Chapter 5
Operating on Peripheral Nerves

5.1 Indications and Objects of Intervention

An experimental study is one: "in which the investigator intervenes in some way to affect the outcome. Such studies are longitudinal and prospective; the investigator applies the intervention and observes the outcome some time later" Petrie [23].

Operation is indicated to:

- to confirm or establish diagnosis;
- to restore continuity to a severed or ruptured nerve;
- to remove a noxious agent compressing or distorting or occupying a nerve.

It is difficult to overstate the significance of worsening of pain and deepening of nerve lesion caused by expanding haematoma or ischaemia. Clinicians must never forget that nerves compressed in a swollen ischaemic limb or in a tense compartment progress from conduction block to much deeper and much less favourable degenerative lesions.

Pain persisting after a focal injury to a nerve is an indication for operation at almost any interval after injury [4]. In the remarkable case described by Camp, Milano and Sinisi [7], the patient suffered intractable and increasing pain for 18 years. Pain was abolished by neurolysis of the ulnar nerve which had become adherent to the pulsatile vein graft used to repair the brachial artery. That lesion was a conduction block, prolonged by external causes: the pain was neurostenalgia.

5.1.1 The Lessons of War

Surgeons at the London Hospital firmly advocated urgent (primary) over delayed (secondary) suture in the decades before the First World War. During that conflict the principles governing the repair of war nerve wounds were established. These include: the proper treatment of the wound by debridement, excision, and delayed

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closure; excision of scar until a healthy bed is secured; excision of damaged nerve until healthy stumps are reached; and tension free suture by adequate mobilisation and flexion of adjacent joints or grafting. The imperative of rehabilitation was emphasised [3].

The work of the Medical Research Council Nerve Injuries Committee during the Second World War marked a most important stage in improving understanding of regeneration and of applying those lessons to clinical practice. Nerve grafting in all its forms was studied. The first evidence of axonal transport was revealed. The rate of nerve regeneration, the effects of disuse, the regeneration of proprioceptors, the maturation of regenerated fibres and the significance of retrograde influence were amongst the fields of enquiry [3].

Modern war wounds reinforce earlier and costly lessons but also provide new ones [6]. Most wounds are caused by explosive devices; they are multiple and complex. Avulsion, laceration, blast and crush combine to tear and shred tissues of all compartments. Heavy contamination with dirt and debris is usual and meticulous debridement is the essential first step in time-limited resuscitative surgery. The field hospital policy of emergency restoration of arterial flow and extensive decompression led to a remarkably low incidence of ischaemic fibrosis; the sole case occurred in a patient in whom the brachial artery was ligated.

The severity of damage at the level of nerve lesion is probably unparalleled; fracture in 50 %, arterial injury in 32 %, moderate or severe muscle loss in 28 % and moderate or severe skin loss in 50 %. Two of more nerves were injured in 70 % of patients. Such massive damage to the skin and muscle is inimical to nerve regeneration and function. The resultant fibrosis is an important cause of pain and loss of function. Thirty six patients came to secondary operations because of persisting severe neuropathic pain. Thirty experienced such relief after operation that analgesic medication was considerably reduced or abandoned. Some patients experienced relief when they awoke from the anaesthetic. The operations included six revision repairs, 11 neurolyses of repaired nerves, and neurolysis in the other 19 patients. The causes of persisting pain included displaced bone fragments, heterotopic bone, retained metallic fragments or suture material, and most commonly, scar tissue which enveloped and constricted the nerve. Resurfacing by free fascio cutaneous flaps were used in 15 patients, to relieve pain and enhance nerve regeneration. No case of false aneurysm or arterio-venous fistula was encountered.

5.1.2 Timing: Nerve Lesions in Fractures and Dislocations

Some important practical advantages of urgent exploration include the ease of recognising a rupture and the ease with which the stumps can be approximated. The best time to explore such injuries is before distal conduction is lost (Figs. 5.1, 5.2 and 5.3). Primary repair is defined as one performed within 5 days of injury and delayed primary repair for one completed at intervals from 5 days to 3 weeks after

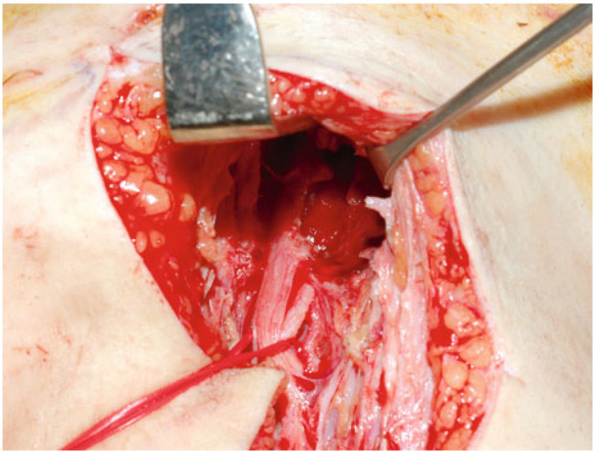


Fig. 5.1 Ease of diagnosis at operation done soon after injury. Incomplete transection of the femoral nerve occurred during a difficult pelvic operation. The surgeon recognised the event and enabled display and repair 24 h after wounding

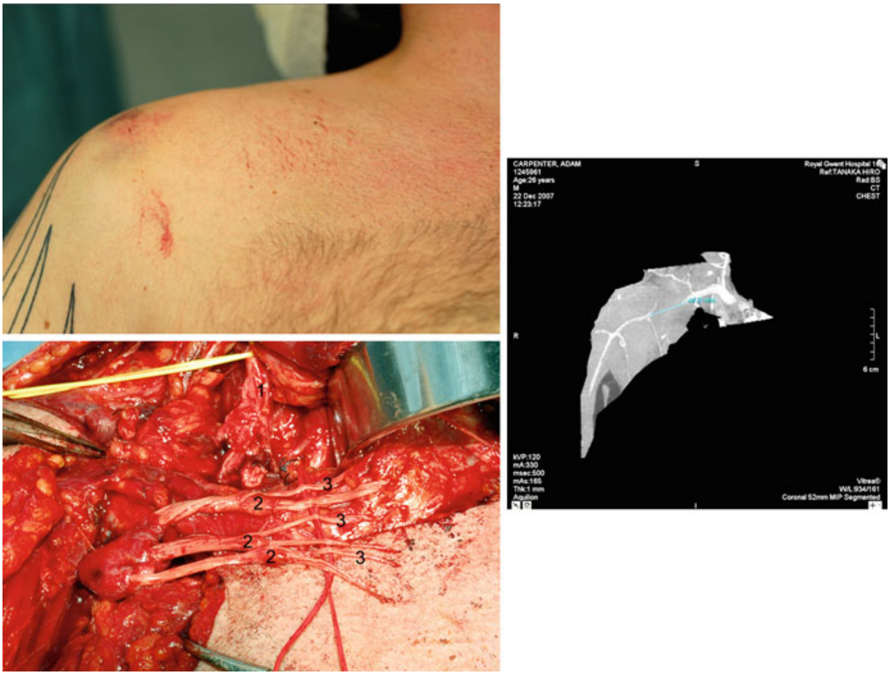


Fig. 5.2 Ischaemia and conduction. Traction lesion of the brachial plexus was accompanied by rupture of the subclavian artery. There was a weak pulse. At operation, 54 h after injury, stimulation of the avulsed ventral roots of C7, C8 and T1 evoked strong contraction in the relevant muscles distally. This showed that there was neither critical ischaemia within the limb nor that there was a second, more distal, lesion. Strong SSEP's were recorded from the stumps of C5 and C6 (*1*). The dorsal root ganglia of C7, C8 and T1 (*2*) and their ventral roots (*3*) are shown. An extensive repair was done

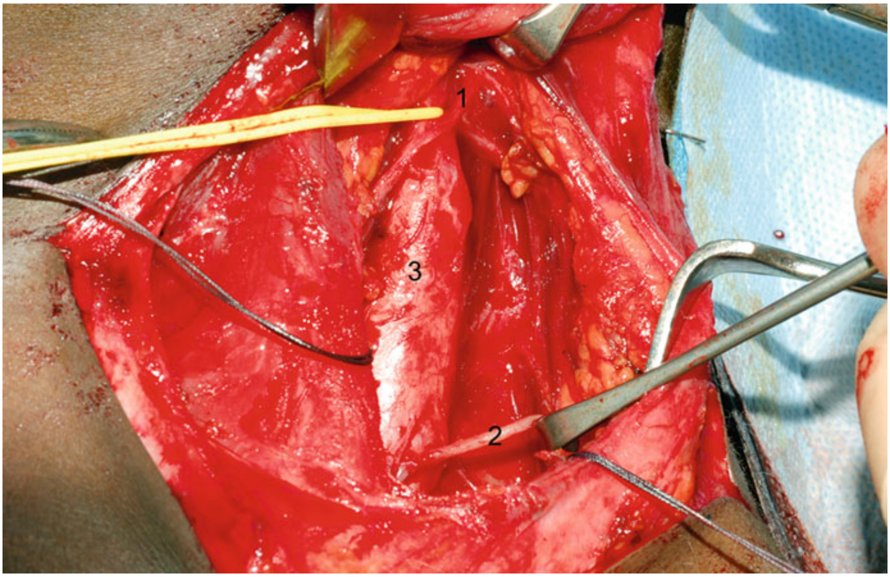


Fig. 5.3 It is often very hard to determine from inspection alone the nature of the injury in delayed or neglected cases. Ten weeks after a severe lesion of C5, C6 and C7 it was not possible to distinguish between rupture and avulsion. The phrenic nerve (*1*) suprascapular nerve (*2*) and the neuroma (*3*) are seen

injury. Secondary repair is performed at between 3 weeks and 3 months after injury. Late, or neglected, repair is reserved for those cases where delay exceeds 3 months.

Indications for exploring nerves injured by fractures and dislocations include:

- the fracture needs internal fixation;
- there is associated vascular injury
- wound exploration of an open fracture is necessary
- a fracture or dislocation is irreducible.
- the lesion deepens while it is under observation,
- the lesion occurred during operation for internal fixation.
- If the clinician elects to convert a closed fracture to an open one by internal fixation, then it is wisest to expose nerves which are not working. The fracture surgeon who does not do this is asking for trouble (Fig. 5.4).

5.2 General Principles of Operation

5.2.1 Control of Bleeding

The emergency control of bleeding by pressure is an art to practise for we have seen cases where patients were close to exsanguination following stab wounds to the

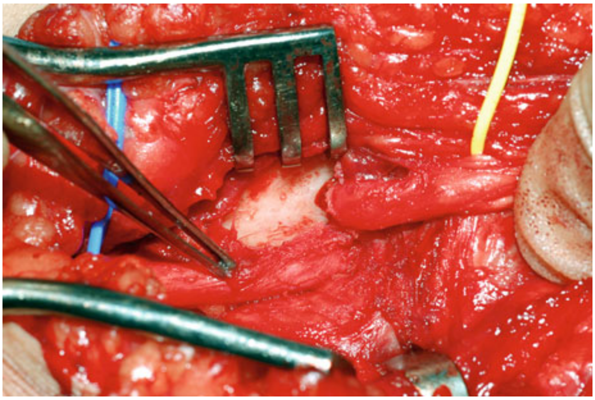


Fig. 5.4 The explanation for persisting painful median palsy in a 7 year old child after fracture of distal humerus, which had been treated by "closed" wiring, was revealed when the nerve was found embedded within the bone 11 months later

axillary, brachial, or femoral arteries. Firm digital compression of the subclavian artery against the first rib of the femoral artery at the groin which enabled successful disarticulation at the shoulder or the hip on the battle fields of the Napoleonic wars [12]. Accidental damage to an artery during operation should be treated by firm compression at the point of bleeding, NEVER by hurried, blind clamping. With this local control the incision may be extended to expose the artery above and below allowing the accurate use of slings and clamps.

