

The treatment of brachial plexus injuries

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Summary. *The author describes 1068 patients with brachial plexus lesions who were referred to him during a period of 18 years. Seventy two percent of the injuries were caused by road traffic accidents. Traction or crush injuries were the usual type encountered. They may occur at five levels above, behind and below the clavicle.*

Of 329 patients who underwent operation, 23% had an associated injury of a major vessel and 80% had multiple injuries elsewhere. The operative approach preferred is described and the principles governing the choice of nerve repair, nerve graft and nerve transfer are discussed. The details of the problems encountered and the procedures carried out in this group of patients are given, and the results obtained are closely analysed. In about 15% of supraclavicular injuries reconstruction of the plexus is worthwhile. The results in infraclavicular lesions are much better with a high level of success if treated early.

Only 5 patients had direct lacerations of nerves of the plexus and another 5 had suffered gunshot wounds.

Only 11 out of 80 cases of obstetric palsy seen since 1976 have been operated on. The majority of the patients were seen late. At operation similar lesions were encountered as in adults, and useful improvement was obtained in some cases.

In post-irradiation lesions of the plexus good results may be obtained if operation is undertaken early. Otherwise surgery should only be performed to relieve severe pain.

Résumé. *L'auteur décrit 1068 patients présentant une lésion du plexus brachial, qui lui ont été adressés en 18 ans. 72% des lésions étaient causées par les accidents de la circulation routière. Il s'agissait habituellement de lésions par élongation ou écrasement qui se produisent à cinq niveaux*

différents, au-dessus, en arrière et en dessous de la clavicle.

23% des 329 cas opérés présentaient une lésion vasculaire majeure associée et dans 80% des cas, il s'agissait de polytraumatisés. L'auteur décrit son approche chirurgicale et son choix de réparation nerveuse par greffes ou transferts nerveux, en détaillant les problèmes que l'on rencontre, les procédés utilisés dans ce groupe de patients et il analyse les résultats obtenus.

A peu près dans 15% des cas avec lésions sus-claviculaires, il vaut la peine de procéder à une reconstruction plexuelle. Les résultats des réparations infra-claviculaires sont nettement meilleurs, avec un taux de succès élevé si la réparation est faite précocement.

5 patients seulement ont présenté des sections du plexus et 5 opérés avaient des lésions par projectiles.

Sur 80 cas de paralysie obstétricale vus dès 1976, 11 seulement ont eu une réparation chirurgicale directe du plexus. La majorité d'entre eux furent vus tard après le traumatisme obstétrical. Des lésions similaires à celles de l'adulte furent observées opératoirement et une amélioration utile fut obtenue dans quelques cas. Dans les plexopathies par radiothérapie, de bons résultats sont obtenus si l'opération est précoce; sinon, la chirurgie n'est indiquée que pour amender les états douloureux.

Key words: *Injuries, Brachial Plexus, Nerve grafts.*

More than 30 different causes of brachial plexus lesions have been recognized. The author's 1068 cases are representative of patients referred to a specialist in hand, upper limb and peripheral nerve microsurgery. These, mostly selected for consideration of operation, were seen over a period of 18 years. One third came from countries

other than Switzerland. The numbers given do not, therefore, reflect the incidence of any particular type of lesion in a local population. Among the traumatic cases, 72% of patients were involved in road traffic accidents, 70% of them using a pedal cycle or motorcycle. Gunshot wounds and lacerations were exceptional. The distribution of lesions was as follows:

Traumatic traction and/or crush lesions	722
Lacerations (excluding iatrogenic)	5
Gunshot wounds	14
Obstetrical lesions	80
Secondary compression after trauma	10
Iatrogenic lesions	21
Lesions due to irradiation	50
Tumours	15
Thoracic outlet syndrome	120
Parsonage-Turner syndrome	5
Vascular and other various and unknown causes	26

Traction and crush lesions

According to our estimates approximately 2% of victims of cycle or motorcycle accidents present with a brachial plexus injury. It must be appreciated that the majority of these accidents involve high kinetic energies. By comparison between 7 and 25% of patients with dislocations of the shoulder may present with a nerve injury, sometimes very similar to a brachial plexus lesion, but with a good prognosis. The violence of the trauma causing the dislocation determines the severity of the nerve lesion, not the dislocation itself.

