculocutaneous and radial nerves were each found to be completely ruptured in two patients. Ruptured nerves were cut back to healthy fascicles under the operating microscope and sural nerve grafts sutured into the defects with 10/0 nylon. Anterior

epineurectomy was performed in three patients with a localised area of scarring near the origin of the musculocutaneous nerve. Although intraneural fibrosis was present, in each instance the fascicles appeared intact and a more extensive neurolysis was not performed. Intra-operative electrophysiological studies were not performed, although we recognise that intra-operative sensory evoked potential studies may be helpful in confirming functional continuity between the proximal nerve stumps and the cord (Landi *et al.* 1980).

DISCUSSION

A consistent pattern of injury occurred in these patients. The short nerves—musculocutaneous, axillary and suprascapular—were affected most often. When a partial radial nerve lesion was present, the proximal branches to triceps and brachioradialis were involved more often than the distal muscles. A possible explanation for the distribution of nerve lesions is as follows: when the limb is displaced away from the trunk at the time of injury, traction is applied to the nerves. We suppose that the tissue planes which the nerves traverse allow a degree of gliding, and that most of the traction force is applied to the nerve by its point of muscle attachment. For a given limb displacement, those nerves with the shortest distance between the plexus and their muscle insertion will undergo the greatest elongation in proportion to their length, and will presumably be most likely to rupture. A ruptured suprascapular nerve was not found in this series, possibly because the muscles it supplies are attached to the scapula and this bone probably undergoes less displacement than the humerus.

The prognosis for recovery after closed injury to the infraclavicular brachial plexus is good when a complete paralysis is due to neurapraxia or when the presence of some function in each muscle group signifies nerve continuity. A conservative approach is appropriate in such cases (Leffert and Seddon 1965). However, if nerves are ruptured, early exploration and nerve grafting offers the only chance of useful recovery. It is clear from the work of Narakas (1981), Millesi (1977) and Petrucci, Morelli and Raimondi (1982) that the best results of brachial plexus surgery are obtained by repairing lesions affecting the origin from the plexus of those nerves which supply proximal muscles. Nerve grafting is particularly worthwhile if, as in this series, good hand function remains but the ability to position the hand in space is diminished.

The belief that incomplete lesions of the brachial plexus have a better prognosis for spontaneous recovery than complete lesions, although generally correct, must be applied with caution to any particular patient. The degree of injury to each nerve, and the number of nerves involved, are factors which require separate consideration. On the one hand, a lesion in continuity of the entire infraclavicular plexus which results in a completely paralysed and anaesthetic limb may achieve satisfactory recovery, as reported in 10 out of 14 cases by Leffert and

Seddon (1965). On the other hand, a limb which lacks only axillary and musculocutaneous nerve function may have no potential for recovery of the affected muscles because those nerves are ruptured. The surgeon must decide whether, for example, paralysis of deltoid, triceps and brachioradialis represents a lesion in continuity of the posterior cord, or rupture of the axillary nerve accompanied by a partial radial nerve palsy; the second possibility requires exploration, the first does not. Frequently, of course, the injury is mixed; partial lesions of some nerves accompany complete lesions of others. The importance of systematic physical examination and correlation of all the findings with the anatomy of the plexus and with the results of electrophysiological tests in these patients cannot be overemphasised.

The difficulty in reaching a precise diagnosis of the nature and location of nerve trauma in this area is one reason why exploration of infraclavicular plexus lesions has often been delayed until it is clear that recovery has not occurred in the expected time. However, except for neurapraxia, the time taken for recovery is a minimum of four months for shoulder muscles and six months for the elbow (Sunderland 1968). Although useful recovery may follow nerve grafting performed many months after injury, it is generally agreed that the quality of recovery diminishes if the delay exceeds four to six months. In our view, the surgeon must decide whether exploration is indicated long before signs of recovery can be expected. Most of the information upon which this decision is based can be obtained within three weeks of injury.

The factors which influence the selection of patients for surgical exploration of the plexus have been reviewed recently by Narakas (1981), who states that "severe regional trauma is as good a reason as any for considering surgical exploration as early as possible in complete plexus lesions". It is noteworthy that five of our patients were motorcyclists and that all had severe injuries. However, infraclavicular plexus lesions which accompany low-violence injuries, such as shoulder dislocation, have a good prognosis for recovery and should be treated non-operatively (Seddon 1975), for the nerves are presumably in continuity and the lesion is either a neurapraxia or is due to axonotmesis.

In our series, when the muscles supplied by one or more branches of the plexus were paralysed, and electrophysiological studies demonstrated complete denervation with no surviving motor fibres, it was not possible pre-operatively to distinguish a rupture from a lesion in continuity (see Table II). In these circumstances, therefore, the nerves should be explored as soon as the patient's other injuries allow, so that nerve ruptures can be identified and grafted and the best chance of recovery offered. If the lesion of each branch of the plexus is incomplete, or if a complete paralysis is due to neurapraxia, non-operative management is indicated. Electromyography of apparently paralysed or severely weak muscles is a very sensitive method of demonstrating even

Table II. Pre-operative assessment and operative findings

Nerve	Pre-operative assessment	Operative findings
Axillary	Incomplete 0 Complete 6	6 ruptures 0 in continuity
Musculocutaneous	Incomplete 0 Complete 5	2 ruptures 3 in continuity
Radial	Incomplete 3 Complete 2	2 ruptures 0 in continuity
Suprascapular	Incomplete 3 Complete 1	0 rupture 1 in continuity

one or two surviving functional motor nerve fibres. If at least partial continuity of the nerve is present, spontaneous recovery is likely to occur.

The axillary nerve was ruptured in all six patients in this series. Nerve rupture may have accounted for the poor recovery of axillary nerve lesions which occurred in Leffert and Seddon's series (1965), despite good recovery in other parts of the infraclavicular plexus. Alnot and Jolly (1983) explored 19 patients with injuries of the axillary nerve and found rupture in each case. However, no axillary nerve lesions were reported in 13 partial infraclavicular injuries explored by Sedel (1982).

In our view, repair of axillary nerve rupture is worthwhile. Petrucci *et al.* (1982) reported recovery of abduction to Grade 4 or better in 11 out of 12 patients 12 months after grafting isolated axillary nerve lesions. Although patients with isolated deltoid palsy may learn to abduct the shoulder by scapular rotation and substitution by other muscles (Wynne Parry 1981), some patients fail to achieve full strength (Petrucci *et al.* 1982) and have significant persistent functional disability. Furthermore, deltoid paralysis may result in severely weakened shoulder abduction if the compensatory muscles, especially those supplied by the suprascapular nerve, are also weak.

The timing of surgery naturally depends on its priority in relation to the patient's other injuries. Despite our intention to explore the plexus as early as possible, the average time between injury and grafting in the five acute cases was nine weeks. Injury to other systems was the principal cause of delay, although logistical reasons were responsible for delay in some patients. Not only is the procedure well tolerated by the patient, but the operation is less difficult when undertaken early. Since the disability resulting from injury to the plexus is likely to persist long after the other injuries have healed, exploration and nerve grafting should be placed high on the list of surgical priorities.

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