The tourniquet is potentially dangerous. It is absolutely contraindicated in a limb in which an arterial prosthesis has been inserted. It seems that the implant is insufficiently elastic to dilate after release of the cuff; also, collateral circulation is likely to be defective. Tourniquet times must be reduced in patients with rheumatoid arthritis, diabetes mellitus, alcohol addiction or other possible causes of neuropathy. In many such patients it is best to avoid altogether the use of a tourniquet. Klenerman [14] provides an important manual about tourniquet use. Post operative pain is worsened by the tourniquet by longer periods of ischaemia and in older patients. The duration of application, inflation pressure and site of application should be always recorded in an ordered operating note and the times of application and release should be written on board in the operating theatre and in the case notes. The duration of tourniquet ischaemia is reduced by inflating the cuff after preparation and towelling of the limb. Elevation of the limb before inflation of the cuff is preferred to the exsanguinating bandage.

5.2.2 Preparation

Because these operations are usually time-consuming, it is especially important adequately to protect the pressure points at the knee, the elbow and elsewhere with suitable padding. In operations on the nerves of the neck in particular, special care must be taken to avoid air embolism, to recognise it if it does occur and to be prepared to deal effectively with any such occurrence. In the case of severe injuries to the brachial plexus, when there may be a sudden release of spinal fluid, it is necessary to be prepared quickly to alter the position of the patient to avoid "coning" of the medulla. If it seems likely that nerve or vein grafts are going to be needed, the donor sites should be prepared and monitoring equipment, arterial and venous lines and the drapes should be placed accordingly. It is all too easy to get lost especially in a swollen, deformed or scarred limb. Inclusion of joints above and below the presumed site of injury within the area of skin preparation helps to prevent this.

5.2.3 Prevention of Pain

Surgeons can and should do more to prevent post operative pain. The complications of blind nerve or regional blocks can be severe. Infarction of the spinal cord is a catastrophic complication of interscalene or intervertebral block; laceration of a nerve trunk by a needle can cause severe intractable pain; laceration of a vessel adjacent to a nerve may lead to a haematoma. Henry [13] describes his technique of thigh amputation without tourniquet or general anaesthetic by a method first described before the Second World War: "so, after infiltrating areas of flap or cuff, and all the operative field – most thoroughly- with procaine (0.5 %), we can in comfort see and block the great sciatic trunk". Then follows ligation of main vessels and then: "during these activities, however, the great sciatic trunk will rest in peace – until the time comes to remove the limb. With procaine infiltration, not less than 20 minutes must elapse before injecting and dividing this capacious conduit of shock impulse. And that, indeed, is little time enough". Surgeons can and should do a great deal more to diminish postoperative pain by the simple and safe expedient of infiltration of the line of incision and the skin on either side, with local anaesthetic use a preparation of Levobupivicaine 0.25 %, with adrenalin 1:200,000. The maximum dose is 2 mg/kg body weight. It is a simple matter to infiltrate the tissues around the supraclavicular nerves and to inject local anaesthetic into the joint itself for operations at the shoulder. If amputation of the lower limb is indicated because of a deformed and painful foot, a circumferential block of the skin of the mid thigh is made before exposing the sciatic nerve. This is bathed in local anaesthetic infused through an epidural catheter, with its tip adjacent to the nerve, before proceeding to amputation. The infusion is maintained for 48 h after operation. Other nerves are infiltrated with local anaesthetic before cutting them.

5.2.4 Apparatus and Instruments

Most operations on injured peripheral nerves are best done with general anaesthesia. The anaesthetist using a muscle relaxant must be prepared to reverse its effect when the nerve stimulator/recorder is being used.

Special apparatus required includes bi-polar diathermy, stimulating and recording apparatus and instruments for magnification.

Neurophysiological examination: Nerve stimulation and the recording of nerve conduction is used to (1) identify the nerve, (2) to identify individual bundles within a nerve or in a prepared stump, (3) to demonstrate conduction across a lesion and (4) to record continuity between the central and peripheral nervous systems. For simple stimulation and observation of motor response only the simplest uni- or bi-polar stimulator is necessary. For stimulation and recording from muscle and nerve, more elaborate apparatus is required. The Medelec synergy monitoring system (Vaisys Health care, Madison, Wisconsin, USA) (Fig. 5.5). The electrodes are provided by Ambu, Ballerup, Denmark. In measuring conduction across a lesion, hand held

Fig. 5.5 The apparatus for recording sensory evoked potentials

bi-polar stimulators are placed on either side of the lesion. The ground electrode can be placed in a convenient adjacent area. The interval between the electrodes and between each electrode and the lesion is measured (Fig. 5.6).

For recording somatosensory evoked potentials (SSEP's) the reference electrode is placed on the forehead, the ground electrode at the temple, and the recording electrode on the skin overlying the second or third cervical intervertebral space. The skin is prepared with abrasive paste and alcohol wipes to lower resistance with the object of balancing impedance between reference and recording electrodes, at a level less than 2.0 kΩ. Once the surface electrodes are positioned they are secured with tape. A hand held stimulator is used to record signals from the median and ulnar nerves before preparing and towelling the upper limb, using the uninjured side as a control. A sterile hand held bi-polar stimulator is used to stimulate the nerve directly. Somato-sensory evoked potentials (SSEP) are recorded using a stimulus rate of 3–5 pulses/s, of duration 2.0 ms, and intensity 150–300 V. Signals are averaged from between 50 and 200 sweeps. The stimulus rate for the hand held bi-polar stimulator is 3–5 pulses/s.

The quality of the traces may be adversely affected by: (1) ambient noise interference from electrical equipment in the operating theatre; (2) when nerves are embedded in dense fibrosis; (3) when the wound is permitted to become too wet or too dry; (4) compression of nerves by haematoma causes anoxic conduction block; (5) SSEP's are relatively unaffected by most anaesthetic agents, but muscle relaxants block neuromuscular conduction (Fig. 5.7).

Magnification: the operating microscope was used by ophthalmic and ENT surgeons for decades before its regular use in orthopaedic and plastic surgery. The discipline of microsurgery seems to have acquired a mystique which is not altogether justified. The elements of microsurgical technique are no more than the application of basic surgical skills. They are acquired by practice. For magnification we use loupes or the operating microscope. The microscopes are OPMI 6SD FC and OPMI 6 (both Carl Zeiss, Oberkochen): the stand is the universal S3B (Carl Zeiss, Oberkochen).

Instruments: The Joll's thyroid retractor is excellent for reflection of skin flaps in the neck. The small Deaver's retractor is useful in the neck. A set of malleable retractors are essential. Conventional toothed self retaining retractors are avoided, because of the risk to nerves and vessels. Three sizes of vascular clamps are used. The Satinsky clamp is especially useful in end to side anastomosis. DeBakey's scissors and forceps are used for both arterial and nerve work. The range of sutures includes: 6/0, 8/0 nylon on a 6 mm or 8 mm vascular needle and 8/0, 9/0, 10/0 and 11/0 which are used with the appropriate needle holders.

Howarth's dental elevator and Lemperts raspatory are very good for fine bone work. A range of spinal punches, angled bone nibblers and bone cutters are needed. Fibrin clot "glue" [28] is now available commercially. (Tisseel (TM) Immuno Ltd, Arctic House, Rye Lane, Dunton Green, Sevenoaks, TN14 5HB). The aprotinin must be diluted with sterile water: otherwise there is a risk of inducing fibrosis. The undiluted preparation is reserved for haemostasis. The needle tip should be directed away from the repair to avoid disruption. A steady gentle pressure is exerted so that

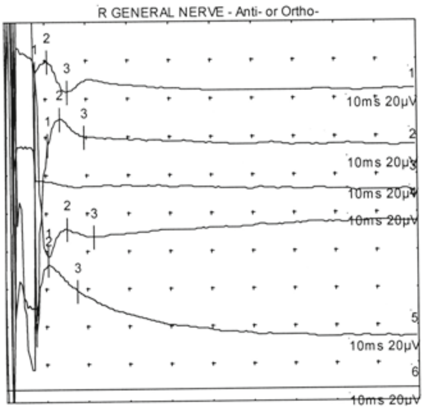
Royal National Orthopaedic Hospital NHS
NHS Trust
Department of Clinical Neurophysiology
Peripheral Nerve Exploration

Patient:
Patient ID:
Sex:
Date of Birth:
Age: Years Months
Ward:
Surgeon: Prof Birch
Technician: Karen Holmes/Catherine Jones
Notes: Exploration of R Brachial Plexus. Fall at home Dec 2006. Dislocation of the R shoulder, altered sensation, loss of power.

Surgeon requires across lesion traces only.

Intra-op

Nerve / Sites	Lat. ms	Amp.2-3 µV
1Musculocutaneous cord – Lateral cord *(present)- distance **5cms**- distal - prox*	0.75	16.5
2 repeat *(present)- distance **5cms***	1.05	9.3
3 Radial nerve – Posterior cord *(absent)- distance **5cms***		
4 Circumflex nerve – Posterior cord *(present)- distance **4cms***	1.05	4.0
5 Medial cord *(present)- distance **3cms***	0.75	13.9



Recorded on "Sylvia"

Fig. 5.6 Severe pain and deep paralysis complicated closed dislocation of the gleno-humeral joint in a 78 year old woman. The nerves were exposed 3 months later; there were no ruptures. CNAP and SSEP were recorded traversing the lesions of median, ulnar and musculocutaneous nerves. They were absent across the radial nerve. Recovery through the radial nerve extended only to the triceps and flexor to extensor transfer was performed later. The other nerves recovered, there was early relief of pain

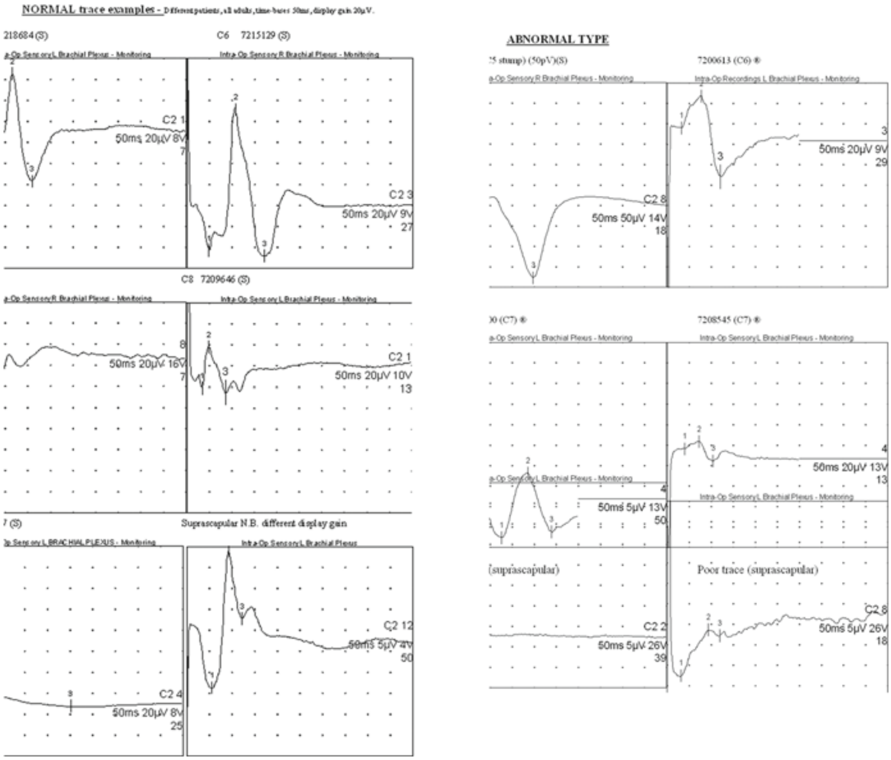


Fig. 5.7 Examples of normal and abnormal SSEP traces

a film of the fluid bathes the repair and seals it. Fibrin clot glue acts as an envelope around the nerve but offers no resistance to tension.