Nature of the traction and/or crush lesions

Sunderland's [1] classification into five degrees of nerve injury can be applied to traumatic lesions of the brachial plexus. With the exception of an electric shock, no trauma will produce the same quantitative and qualitative degree of damage to all the 70,000 to 160,000 myelinated fibres anywhere along their course from the C₅ to T₁ roots to the upper limb. Therefore, apart from total rupture or avulsion from the spinal cord, or a combination of both, several of the five degrees may be associated in a single case. Root avulsion from the spinal cord is present in about 70% of severely injured patients, and is a peculiarity of brachial plexus injuries.

Law of the Seven Seventies (approximation):

70% of traumatic brachial plexus lesions are due to traffic accidents.

70% of the lesions in traffic accidents involve the use of a cycle or motorcycle.

70% of these patients have associated multiple injuries.

70% have a supraclavicular lesion.

70% of patients with supraclavicular lesions will have one or several roots of the plexus avulsed from the spinal cord.

70% of the patients with root avulsions will have the lower roots C₇, C₈, T₁ or C₈-T₁ avulsed.

70% of the patients with lower root avulsion will experience persisting pain.

Location of the lesions

From the surgical point of view, five levels can be recognized.

1. Avulsion of roots i.e. separation of rootlets from the spinal cord. This can be partial affecting the motor or the sensory rootlets alone, or involve some of each.
2. a) Lesions of the anterior branch of the spinal nerves outside the foramina are more common for the C₅, C₆ and C₇ roots than for C₈ or T₁. In severe injuries, the latter roots are mostly avulsed.
b) Lesions of the primary trunks such as C₅-C₆-C₇ or C₈-T₁. Interruption of the latter is not due to traction but to crush injury ("scissor effect") between the first rib and the clavicle.
3. Retroclavicular lesions which cause functional or anatomical interruption of the posterior cord, the lateral cord or both, but almost never of the medial cord.
4. Lesions of the distal part of the cords.
5. Lesions of the main nerves of the upper extremity close to their origin at the plexus such as associated ruptures of the supraclavicular, the axillary and the musculocutaneous nerves.

The distribution of lesions diagnosed in 329 patients with traction and/or crush injuries who were operated on was as follows:

Levels 1-2 supraclavicular	204	155 with root avulsion, 49 without root avulsion
Level 3 retroclavicular		
Level 1-2 and 4-5 associated	31	27 11 with root avulsion 16 without root avulsion
		29
Level 4 distal plexus		
Level 5 nerves at their origin	39	

A three-level injury may be present. Eleven of the patients included above presented a severe injury of the plexus and a rupture of the median radial or other nerves at some point below the axilla. 23% had a major vessel injury, and approximately 80% had multiple injuries to the head, cervical spine, shoulder (rotator cuff, scapula, clavicle, humerus), forearm and hand.

Methods of repair

When a nerve is destroyed over a certain distance in such a way that spontaneous healing will not occur, only repair by autologous nerve grafting or nerve transfer can be considered. Decompression (haematoma, bone fragments, aneurysm) has to be done early. Neurolysis is indicated only in late cases in order to relieve compression from extraneural or intraneural scar, or other causes. It is a potentially hazardous procedure, particularly when external and interfascicular neurolyses are combined, which may lead to devascularization of the nerve. Nerve transfer or neurotization uses adjacent undamaged nerves or intercostal nerves to reinnervate distal stumps which cannot be repaired by other means.

Selection of patients for operation and timing of operation

Clinical experience makes it possible to select the patients who are the victims of violent trauma for early operation in the first days or weeks after the accident. If possible vascular repair ought to be delayed until that time, provided the extremity is adequately perfused, as operation on the brachial plexus a few weeks or months after vascular repair is extremely demanding, and may be only partially successful. Emergency reconstitution of the brachial plexus at the time of vascular and bone repair (when not combined with visceral surgery) is not often necessary, but may be rewarding. Experience has shown that the later operation is carried out on brachial plexus lesions, the more difficult it is and the worse the results.