5.2.5 *Incisions: Handling of Tissues*

This need to be adequate and, where possible, extensile. There is no place for short incisions. Main nerves and major vessels are exposed first proximal to the wound or lesion and then distal to it. The lesions are displayed by dissection from above and below. All tissues must be treated gently. They are, after all, alive, and on their continued viability depend the healing of the wound without infection and the recovery of the nerve lesion. Indeed, avoidance of infection probably has more to do with tender handling of the tissues and accurate haemostasis than has the administration of antibiotics. The line of the proposed incision should be marked and cross-hatched and be planned with cutaneous innervation in mind. Lasting trouble can follow wounding of an apparently trivial cutaneous nerve; it is an ill matter for a surgeon purporting to assist healing of lesions of peripheral nerves to damage one set of

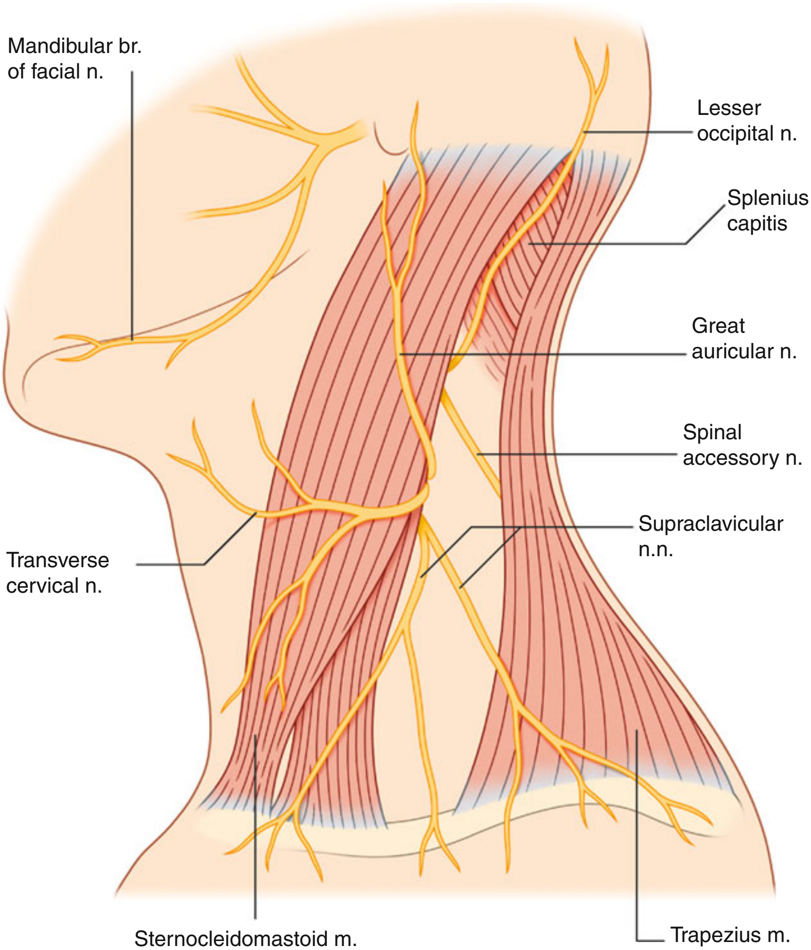


Fig. 5.8 Some of the more important superficial nerves in the neck. Note that the mandibular branch of the facial nerve comes at one point below the lower margin of the mandible. The cervical branch has been omitted

nerves on the way to repairing another (Figs. 5.8 and 5.9). In the neck, the skin flaps should include the platysma; elsewhere, they should be cut to full thickness. Skin flaps should be held with fine skin hooks; if the procedure is going to take a long time, the flaps should be sutured back to the surrounding skin. So far as possible, dissection should be done with the knife or with sharp blunt-ended scissors. Although in the limbs the pneumatic tourniquet can be used during dissection and exposure, it must be released for stimulation, repair and closure. The best possible haemostasis must be secured after the cuff has been deflated, by diathermy, ligation and haemostatic sponge. Cut bone surfaces should be sealed with wax or similar preparation.

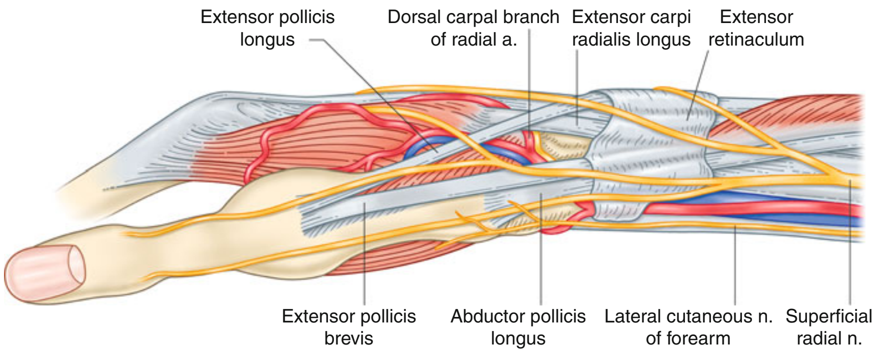


Fig. 5.9 Radial side of the hand, warning about the terminal branches of the radial nerve and lateral cutaneous nerve of forearm

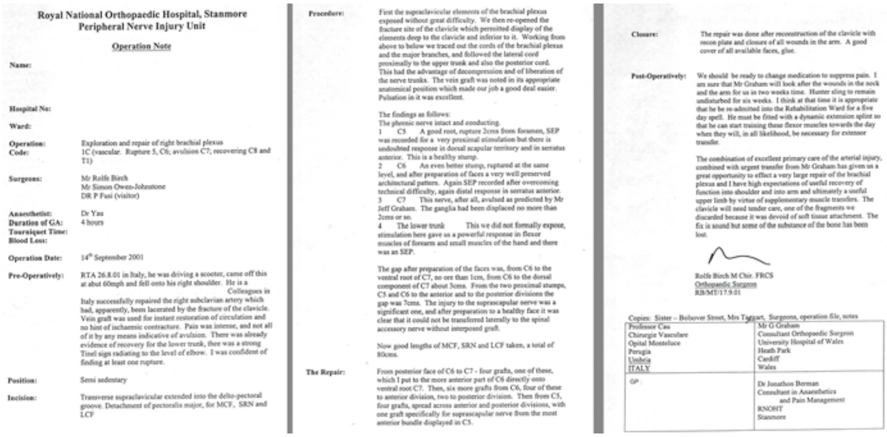
Once the flaps are raised, the field should be kept as free of blood as possible, but it must be kept moist by regular irrigation. Even well shielded operation lamps generate enough heat to accelerate desiccation of the tissues. When muscles have to be divided, their ends should be marked with sutures and if necessary labelled, so that when the procedure is completed they can accurately be re-united. Nerves should be handled with extreme care; retracted with very fine skin hooks in the epineurium or with plastic slings. Colour coding of the slings adds pleasing variety to the proceedings and, more importantly, permits the surgeon to identify to the assistant the nerve to be retracted. They should not be mobilised over such a length as to impair their blood supply.

The wound should not be closed before bleeding points have been checked; even with good haemostasis it is wise to use a suction drain in most wounds. However, the business end of the drain should not be placed near the site of repair, for fear of damage to the anastomosis by the suction or by later withdrawal of the drain. Divided muscle layers should be repaired accurately and securely. In the neck the platysma should carefully be closed with interrupted sutures.

Although with careful handling of tissues wound infection is rare, the exposure is often so much prolonged that prophylactic use of antibiotics is advisable. Such cover should always be used if there is any liability to ischaemia or if there is an associated fracture.

5.2.6 The Record

This should carefully be maintained: it is best to follow a standard form and to supplement this with a diagram and photographs. Under no circumstances must descriptions of the lesion, of the state of the stumps after resection or of the gap after resection be omitted. The operation record should be written or dictated by the operating surgeon as soon as possible after completion of the procedure. The first copy is retained with the medical case notes, a copy is sent to the family practitioner,



Royal National Orthopaedic Hospital, Stanmore
Peripheral Nerve Injury Unit

Operation Note

Name:

Hospital No:

Ward:

Operation: Exploration and repair of right brachial plexus
Code: 1C (vascular. Rupture 5, C6; avulsion C7; recovering C8 and T1)

Surgeons: Mr Rolfe Birch
Mr Simon Owen-Johnstone
DR P Fusi (visitor)

Anaesthetist: Dr Yau
Duration of GA: 4 hours
Tourniquet Time:
Blood Loss:

Operation Date: 14th September 2001

Pre-Operatively: RTA 26.8.01 in Italy, he was driving a scooter, came off this at abut 60mph and fell onto his right shoulder. He is a Colleagues in Italy successfully repaired the right subclavian artery which had, apparently, been lacerated by the fracture of the clavicle. Vein graft was used for instant restoration of circulation and no hint of ischaemic contracture. Pain was intense, and not all of it by any means indicative of avulsion. There was already evidence of recovery for the lower trunk, thee was a strong Tinel sign radiating to the level of elbow. I was confident of finding at least one rupture.

Position: Semi sedentary

Incision: Transverse supraclavicular extended into the delto-pectoral groove. Detachment of pectoralis major, for MCF, SRN and LCF

Procedure: First the supraclavicular elements of the brachial plexus exposed without great difficulty. We then re-opened the fracture site of the clavicle which permitted display of the elements deep to the clavicle and inferior to it. Working from above to below we traced out the cords of the brachial plexus and the major branches, and followed the lateral cord proximally to the upper trunk and also the posterior cord. This had the advantage of decompression and of liberation of the nerve trunks. The vein graft was noted in its appropriate anatomical position which made our job a good deal easier. Pulsation in it was excellent.

The findings as follows:
The phrenic nerve intact and conducting.
1 C5 A good root, rupture 2cms from foramen, SEP was recorded for a very proximal stimulation but there is undoubted response in dorsal scapular territory and in serratus anterior. This is a healthy stump.
2 C6 An even better stump, ruptured at the same level, and after preparation of faces a very well preserved architectural pattern. Again SEP recorded after overcoming technical difficulty, again distal response in serratus anterior.
3 C7 This nerve, after all, avulsed as predicted by Mr Jeff Graham. The ganglia had been displaced no more than 2cms or so.
4 The lower trunk This we did not formally expose, stimulation here gave us a powerful response in flexor muscles of forearm and small muscles of the hand and there was an SEP.

The gap after preparation of the faces was, from C6 to the ventral root of C7, no ore than 1cm, from C6 to the dorsal component of C7 about 3cms. From the two proximal stumps, C5 and C6 to the anterior and to the posterior divisions the gap was 7cms. The injury to the suprascapular nerve was a significant one, and after preparation to a healthy face it was clear that it could not be transferred laterally to the spinal accessory nerve without interposed graft.

Now good lengths of MCF, SRN and LCF taken, a total of 80cms.

The Repair: From posterior face of C6 to C7 - four grafts, one of these, which I put to the more anterior part of C6 directly onto ventral root C7. Then, six more grafts from C6, four of these to anterior division, two to posterior division. Then from C5, four grafts, spread across anterior and posterior divisions, with one graft specifically for suprascapular nerve from the most anterior bundle displayed in C5.

Closure: The repair was done after reconstruction of the clavicle with recon plate and closure of all wounds in the arm. A good cover of all available faces, glue.

Post-Operatively: We should be ready to change medication to suppress pain. I am sure that Mr Graham will look after the wounds in the neck and the arm for us in two weeks time. Hunter sling to remain undisturbed for six weeks. I think at that time it is appropriate that he be re-admitted into the Rehabilitation Ward for a five day spell. He must be fitted with a dynamic extension splint so that he can start training these flexor muscles towards the day when they will, in all likelihood, be necessary for extensor transfer.

The combination of excellent primary care of the arterial injury, combined with urgent transfer from Mr Graham has given us a great opportunity to effect a very large repair of the brachial plexus and I have high expectations of useful recovery of function into shoulder and into arm and ultimately a useful upper limb by virtue of supplementary muscle transfers. The clavicle will need tender care, one of the fragments we discarded because it was devoid of soft tissue attachment. The fix is sound but some of the substance of the bone has been lost.

Rolfe Birch M Chir. FRCS
Orthopaedic Surgeon
RB/MT/17.9.01

Copies: Sister – Bolsover Street, Mrs Taggart, Surgeons, operation file, notes

Professor Cao Chirurgie Vasculare Opital Monteluce Perugia Umbria ITALY	Mr G Graham Consultant Orthopaedic Surgeon University Hospital of Wales Heath Park Cardiff Wales
GP :	Dr Jonathon Berman Consultant in Anaesthetics and Pain Management RNOHT Stanmore

Fig. 5.10 An example of an operating record

another to the referring clinician, and the final copy is stored with files of coded operating records (Fig. 5.10).

5.3 Methods of Repair

There are remarkable similarities between the technique of repair of nerves and vessels. In arterial injury the first principle is rapid control of the vessels proximal and distal to the wound. Whilst the situation is less urgent in nerve repair, the nerve should be exposed first in healthy tissue above and below the level of lesion. Damaged vessel and nerve must be resected, the repair will fail unless healthy tissues are coapted. Undue tension guarantees failure. Adventitial tissue must be resected to expose the media or the epineurium (Fig. 5.11).

5.3.1 *The Vascular Repair*

Of combined venous and arterial injury Barros d'Sa [2] says: "ligation (of the vein) should be avoided at all costs. A vein tolerates lateral suturing much better than an artery. At least one major channel of satisfactory calibre must be restored so as to avoid a serious rise in peripheral venous resistance and pressure which reduces arterial flow to the limb and can lead to thrombosis at the site of the arterial repair with disastrous consequences. In combined venous and arterial injury, the vein should be repaired first".

Having secured proximal and distal control of the injured vessel any associated fracture or dislocation must be neutralised as rapidly as possible. A Rush nail,

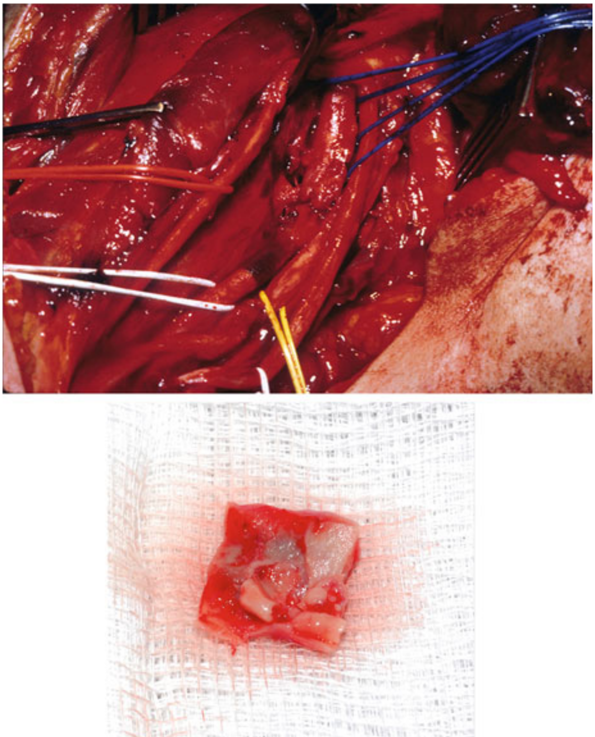


Fig. 5.11 Rupture of axillary artery from fracture/dislocation in a 68 year old man. The atheromatous intima was fractured. A reversed vein graft was necessary after resection back to healthy intima

passed from proximal to distal provides rapid and adequate stability of the humerus before repair of the axillary or brachial artery. Direct suture is sometimes possible in the fresh stab wound; a vein patch is better than lateral suture at the mouth of a false aneurysm. Interrupted sutures are preferred to continuous suture to reduce the risk of stenosis at the suture line, ease co-aptation of vessels of different diameter, and facilitate end to side suture.

Division of the axillary and brachial sheath and of the deep fascia of the forearm is essential in all cases save those where a simple wound is successfully sutured within three hours of injury. Subcutaneous fasciotomy of the forearm is adequate if there is no distal injury of elbow and forearm. The deep fascia of the forearm is exposed through a short incision on the medial side of, and parallel to, the biceps tendon. The skin is retracted and the plane between it and the deep fascia is gently developed by blunt dissection. The fascia is now incised and the plane deep to it opened out in a similar manner so that the fascia can be split safely using blunt tipped scissors. In more severe cases a fasciotomy should include the skin: this is usually susceptible to delayed primary closure at about 48 h. The indications for fasciotomy are more stringent in the lower limb. Decompression of all four compartments of the leg is essential in missile wounds. This principle should be followed in closed lesions complicating fractures of the tibia or deep contusion of the muscles. Two incisions may be used. That over the fibula exposes the deep fascia enclosing the anterior and lateral compartments. The medial incision starts just above the midpoint between the medial malleolus and the Achilles tendon and extends to the upper leg. It is very important to identify and to open the fascia over the deep flexor compartment.

Repair of artery or vein: Both proximal and distal vessels can be infused with heparinised saline but systemic anti-coagulation is not used. The proximal and distal stumps of the vessels are securely controlled by plastic slings and appropriate clamps. A skilful and patient assistant is charged with controlling the clamps and adjusting their position. Adventitia is removed after confirming back flow from the distal stump of the vessel. Repair is by interrupted sutures, 5/0 or 6/0 nylon for the subclavian, axillary, femoral or popliteal arteries, 7/0 or 8/0 for brachial, radial, ulnar and tibial arteries. The first two sutures are placed at the equator. It is often easier to repair the posterior wall first before turning the clamps to expose the anterior wall. The sutures pass through the media and the intima at intervals of about three quarters of a millimetre.

The reversed vein graft: The graft is taken from an uninjured limb where possible. The long saphenous vein in the leg is best for larger arteries. The prepared stumps of the artery are gently drawn together and the gap between them measured, then the vein graft is prepared to match that gap. A very light touch must be used in handling the vein. Diathermy should not be used on the small branches. The proximal vessel is tied off leaving a long strand of suture to indicate that this must be placed distally during the repair. A flexible cannula, mounted on a syringe, is introduced into the distal stump of the vein and secured with another tie. The segment of the vein is distended with heparinised saline. This reduces spasm. End-to-side anastomosis is used when there is disproportion between the stumps of the vessels (Fig. 5.12). Bleeding from the suture lines is best controlled by pressure for several minutes before inserting further sutures. The repaired vessel should be kept exposed for as short a time as possible and kept moist at all times. Nerve grafts must be elevated as swiftly as possible and much of this can be done whilst the arterial repair is underway. Fibrin clot glue is invaluable in these cases, for its saves a great deal of time.

5.3.2 The Nerve Operations

Neurolysis: A good deal of the argument about the value of "neurolysis" arises from imperfect definition of the term [3].

External neurolysis is the freeing of the nerve from a constricting or distorting agent by dissection outside the epineurium and it is especially valuable when the nerve is intact but tethered, strangled or immobilised by scar. Pain (neurostenalgia) is usual in such cases and relief of pain with improvement in function is regularly seen after external neurolysis and decompression.

External neurolysis after repair or amputation: Neurolysis is usually fruitless in a nerve which has been repaired. The decision to revise that repair is governed by failure to progress, persisting pain and a static Tinel sign (Fig. 5.13). However, it is

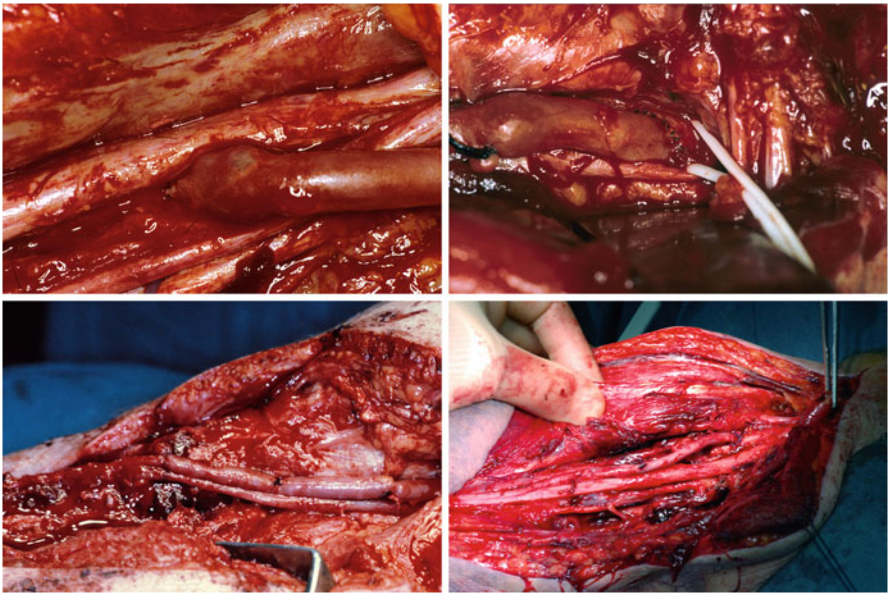
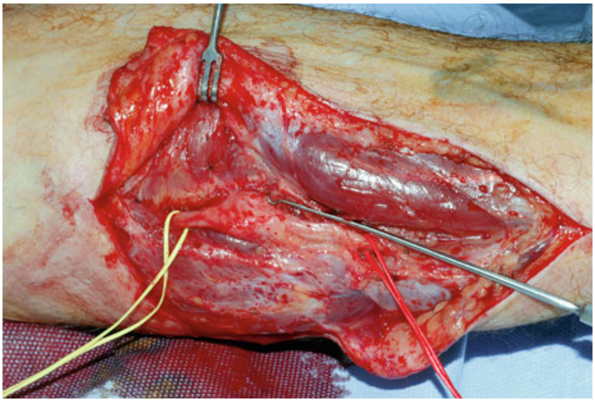


Fig. 5.12 Reversed vein grafting in the axilla: end-to-side (*above*) and end-to-end (*below*)

Fig. 5.13 Futile neurolysis. Poor recovery after primary suture of an ulnar nerve. The nerve was re-explored at 8 months. A CNAP was detectable and neurolysis was done. There was little recovery



not uncommon to find that the function regained after successful suture of the median or ulnar nerves at the wrist is marred by pain because the nerve has become adherent to the adjacent flexor tendons. Pain is worsened by movements of the digits and the neuroma can be seen moving up and down during flexion and extension. Liberating the nerve by incision of adhesions is often successful but a bed of healthy synovium must be restored. A neuroma which has become adherent to the scar over an amputation stump is often extremely painful. Again, liberation of the nerve from scar, which may require cutting the nerve again so that the stump lies in healthy tissue, usually relieves the pain.

Epineurotomy: means the simple division of the epineurium in the line of the nerve and it probably has a limited place in cases of damage from injection of a noxious substance near a nerve or by localised pressure on a nerve, which has produced localised thickening and fibrosis of the epineurium. Unhappily, the fibrosis is unlikely to be limited to the peri-fascicular epineurium: there is likely to be fibrosis of the interfascicular epineurium too. The place of epineurotomy in radiation neuropathy is uncertain. The most that can at present be said for it is that when done carefully it is unlikely to do any harm.

Internal neurolysis or *inter fascicular neurolysis* is the exposure of the bundles by epineurotomy and their separation by dissection between them or by the removal of interfascicular scar tissue. It is an essential part of three important procedures: (1) separation of intact from damaged fascicles in nerves which have suffered partial damage; (2) separation of a motor fascicle of a nerve for transfer; (3) separation of intact fascicles during removal of a benign but infiltrative tumour.

The traction lesion in continuity is a common finding at exploration and it is very difficult. The nerve, which is usually in the axilla or at the knee, is exposed after a severe closed traction injury, and is found elongated by one third or more. The epineurial blood vessels are torn, but the perineurium and individual bundles appear intact. The damaged segment may exceed 25 cm. in length and resection and repair of such extensive lesions is scarcely feasible. Useful recovery occurs naturally in-between one third and one half of these injuries. It seems that the damaged segment acts as an imperfect graft because the perineurium is in continuity and some, at least, of the Schwann cells survive.