Conservative treatment

Patients with mild trauma should not be considered for early operation. Their upper limb should be put at rest for at least 2–3 weeks and then physiotherapy started. Electrical stimulation of paralysed muscles is still controversial and, if commenced very early after trauma, should be confined only to muscles situated far from the site of the lesion, so as not to disturb the healing nerves. Even a benign second degree axonotmesis may require 8 to 15 months to recover useful function. This is precious time lost for patients whose average age is 20. As soon as possible they ought to return to work and study, rehabilitation being carried out vigorously.

Operative technique

The patient is positioned supine and slightly reclining to diminish venous pressure at the site of operation. The operative field can be infiltrated with Vasopressin, diluted 1:20, to diminish capillary bleeding, and meticulous haemostasis with bipolar microcoagulation must be undertaken in order to obtain an almost bloodless field. The supraclavicular and the infraclavicular plexus must both be explored. The incision (Fig. 1) is "Z"-shaped along the posterior border of the sternocleidomastoid muscle down to the clavicle, then parallel about 1 cm above it until the coracoid process is reached, turning downwards to the anterior fold of the axilla. The supraclavicular (interscalenic) plexus is exposed through the midcervical fascia; the infraclavicular portion is exposed through the deltopectoral sulcus, sparing the pectoral vessels and nerves, and, if necessary, detaching the pectoralis minor tendon from the coracoid process.

When needed an oblique osteotomy of the clavicle is carried out. A plate is adapted to the shape of the bone and holes for screws are drilled before the bone is divided. This allows an accurate osteosynthesis with interfragmentary compression.

Nerve Repair

Once the nerve lesions are identified, a plan for reconstruction is made which takes into account the possibilities of late palliative orthopaedic surgery. Autografts can be taken from both sural nerves and, when the lower roots are avulsed, the medial cutaneous nerve of the forearm, the ulnar nerve and the radial sensory branch can be used. Usually vascularized nerve grafts do not offer any advantage in the author's experience, though they are indicated when the bed is very poor. Pedicle or free omentoplasty may be considered in such cases.

The usual requirements of nerve grafting have to be met. The length of the graft should be 15% longer than the defect, there must be a good bed, precise fascicular alignment should be achieved and the fascicular patterns of the stumps carefully matched. Microsurgical techniques are essential. For 3 years the author has used nerve glue, often in addition to a minimum of 9/0 and 10/0 stitches. This technique represents many advantages compared with the usual method of suture.

Nerve Transfer

The spinal accessory nerve, the suprascapular nerve, rami of the still functioning long thoracic nerve and up to six intercostal nerves can be used as a source of axonic sprouts to reinner-

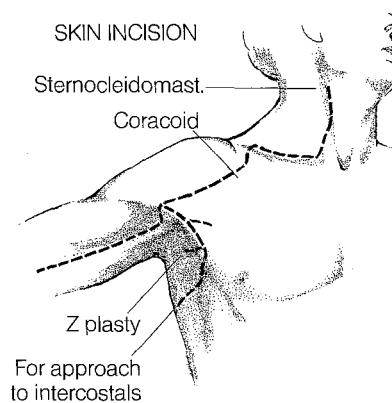


Fig. 1. Skin incision

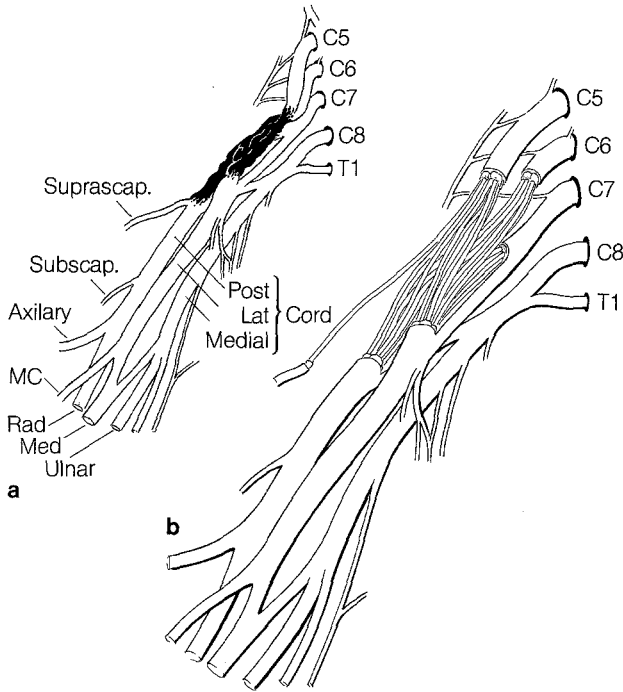


Fig. 2. a Diagram of a typical Erb-Duchenne palsy with extraforaminal ruptures of C₅, C₆ and the posterior division of C₇, **b** All repaired by autologous nerve grafts