5.3.3 Biopsy

Biopsy of a nerve requires removal of portions of conducting tissue and it necessitates at least epineurotomy and excision of one or more bundles so that the perineurium and its contents are made available for examination. Biopsy may extend to the entire nerve. Nerve biopsy is neither trivial nor without risk and it should never be a matter of unthinking routine.

Case report: A 52 year old woman with chronic inflammatory peripheral neuropathy experienced increasing pain and a deepening sciatic neuropathy raising the possibility of plasmacytoma. One fascicle of the nerve was biopsied. On the following day she noted a virtually complete but painless, sciatic palsy. Haematoma was excluded by ultrasonography and by reexploration. The biopsy excluded plasmacytoma and it seems that an apparently relatively innocuous intervention in which a segment of one fascicle of the sciatic nerve was removed induced a dense ischaemic lesion of the whole trunk.

It is in the investigation of nerve tumours that the greatest errors are seen.

Case report: A 43 year old woman presented with a 3 year history of intermittent abdominal symptoms; a mass was palpable. MRI showed a large tumour in the retroperitoneum, extending from L1 to the sacrum. A diagnosis of soft tissue sarcoma was made on the basis of a needle biopsy and the mass was excised, including a segment of the lumbo sacral plexus L4, L5 and S1. Chemo-and radiotherapy followed, complicated by a massive pulmonary embolism. The histological material was reviewed: the diagnosis was revised to a benign schwannoma. The patient now has profound weakness of the abductors and extensors of the hip, paralysis of the dorsi flexors of ankle and foot, weakness of quadriceps and other muscles of the lower limb. She is able to walk 50 yards with two sticks.

Knight et al. [17] described the complications attending biopsy, usually by fine needle, in 53 patients with benign solitary schwannoma.

- Eight biopsies failed to yield diagnostic material
- Ten biopsies removed portions of normal nerve
- An erroneous diagnosis of a soft tissue sarcoma was made in two core needle biopsies
- Most patients experienced significant or severe pain as a result of the biopsy and there was significant loss of function in 22 of them.
- Fibrosis induced by the biopsy distorted the tissue planes of the nerve and added greatly to the difficulties of later enucleation of this benign tumour.

It is important for the surgeon who comes to treat such lesions to ask to see the sections taken from the material removed at the primary operation. Often enough, a cross section of a trunk nerve is included in the specimen (Fig. 5.14). There is no justification for biopsy in tumours of nerves which are clearly benign. The clinical

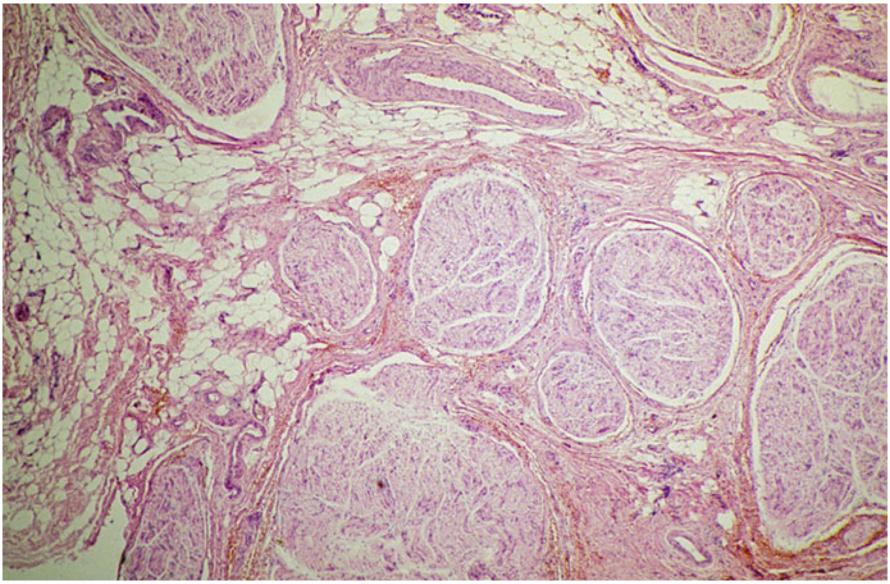


Fig. 5.14 Biopsy of a benign lesion of the femoral nerve caused severe pain and complete paralysis of the extensor muscles of the knee. No action was taken for 10 months. The first surgeon did not examine the specimen. Histological findings: fascicles of a main nerve

features supported by the findings from magnetic resonance imaging and ultrasonographic scanning enable the accurate diagnosis of nearly all cases of schwannoma and intraneural ganglion.

An incorrect diagnosis of a benign lesion in malignant peripheral nerve sheath tumour (MPNST) may cost the patient his or her life because of dissemination of tumour from the nerve into adjacent soft tissues or because of the continuing extension of the tumour during the months before the correct diagnosis becomes all too clear (Fig. 5.15). Ten such cases have been seen. In five of these the initial error, compounded by delay, lost the chance of adequate surgical excision. Whilst biopsy is essential in cases in which there is any doubt about diagnosis and in particular in those where there is a possibility of primitive neurectodermal tumour, neuro-epithelioma or extra osseous Ewing's tumour, that biopsy is best performed within the Institution where definitive treatment will take place. The possibility that the tumour is catecholamine secreting should be considered in adrenal and extra-adrenal retroperitoneal lesions.

It is for the responsible surgeon to decide whether biopsy is needed and which method is used. It is the responsibility of that surgeon to examine the biopsy tissue with an experienced pathologist. Surgeons do not always get things right, neither do radiologists or pathologists. A surgeon encountering an unexpected tumour within a nerve, one which is not evidently a benign schwannoma, will do no harm in leaving the nerve well alone, closing the wound and referring the patient to an interested

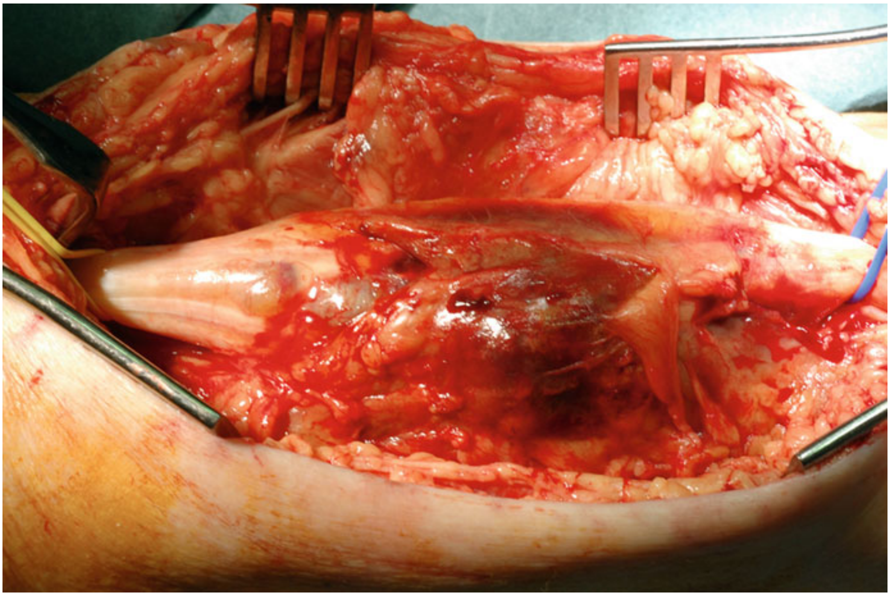


Fig. 5.15 Open biopsy was performed on a lump in the thigh in an 87 year old woman. She experienced intense pain and raid progression of neural deficit. The lesion was re explored 1 month later, the tumour had burst out of the epineurium and infiltrated the muscles of the thigh and had extended to the skin

colleague. We emphasise the importance of frozen section biopsies during resection of MPNST which are essential in proving an adequate margin of resection.

5.4 The Nerve Repair

- The object of nerve repair is the accurate coaptation of healthy conducting elements without tension. In practical terms this means accurate coaptation of the bundles (Fig. 5.16).
- This is done after skeletal injuries have been stabilised and vessels repaired, and after muscles, tendons, joint capsule and synovium have been drawn together so restoring gliding planes.
- Cover by healthy full thickness skin is essential (Fig. 5.17).

Once the decision is made for or by the surgeon, the nerve ends are cut back progressively until healthy pouting bundles show in the cut surfaces (Fig. 5.18). Resection is less in urgent repairs. No more than 1–2 mm of nerve is removed in tidy wounds. Finding the right level of section in the closed traction rupture or in the untidy wound is much easier in urgent repairs where there is still conduction in the distal trunk. In ruptures of the spinal nerves, the stimulator is moved slowly from the rupture towards healthy tissue until an SSEP becomes detectable (proximal stump), or, until muscular activity returns (distal stump). This usually coincides with a healthy looking nerve face. In traction ruptures, the amount of tissue resected

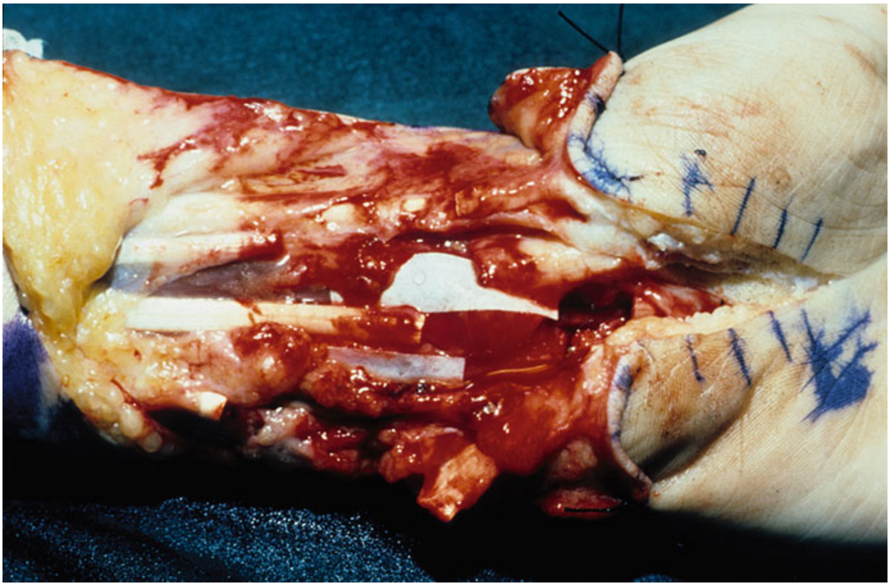


Fig. 5.16 A tidy wound. Primary repair of all divided structures is indicated

Fig. 5.17 A 28 year old woman suffered a gunshot wound to the elbow destroying the brachial artery, median nerve, and overlying skin. These were repaired and skin cover provided by a free latissimus dorsi myocutaneous flap

usually lies between 5 and 10 mm. More nerve must be resected in late cases. When the case has been complicated by infection as much as 4 cm of proximal and distal stumps are irretrievably fibrosed. Palpation of the nerve detects the difference between soft, healthy tissue from the firm or hard, scarred segment.

Then the ends must be united, preferably by end to end suture. So long as the gap after resection is small, little mobilisation of the nerve is needed to close it, and the repaired nerve lies without tension, without excessive flexion of adjacent joints. One simple test as to the advisability of direct suture of a nerve trunk at the wrist or in the forearm involves passing an epineurial suture of 7.0 nylon, with the wrist flexed to no more than 30°. If this suture will draw the stumps together without tearing the epineurium and without causing blanching of the epineurial vessels, then

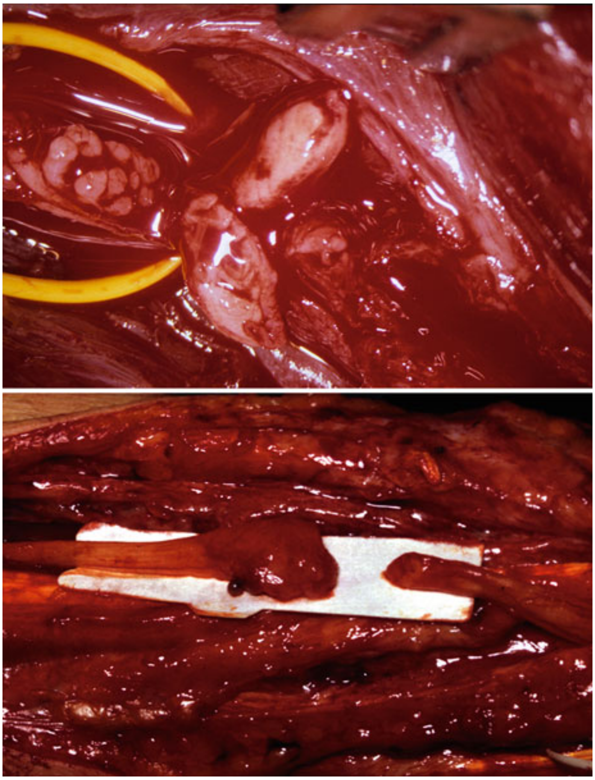


Fig. 5.18 Good stumps after resection in traction injury of the radial nerve. *Below*: the rupture displayed. *Above*: resection is done back until clearly separated "pouting" bundles are visible

suture is reasonable. Failing that, grafting is necessary. It will be seen that in many circumstances it is better to bridge a gap with a graft than to force direct suture; it is better to resect to healthy bundles and create a wide gap than to resect too little in order to facilitate direct suture. We take as guides the following principles:

- End to end suture of the nerves of the brachial plexus above the clavicle or of the accessory nerve is never practicable.
- It is impracticable to bridge with grafts gaps in lesions of the whole sciatic nerve. Sufficient graft material is not available. The gap has to be closed by flexion of the knee and extension of the hip and later maintenance of that position for the appropriate time.
- Anterior transposition of ulnar or radial nerves gives at most 3 cm.
- No gaps in the median nerve in the forearm can be closed by end to end suture.

Ideally, it is best to match bundle to bundle, sensory fibres to sensory fibres and motor fibres to motor fibres. It is often easy to match bundle to bundle simply by looking at the nerve end under the microscope or with the loupe, though the changing architecture of the nerve along its length makes this difficult when a long gap has to be bridged. When operation is done soon after injury it is easy to determine the sites of motor fascicles in the distal stump and to effect an electrophysiological orientation.

5.4.1 Methods of Suture

Orgell [21] described a modified fascicular suture: “group fascicular suture” and he concluded that since there was little difference between the results of epineurial and perineurial suture, epineurial suture was “the technique of choice for most acute nerve lacerations.” He pointed out that it was easier and faster and entailed less manipulation of the internal structure of the nerve than did fascicular suture. Spinner [25] thinks that “fascicular” suture is useful in distal median and ulnar repairs and he emphasises that the most important cause for failure of suture is “inadequate resection of injured nerve back to healthy tissue”.

During urgent or emergency operation the surgeon should indeed proceed to a neat epineurial suture using 6/0 or 7/0 sutures or to immediate grafting if circumstances permit. Many excellent results have been seen by this approach in severe cases of injury or when the nerve has been inadvertently divided during an operation.

Accurate matching is assisted by the orientation of epineurial vessels, and by making a sketch of the prepared faces indicating the size and the disposition of different bundles.

The preferred method is bundle (fascicular) suture, combined with epineurial suture for most main nerves, with the exception of the sciatic. In the early days after division of a nerve bundles are mobile within the epineurium, and epineurial suture increases the risk of mal alignment. Dissection within the nerve is avoided as this surely leads to fibrosis. The needle is passed through the condensed inner epineurium and the perineurium to secure accurate coaptation of larger bundles. The repair is completed by epineurial suture (Fig. 5.19). In delayed repair, fibrosis within the epineurium stabilises the bundles so that they cannot rotate within the epineurium. In these, epineurial suture may be adequate. The atrophy of the distal stump and the extent of fibrosis in both proximal and distal stumps increases the difficulties in neglected cases (Fig. 5.20).

In both primary and secondary suture, the areolar adventitial tissue is pushed back from each stump to expose the true epineurium. In fascicular suture, matched bundles, identified by size and by position in the nerve, are united by perineurial sutures of 9/0 or 10/0 nylon. Once these “key” bundles have been united, the union is completed by passing sutures of 8/0 or 9/0 nylon through perineurium and epineurium The nerve can be rotated on a saline-soaked dental swab, first from one side and then from the other, so that the whole circumference is accessible. Between 18 and 25 sutures are used to repair the adult median nerve at wrist level. In epineurial repair, orientation of bundles is achieved as well as is possible, and the epineurium is united with two lateral sutures of 8/0 nylon, the ends of which are left long. The repair of the anterior face is completed with sutures of 8/0 or 9/0 nylon, and the nerve is then rotated by manipulation of the lateral sutures so that the posterior epineurium can be united. If fibrin clot glue is available this reduces the number of sutures required. The glue is applied after suture. Heavier epineurial sutures (6/0 or 7/0) are used for suture of the sciatic nerve.

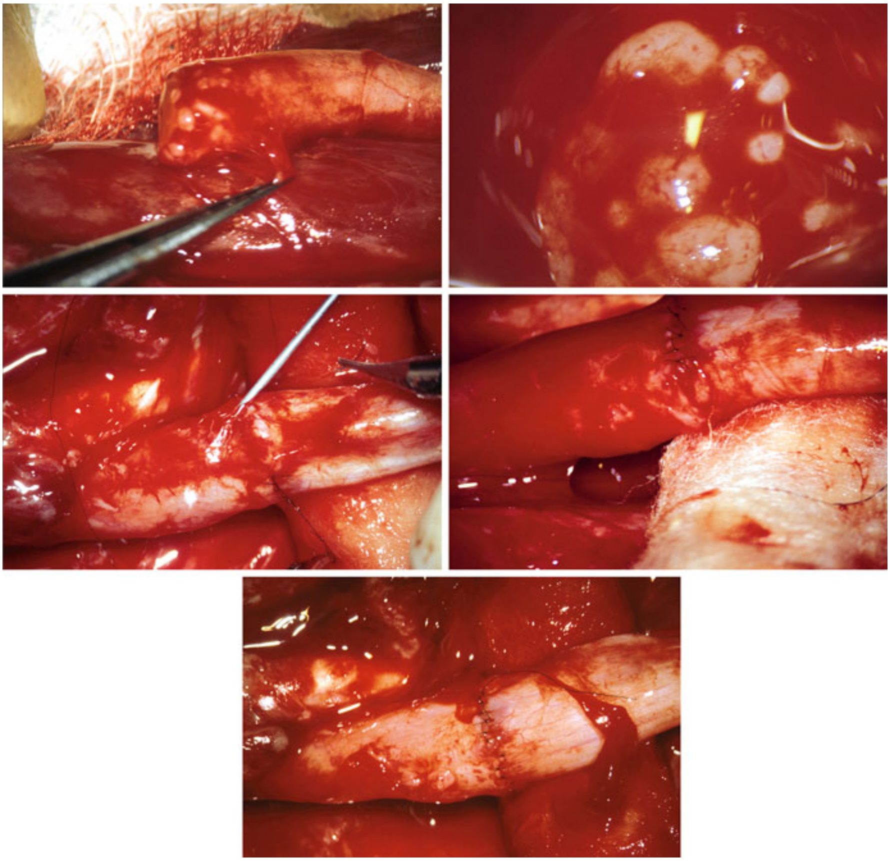


Fig. 5.19 Primary suture of median nerve at the wrist. *Top right*: the pattern of the bundles is examined. *Top left*: the first sutures pass through the perineurium of the larger bundles then follows epi-perineurial suture. *Middle*: the nerve is rolled on a swab for access to the posterior aspect. The completed repair is seen *below*

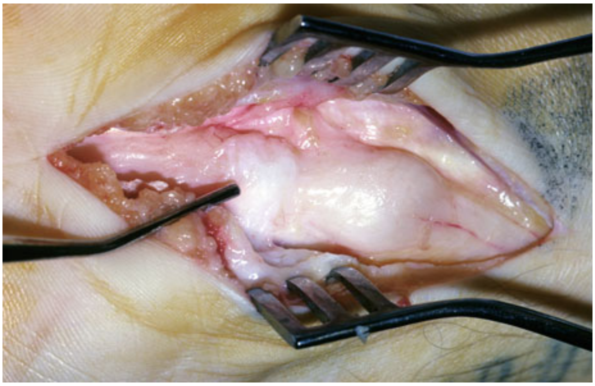


Fig. 5.20 The opportunity for primary suture was lost in this transection of median nerve displayed 3 months after wounding

5.4.2 Grafting

Clinicians must never forget that nerve grafts obtain their blood supply from the bed in which they lie. “Since the wounds of nerves that call for repair by grafting are usually extensive the need for the replacement of skin scars by healthy tissue arises with corresponding frequency. Nothing less than a full thickness flap or tube pedicle graft will suffice since it is important the graft should lie, so far as is possible, in healthy well vascularised tissue” [24]. Leaving a nerve graft within scarred muscle or underneath split skin graft just will not do.

The limitations of conventional grafting.

- There is only a limited amount of cutaneous nerve available. In an adult with a complete lesion of the brachial plexus it is possible to collect about 180 cm of nerve by using both sural nerves with the cutaneous nerves of sensation from the injured limb.
- The added defect imposed upon the patient may be too severe. The lateral cutaneous nerve of forearm and the superficial radial nerve provide significant innervation to the skin of the thumb, the thenar eminence and the palm of the hand. They are used only when the parent nerve is irreparably damaged. The supraclavicular nerves provide important sensation from the skin above the clavicle, over the shoulder and the upper part of the chest. The sural nerve innervates the heel and it should not be used for repair of low lesions of the ipsilateral tibial nerve. Pain is a common complication after deliberate wounding of the terminal branches of the nerves of cutaneous sensation and it is advisable always to section the donor nerve proximally, deep to the deep fascia.
- The architecture of a cutaneous nerve bears little resemblance to that of a main nerve trunk. The fifth cervical nerve contains between four and eight bundles. The largest of these requires one strand of cutaneous nerve which may contain between 8 and 20 such bundles.
- There is much disproportion in the volumes occupied by conducting tissue and the calibre of nerve fibres between the proximal segments of main nerves and cutaneous nerves. Myelinated nerve fibres (MNF) account for between 46 and 70 % of the cross sectional area of the ventral root of L5, and between 35.8 and 50.1 % of the dorsal root. The area falls to between 23.8 and 34.5 % in the proximal sural nerve. The median diameter of MNF in the ventral root of L5 is 12 μm. It is about 5 μm in the tibial nerve and just under 4 μm in the sural nerve [9] The problem worsens when regenerating axons having traversed the graft reach the distal trunk of the nerve for here, particularly in late or neglected cases, the Schwann tubes are embedded in dense collagen.
- The recognition that Schwann cells may be specific either to motor or to sensory axons casts a shadow over the use of cutaneous nerves for the repair of main nerves. Regeneration of motor axons is better promoted by a graft of a “motor” nerve whilst the regeneration of sensory axons is better through a graft from a cutaneous nerve [11].

Wherever possible cutaneous nerves from the damaged limb are used. The medial cutaneous nerve of forearm (MCNF) is best, if it is available. The ipsi lateral sural nerve should never be used for the repair of a low lesion of the tibial nerve for this adds to the denervation of the skin of the heel. These patients are better off losing one of the medial cutaneous nerves of forearm.

No graft should be elevated until the injured nerves have been exposed and the extent of lesion defined and the gap between the prepared faces measured. This is a good time for the surgeon to pause for a few minutes of reflection, so that the repair can be properly planned. This is particularly important when repairs of several main nerves are necessary. A map of the proximal and distal faces is prepared outlining the pattern of the bundles in each stump and measuring the length of the gap between the prepared stumps. Then, a calculation is made of the number of grafts required for each nerve, and the disposition and length of the grafts which are cut to about 15 % more than the measured gap.