vate distal stumps. While the cervical “neurotizers” seem to allow natural movements, the function obtained with intercostals is not always integrated into the patterns of movement of the upper limb. Examples of operative repair are given in Fig. 2 and 3.

Details of patients undergoing autologous nerve grafting

Three hundred and twenty nine patients with traction lesions and/or crush injuries of the brachial plexus have been operated on since 1966 when autologous nerve grafting was started. Before then patients only underwent exploration, decompression and suture, which was the usual type of surgery practised twenty years ago. The following procedures were carried out on the 329 patients:

Exploration only (4 as emergencies); no repair	7
External (epineural) neurolysis only	32
Internal (interfascicular) neurolysis	14
Neurolysis and autologous nerve grafting	189
Neurolysis and nerve transfer (neurotization)	43
Neurolysis, autografting some parts, neurotizing others	44

Additional procedures carried out at the same time were;

Amputations of the upper limb (through the neck of the humerus or through the forearm)	3
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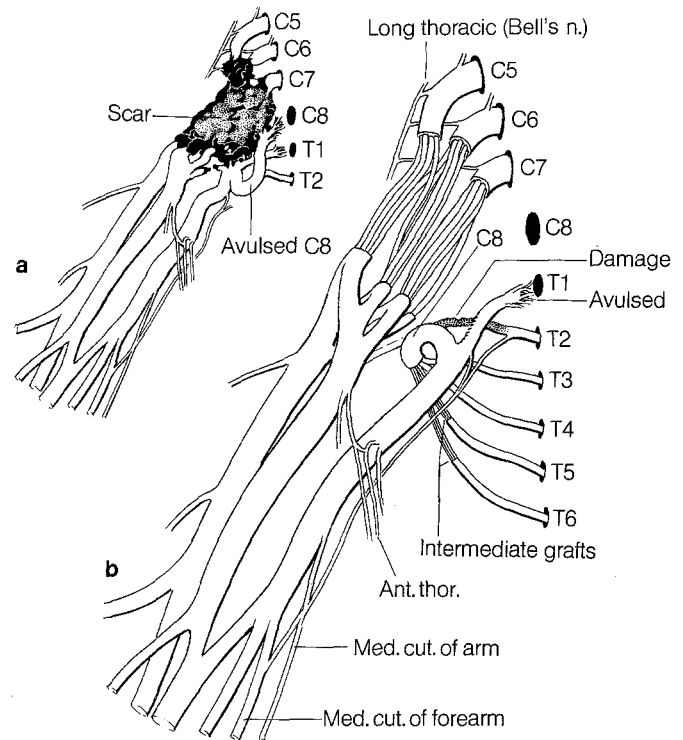


Fig. 3 a Diagram of a frequent and typical severe supraclavicular brachial plexus traction injury: extraforaminal ruptures of spinal nerves C₅, C₆ and C₇, associated with avulsion of C₈ and T₁ coiled up on the subclavian artery, **b** Repair is made with a dozen autologous grafts, 6–8 cm long, from the proximal stumps leading to the distal stumps. The lowest division of the posterior cord, normally coming from C₈, is connected to C₇ to “neurotize” it. Four intercostals have been put onto the avulsed C₈, either by direct suture or grafts to give some sensibility to the hand

Major vascular repairs (artery, vein)	23
Osteotomies of the clavicle	133
Tendino-muscular transfers, arthrodesis etc	7
Rotator cuff repairs and other bone or soft tissue reconstructions	9

Late additional procedures were:	
Re-exploration and neurolysis of grafts	3
Secondary suture or replacment of grafts	7
Seondary amputations	7
Arthrodesis of shoulder	8
Repair of rotator cuff or subscapularis ruptures	5
Various acromio clavicular or sternoclavicular repairs	7
Various osteotomies	13
Various musculo-tendinous transfers	74
Free muscle transplants	5