Elevation and preparation of the graft: The MCNF is taken from the arm through a straight incision. One anterior branch will be seen in the middle of the arm, lower down the nerve divides into two branches which straddle the main brachial vein. The SRN is delivered through separate incisions. The nerve is identified where it emerges from deep to the brachioradialis. The terminal branches are divided at the wrist. The radial nerve is displayed between brachioradialis and brachialis, and the superficial branch identified by gentle traction. It is delivered into the elbow wound, a manoeuvre which has the advantage of stripping it of much of its adventitia. Up to 30 cm of nerve are available in the adult. The LCNF is found just lateral to the biceps tendon and it can be displayed, in the lower part of the arm, between the biceps and brachialis muscles. About 15 cm of graft is available. The terminal 4 cm of the posterior interosseous nerve provides useful material for grafting palmar digital nerves (Fig. 5.21).

The sural nerve(s) is almost always required in repair of lesions of the brachial plexus in the adult and in cases where more than one main nerve must be repaired. The patient is prone for repair of the sciatic nerve and its divisions, otherwise they are placed supine. The lower limb(s) is elevated by a stoical assistant or the knee is flexed to about 70° with the foot resting on the table. The nerve is exposed through a long midline incision which moves laterally in the distal one third of the leg to a point midway between the posterior aspect of the lateral malleolus and the lateral margin of the Achilles tendon. The incision may be extended into the popliteal fossa as a Z. Up to 50 cm of graft is available.

The grafts, tenderly handled, are laid between saline soaked swabs and cut to appropriate length with a new blade or with vascular scissors. The nerve ends are prepared so that the fascicles protrude, and are laid in the prepared bed which must be healthy and unscarred. Fixation is usually by fibrin clot glue but the grafts can be sewn into place, two lateral sutures of 9/0 nylon being used for each. The sutures unite the fascicles of the stumps with the grafts. Because the individual strands of the grafts are likely to be around the same size as the individual bundles, the suture unites epineurium of graft to perineurium of bundle (Fig. 5.22).

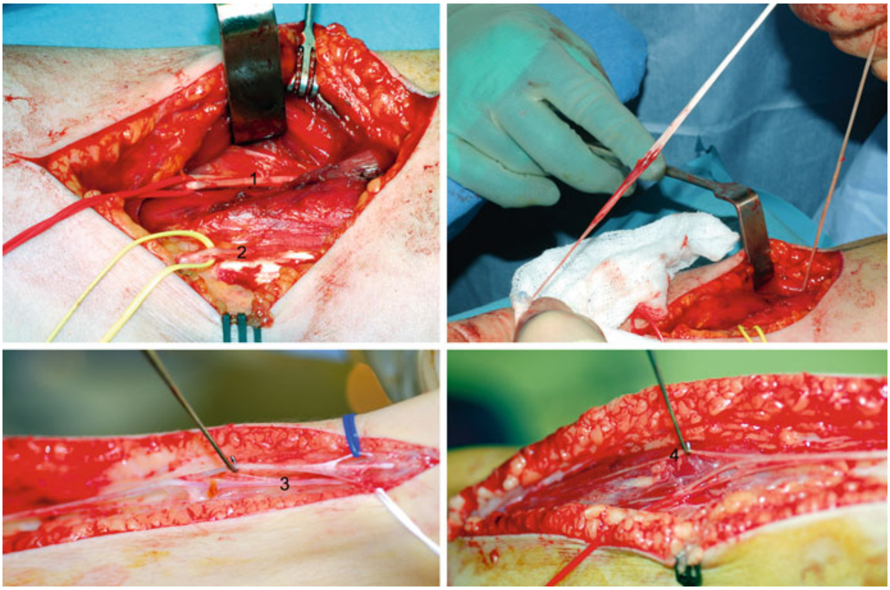


Fig. 5.21 Nerve grafts. *Above left*: the superficial radial nerve (*1*) and lateral cutaneous nerves of forearm (*2*) are displayed at the elbow. *Above right*: the radial nerve is drawn into this wound after section of the distal branches at the wrist. *Below*: the communicating branches of the sural nerve are variable. This nerve is best elevated through a long incision. *Below left*: the sural nerve divides into its terminal branches close to the short saphenous vein (*3*) above the ankle. *Below right*: note the communicating branch from the common peroneal nerve in the upper leg (*4*)

The proximal stump of the nerve is grafted first, leaving the distal ends of the grafts laid out across the bed before proceeding to the distal stump, matching as far as is possible, fascicle to fascicle. It is very important, once both ends have been anastomosed, carefully to inspect the grafts and the suture lines to make certain that during the union of one end the union of the other end has not been disturbed.

- It is better to bridge the gap with grafts if intact fascicles have been separated from the lesion.
- All nerve repairs must be secluded from naked bone, tendon, or lacerated muscle by healthy tissue.
- Grafts are stabilised by closing healthy synovium or fat, or muscle, over them. The fat pad is a valuable shield in the posterior triangle of the neck and it should be carefully apposed over the repair.
- It is necessary to restate that repairs of nerves and vessels must be covered by healthy, full thickness skin. Split skin grafts induce severe fibrosis which strangles.

Vascularised grafts: the free vascularised ulnar nerve graft in repair of the brachial plexus was a development of the ingenious operations described by Strange [26] and MacCarty [19]. In Strange's operation the ulnar nerve is used to

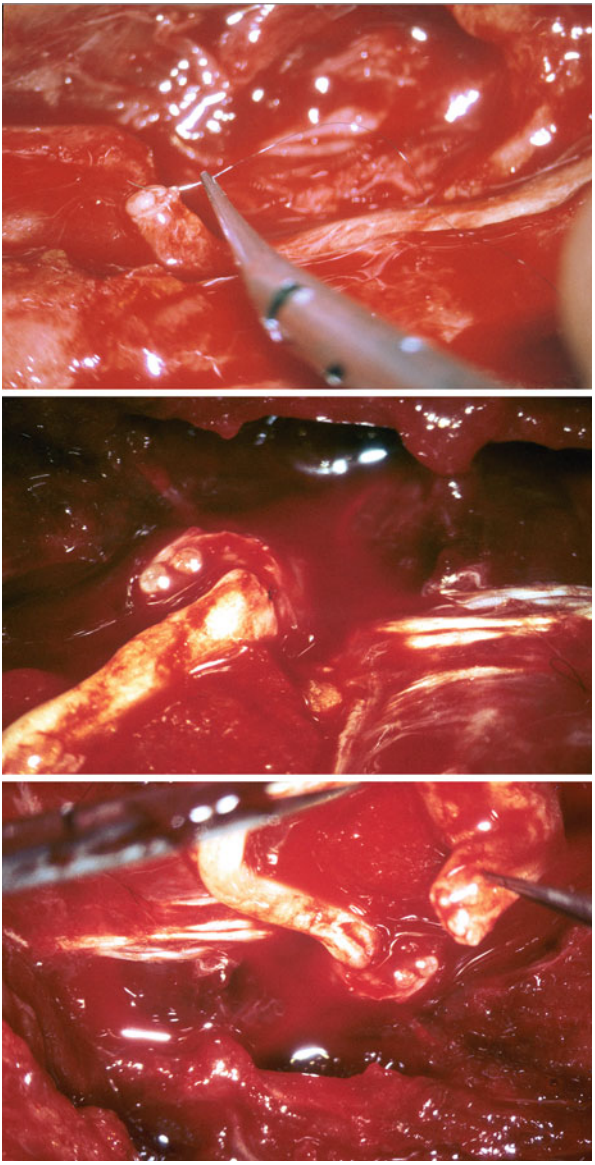


Fig. 5.22 In grafting the suture unites epineurium of graft to perineurium of the bundle

repair the median nerve in cases where both are otherwise irreparable and in MacCarty's technique the common peroneal nerve is used to bridge long gaps in the tibial nerve in otherwise hopeless injuries of the sciatic nerve. These techniques provide a full calibre graft which is not only vascularised but also predegenerate, and they remain valuable in the most severe injuries. The steps required are described using the sciatic nerve injured in the mid or lower part of the thigh as an example.

- At the first operation the proximal and distal stumps are identified and the gap between them measured.
- The proximal stumps of the tibial and common peroneal nerves are prepared and then sutured together.
- The proximal segment of the common peroneal nerve is traced and then the bundles within the trunk are cut across at a distance from the suture line equivalent to the gap already measured. *The blood vessels in the mesoneurium and in the epineurium are preserved. In effect a vascularised graft has been prepared.*
- At the second operation which is performed no sooner than 3 weeks after the first the proximal segment of the common peroneal nerve is sectioned and brought down to the distal stump of the tibial nerve to which it is sutured. Bleeding, which is at times quite copious, is seen at the face of the common peroneal graft when it is apposed to the distal tibial nerve.

Case report: An 18 year old woman sustained open fracture of mid shaft of femur in a rod traffic accident. Most of the skin of the lower part of the thigh was avulsed and there was much destruction of muscles. Extensive skin grafting proved necessary. The tibial nerve was repaired by the pedicle technique: a 24 cm long segment of the proximal common peroneal nerve was prepared and it proved a simple matter to separate this from the tibial division as far as the level of the neck of the femur. The proximal stumps of the tibial and of the common peroneal nerves were prepared and sutured. The bundles within the common peroneal nerve were sectioned 25 cm proximal to this suture line. Four weeks later the common peroneal graft was mobilised and sutured to the distal stump of the tibial nerve in the upper part of the leg. She regained flexion of the heel and of the toes to power MRC grade 4, warm and cool sensation in the sole of the foot and accurate localisation to the plantar skin without over reaction. There was recovery of sweating.

5.4.3 Indications for and Methods of Nerve Transfer

Nerve transfer, also known as neurotisation, or nerve crossing, involves the passing of nerve fibres from a healthy nerve to the distal stump of an injured nerve or directly to the target tissue. This principle can be applied in a number of ways.

- End to side transfer by suture of the distal stump of the injured nerve onto or within the epineurium of the healthy donor.
- Transection of a healthy donor nerve and transfer onto the distal stump of the injured nerve.
- Transfer of one or more healthy bundles within an uninjured donor to the recipient. This important technique rests on the functional segregation and topographical organization of nerve fibres within the donor nerve trunk so that it is possible to take one bundle, say, from the ulnar nerve to reinnervate the nerve to biceps without inflicting any significant loss of function within the hand. The method has wide application.

- Transfer of the proximal stump of a divided nerve onto the distal stump of another divided nerve.
- Direct muscular neurotisation. Sometimes a nerve is avulsed from the muscle. The musculocutaneous and the circumflex nerves are most commonly affected. The technique of implanting the working proximal stump of the nerve directly into the target muscle has considerable support from laboratory and clinical study [3]
- Nerve transfers work best when a healthy nerve, or a portion of a healthy nerve, is transferred to a nerve to muscle of roughly equivalent size without any interposed nerve graft. They cannot be asked to do too much; a rivulet cannot feed the Nile. Addas and Midha [1] provide a valuable review of this field. They say "nerve transfers tend to take the surgeon away from exploring the injury site, the brachial plexus, which carries the potential for surgeons to not even offer an anatomic nerve reconstruction, even in situations when these are perfectly appropriate…. With the increasing use of transfers, newly trained peripheral nerve surgeons are less likely to have exposure to the brachial plexus and they will be increasingly unfamiliar with the detailed anatomy and intraoperative electrophysiology assessment of the lesion".

  These are important warnings. Here are two more.

- There are far fewer MNF in the donor nerves than in the main trunks. The number of MNF in the spinal accessory nerve at the base of the posterior triangle is about 1,500; that number in C5, usually the smallest of the spinal nerves forming the brachial plexus, is at least 25,000.
- The deficit imposed on the patient must not be too severe. No nerve of vital function should be used for the sake of regaining a non vital function. Phrenic nerve palsy at birth is life threatening. Transfer of the hypoglossal nerve in infancy causes a high morbidity and disturbance of speech. Some adults experience serious ventilatory impairment following injury to the phrenic nerve complicating lesions of the brachial plexus. In one adult patient where both hypoglossal nerves were used there was very serious disturbance of speech and swallowing for as long as 6 months after operation.