The principle complications encountered were:	
Infections (mostly superficial, all healed)	2

Pneumothorax, haemothorax	23
Pseudomeningocele fistula (healed spontaneously)	1
Nonunion or pseudarthrosis of the osteotomized clavicle	5
Injury to the subclavian or axillary vessels during operation (all but two were repaired successfully)	23
Phrenic nerve palsy	8

The majority of vascular injuries during operation happened in patients whose subclavian or axillary vessels had been repaired as an emergency, while the plexus lesion was not dealt with. There was almost always no proper description of nerve lesions seen at the primary operation. The subclavian-axillary vein was injured and repaired on seven occasions. One developed a secondary thrombosis but had a favourable outcome. Of the 16 arteries repaired by suture or vein graft, four thrombosed, two with little consequence to the circulation of the upper limb because of good collateral circulation, one had some ischaemic sequelae and in one case, in spite of revision of the vascular repair, the hand was lost because of a very distal occlusion which was overlooked until it was too late.

Results

At present there is no adequate classification to demonstrate the results because of the complexity of the lesions and the repair. For example if, following avulsion of all roots, abduction of the shoulder to 45° and flexion to 30° is gained by transfer of cervical nerves, while complete flexion of the elbow is achieved by transfer of 3–5 intercostal nerves into the lateral cord and an excellent sensory result is obtained with protective sensibility of the thumb and index finger, is this a good, fair or a poor result? The limb is of very little use, but is better than a prosthesis, which is very difficult to apply and use. The patients usually prefer this result to an amputation.

In future meetings of surgeons who are concerned with brachial plexus lesions, which are arranged yearly in Lausanne (Switzerland), a consensus has to be obtained on a method of evaluating the results.

It is not possible to give the detailed results of the present series because of the limited space available. This is at least partly because of the number of variable factors which are present such as the severity and distribution of the lesions, a

complete or incomplete repair, the willingness of the patient to use his disabled extremity and the influence of the pain still present.

Therefore only the following practical criteria have been used.

Good: Abduction and flexion of the shoulder to 90°. External rotation to neutral or more.

Elbow flexion 120° with a force of power 4 or more. Elbow extension not more than 20° from full extension or better, with at least power 3 or better.

Extension of the wrist to neutral or better. Flexion of the wrist with power 3 or better.

A hand which can grasp an object the size of an egg and which can appreciate at least light touch.

Fair: Abduction of the shoulder to 50°–85°.

External rotation to 30° at least from a position with the forearm against the chest when the elbow is flexed.

Elbow flexion to between 90° and 115° with a force of power 3 at least.

Passive or active extension of elbow lacking 35°–50° from full extension.

A hand with a weak grip, with some fingers capable of holding a light object, and protective sensation at least in the median nerve area.

Nil and poor: Self-explanatory.

The results are summarised in the following Tables 1, 2 and 3.

Lacerations

Four of the five patients with lacerations were operated on, one of them had a through-shoulder traumatic amputation of the upper limb which was successfully replanted. This was the only patient with a fair result. The others with lacerations of the upper trunk (2 cases) of the lateral and medial cords (a child 5 years old) had good or even excellent results. The last patient, who had been hit across the neck by an axe, was seen 5 years later and presented with a Brown-Sequard syndrome. He was not operated on.

Table 1. Results obtained with nerve grafts or transfers (follow up of more than 3 years)

Supraclavicular lesions N = 126	Zone 1 and 2			
	Good	Fair	Poor or Nil	
Satisfactory complete or almost complete repair	30	2	24	4
Partial repair	75	0	47	28
Limited or impossible repair	21	0	6	15
	126	2	77	47
		1.6%	61%	37.3%
Retroclavicular lesions N = 16	Zone 3			
	Good	Fair	Poor or Nil	
Satisfactory repair	12	3	7	2
Partial repair	4	0	2	2
	16	3	9	4
		19%	56%	25%
Two Level lesions N = 17	Zones 1-2 and 4-5			
	Good	Fair	Poor or Nil	
Satisfactory repair	6	0	3	3
Partial repair	7	0	2	5
Limited or impossible repair	4	0	0	4
	17	0	5	12
		0%	29%	71%
Distal lesions N = 28	Zones 4 and 5			
	Good	Fair	Poor or Nil	
Satisfactory repair	16	6	8	2
Partial repair	6	0	4	2
Limited or impossible repair	6	0	0	6
	28	6	12	10
		21%	43%	36%

Gunshot wounds

Five patients with gunshot wounds were operated on, 4 soon after injury, the other one year later. Isolated severed nerves were found in each case and repair was achieved by grafts with excellent results in the four early cases. The result was only moderate in the last patient who was seen one year after extensive injury from shrapnel.

Our attitude at present is to advocate early operation since modern surgical exploration is not

Table 2. Results of 44 Neurolyses in 36 Patients*

	Excellent	Good or fair	Poor or nil	Worse
For C ₅ , C ₆ , C ₇ and their distal fasciculi				
Epineural neurolysis	3	6	3	0
Fascicular neurolysis	3	2	6	2
For C ₈ , T ₁ and their distal fasciculi				
Epineural neurolysis	1	7	3	0
Fascicular neurolysis	0	1	5	2
Totals	7	16	17	4
Positive results	23			(52%)
Negative results	21			(48%)

* Four patients also had one grafted nerve, the result of which is not included here

Table 3. Effect of reconstructive neuro-microsurgery on pain

	With severe pain	Cured after operation	Improved
42 patients with supraclavicular lesions	15	10	3
38 patients with retroclavicular or distal lesions	7	6	1
165 patients with a follow-up of more than 3 years	58 35%	32 55% of 58	11 19% of 58

harmful. It is better to find a lesion in continuity, not requiring grafting, than to procrastinate and so miss a nerve which is divided.

Obstetric palsy

A survey of about 300 cases carried out by A. Gilbert in Paris has shown that babies with obstetric palsy can be divided into three groups with regard to prognosis:

- Those who start recovering within 3 weeks; they will recover completely and will not require palliative surgical measures. They have Sunderland first and second degree injuries.
- Those who start recovering after the third week and continue to improve. They will have a fair result which will often require secondary palli-

ative surgical measures. They must have third or fourth degree injuries.

- c) Those who have not started to recover after the second month of life. In these cases the plexus should be explored as soon as possible.

While Gilbert has operated on about 100 cases in the last three years, the author has explored the brachial plexus of only 11 of the 80 cases seen by him since 1976 (the majority being late cases). The same type of severe lesions were found as in the adult, with ruptures of trunks and avulsion of roots (Fig. 4). The few cases followed up for more than three years indicate that operation allows the prospect of recovering some useful function, i.e. Sunderland's fourth and fifth degree, or third degree root avulsions may be improved, which is better than without operation.

Tumours

Fourteen patients with tumours have been operated on, often to relieve excruciating pain. In one case of lipofibromatosis, decompression stopped the progressive palsy. In four cases metastases of

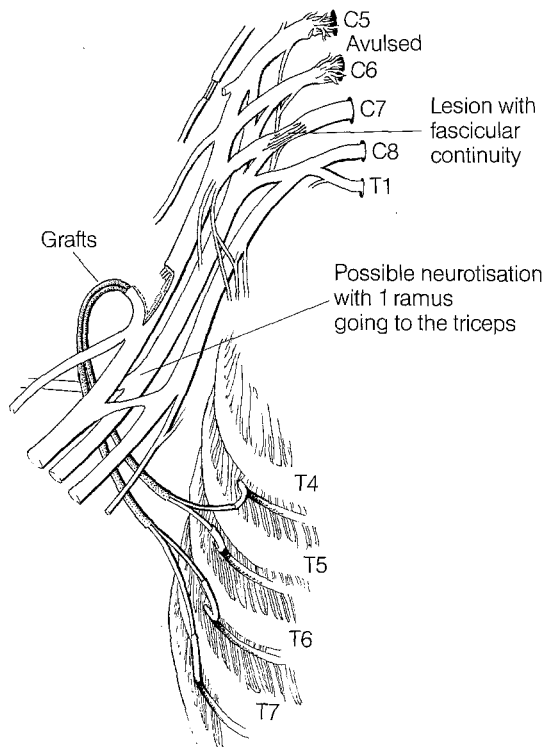


Fig. 4. Extended Erb-Duchenne palsy with avulsion of C₅ and C₆, and a stretch injury to C₇, not rupturing the fascicles. Neurotization of the suprascapular nerve with the accessory nerve, and of the musculocutaneous with intercostals. The axillary nerve can be neurotized with a branch to the triceps

breast cancer were found. One patient has now survived for 7 years. Three died without pain. Three plexiform neurinomas (one with von Recklinghausen's disease) were operated on, but all died within two years with massive recurrences.

There were 3 neurinomas: one was decompressed and deteriorated progressively; one was excised leaving a severe defect. One (a child) with involvement of C₈ was excised and grafted, but without improvement after three years. One schwannoma was excised leaving a minor defect. Two Pancoast tumours invading the plexus were operated on because of very severe pain; in one a decompression was achieved by partial excision. One died with tolerable pain, in the other the pain recurred two months after operation and he died 2 months later in excruciating pain in spite of a cordotomy.

Decisions about treatment are still very difficult to take when tumours involve the brachial plexus.

The brachial plexus and radiotherapy

Therapeutic irradiation, especially for breast cancer, produces in a few cases "hot spots" at the level of the plexus, inducing degeneration due to local ischaemia with a direct effect on the axons. The resulting scar and ischaemia causes a progressive palsy, prevents regeneration and can cause severe, intractable pain. The interval between irradiation and symptoms varies from 1 to 20 years.

Neurolysis in these cases ought to be carried out early as possible after the onset of symptoms. It is dangerous and can aggravate the palsy, but it can relieve pain.

Revascularisation of the plexus must be obtained, usually using pedicled or free omentum which is wrapped around the released nerve trunks. Of the 50 cases seen, 24 were operated on. In most cases the results were good for relief of pain, but poor for function except in the cases which were operated on early.

In about one fifth of the cases operated on, carcinomatous infiltration of the nerve trunks was found in addition to the post-irradiation lesions.

The results are given in Table 4.

Conclusions

Sophisticated micro-neurosurgical reconstruction of the supraclavicular brachial plexus leads to only limited success because of the severity of the traumatic lesions, since 70% of the patients have not only ruptures of the spinal nerves, but one,

Table 4. Relief of pain

Condition before operation		Cured	Improved	No effect
Patients with progressive palsy and severe pain	14	11*	1	3*
Patients with progressive palsy and little or no pain (5)	10	1	2+	pain appeared later 2
Effect on Function				
Condition before operation		Improved	Stabilized	Immediate or late aggravation
Patients with progressive palsy and severe pain	14	1	3	10*
Patients with progressive palsy and little or no pain	10	1	4	5
(Follow-up of 3 years)				

* In five patients with breast cancer, metastases were found in the trunks of the brachial plexus. All five patients died within about 2 years; two of them were free of pain till they died.

several or all of the roots may be avulsed from the spinal cord. In these desperate cases very demanding techniques, such as nerve grafting and transfer, yield at best moderate results.

In about one case out of seven with supraclavicular brachial plexus injury, reconstruction is worthwhile and gives far better results than any palliative surgery which may further improve the result achieved.

Infraclavicular plexus injuries sometimes give very good results provided the median and ulnar nerves have not been ruptured. It is of interest to note, for example, that in the author's series of 52 axillary nerve repairs in association with repairs of other nerves (such as the suprascapular) 77% good to excellent results were obtained, provided the repair was done within 6 months of injury.

Operations for obstetric palsy of the brachial plexus seem to be worthwhile in the severe cases, which appear more frequent than the 5% of ob-

stretical palsies usually admitted. Unfortunately normality is never attained and only very early operation can yield good results, provided the upper trunk alone is affected and no root avulsions are present.

In post-irradiation plexus lesions, operation should be reserved for the very early cases if good results are to be expected; otherwise it is surgery of despair and indicated only to relieve severe pain.

In tumours the author advises exploration but has no rational advice to give unless a benign schwannoma is present.

In this paper we have not considered iatrogenic lesions which can still occur when operations are carried out around the shoulder.

References

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