The intercostal nerves: The patient is placed in a semi-sedentary position with preparation including the forequarter and the chest wall from the mid line to the iliac crest. An incision is made below the fold of pectoralis major extending to the axilla as a "Z". The serratus anterior is exposed, and the neurovascular pedicle to that muscle identified and protected.

The lateral perforating branches of the intercostal nerves are identified. The upper four digitations of the serratus anterior are released from the ribs, leaving a sufficient cuff of muscle for later repair. The muscle is reflected so opening the plane between the muscle and the rib cage. The cutaneous branch of the intercostal nerve is traced back to a narrow foramen in the external intercostal muscle. The muscle is released from the rib above as far as the posterior angle.

The deep division of the intercostal nerve is found by dividing the attachment of the middle intercostal muscle from the rib above. Gentle traction with a phrenic

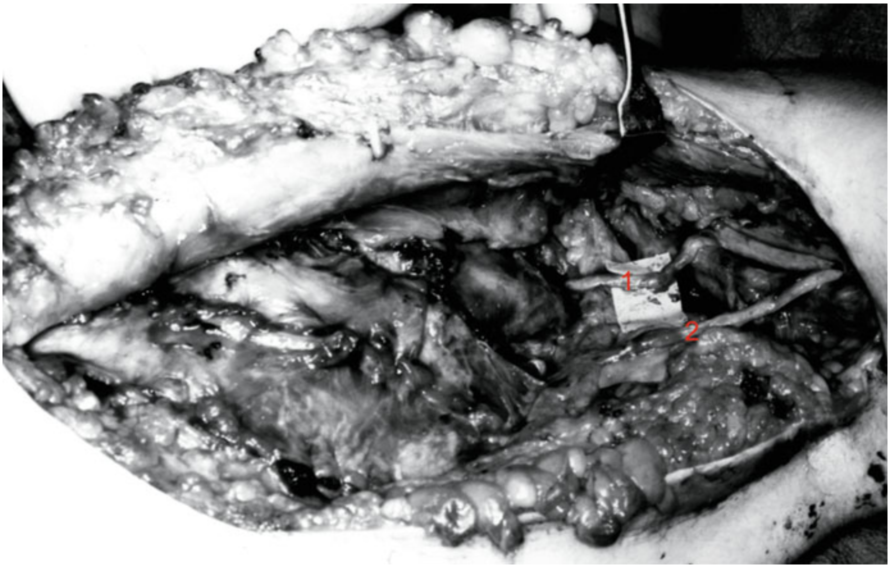


Fig. 5.23 Nerve transfer. Upper left intercostal nerves T2, T3, T4 (*1*) raised and united to the lateral cord of the plexus (*2*)

hook, underneath the upper rib, reveals the deep branch which is divided anteriorly. A Gelpi knee retractor can now be inserted to spread the rib cage. The deep division is traced back to its junction with the perforating branch. Elevation of the nerve becomes progressively easier. Bi-polar diathermy must be used throughout (Fig. 5.23).

The intercostal nerves from T3 to T6 are available by this method. These are brought to the anterior surface of serratus anterior through a tunnel in the upper part of the muscle. The serratus anterior is repaired.

If only one or two deep divisions of the intercostal nerves are being used for the nerve to serratus anterior, one of the most effective of all nerve repairs, then a suitably placed transverse incision in that muscle is adequate. It is wise always to see a radiograph of the chest before the patient leaves the operating theatre.

The spinal accessory nerve: This is a powerful motor and it should be used with discrimination. *The innervation of the upper one third of trapezius must not be compromised*. Even when the nerve is divided deep to the clavicle, the loss of function is less but it is not insignificant. The nerve is found at the lateral end of the transverse supraclavicular incision in the plane between the fat pad and the deep face of trapezius. The nerve passes down it in a rather sinuous fashion and is accompanied by a longitudinal artery and vein. These can cause troublesome bleeding. The nerve is joined by a branch from the cervical plexus just above the level of the clavicle and intra-operative stimulation of this branch only occasionally evokes a muscle twitch. The nerve is sectioned distal to that junction (Fig. 5.24).

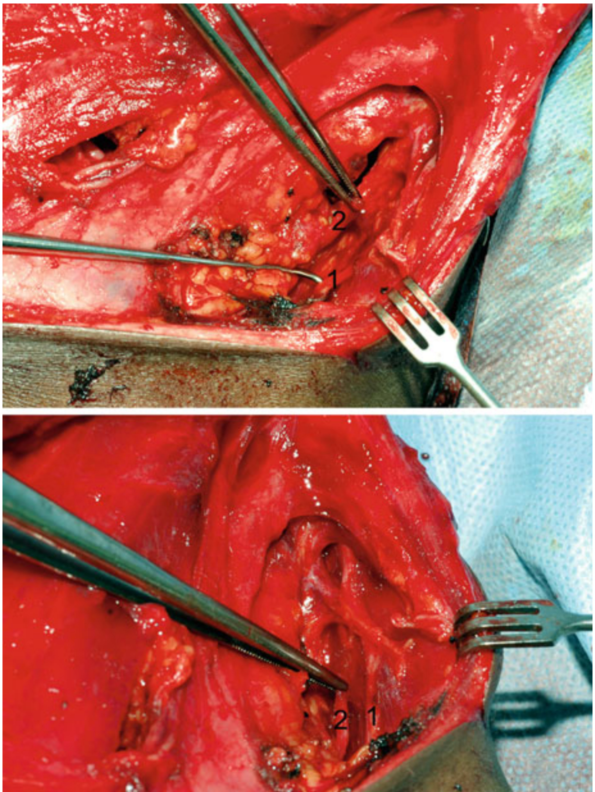


Fig. 5.24 Accessory (*1*) to suprascapular (*2*) transfer. *Above*, seen from the head: the spinal accessory nerve is displayed on the inner face of the trapezius at the base of the posterior triangle, *middle* and *below*, the view from the shoulder: the suprascapular nerve is passed deep to the fat pad and united to the spinal accessory nerve

Ulnar to biceps transfer is regularly effective in cases of avulsion of C5 and of C6. With care, it can be extended to cases where C5, C6, C7 or even C5, C6, C7 and C8 have been avulsed. Fastidious dissection of the bundles within the ulnar nerve is necessary. The nerves are exposed through an incision along the length of the brachial bundle. The musculocutaneous nerve is identified. It is not uncommon to find that the nerves to biceps and brachialis arise directly from the median nerve. The nerve to biceps is accompanied by a sizeable artery and vein. It is traced proximally and separated from the main nerve. It is sectioned here so that it drops down onto the ulnar nerve. The epineurium of the ulnar nerve is incised and the bundles exposed (Fig. 5.25). Nerve stimulation used at very low intensity leads the surgeon to a bundle in the antero-lateral quadrant of the nerve passing to the flexor muscles of the forearm but not to the muscles of the hand. This is divided and an end-to-end suture is done. This valuable principle has been extended widely, using bundles from the median or the ulnar nerve to nerves to triceps, to the nerve to extensor carpi radialis brevis, or to reinnervate free functioning muscle grafts. It has proved particularly valuable in the repair of injuries to the brachial plexus in which some spinal nerves are intact whilst others are avulsed. In these a bundle from an intact nerve may be used to reinnervate the suprascapular nerve or an avulsed ventral root (Figs. 5.26, 5.27 and 5.28).

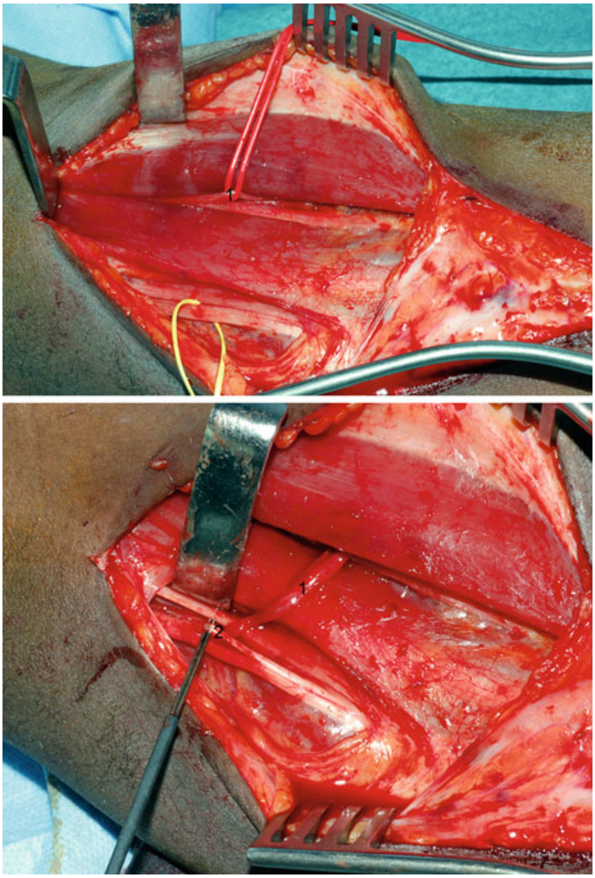


Fig. 5.25 Transfer of a bundle from the ulnar nerve (*2*) to the nerve to biceps (*1*)

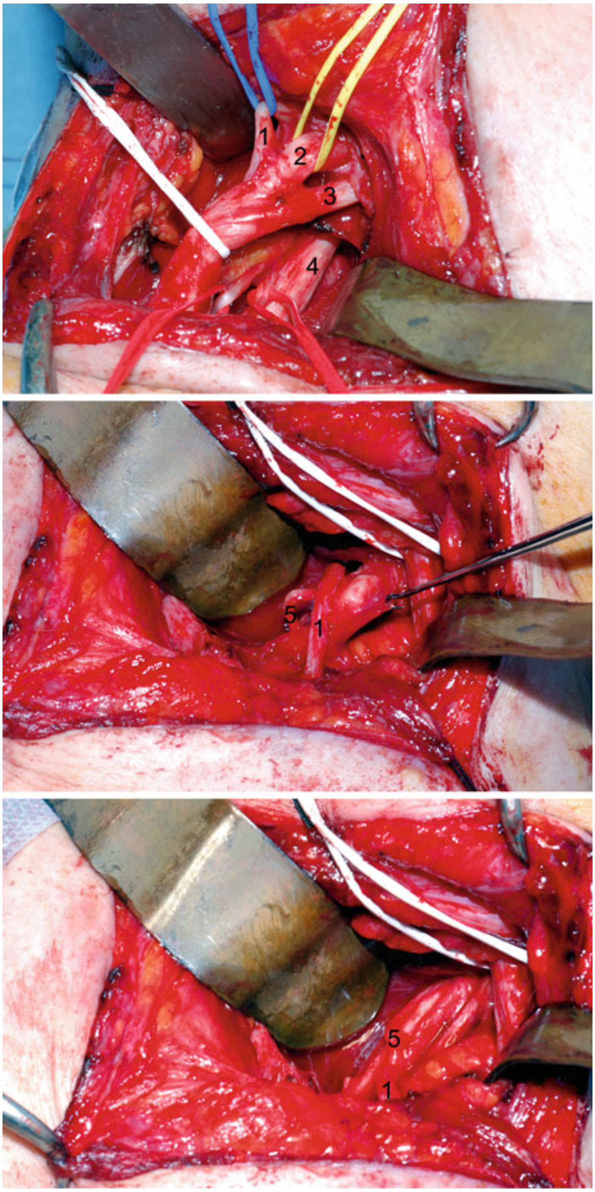


Fig. 5.26 Avulsion of C5 and of C6 with dorsal scapular palsy. The suprascapular nerve was reinnervated by one bundle from C7. The suprascapular nerve (*1*) posterior division of upper trunk (*2*) anterior division of upper trunk (*3*) C7 (*4*) and the selected bundle from C7 (*5*) are displayed

Direct muscular neurotisation is useful in lesions of the circumflex or musculocutaneous nerves in which the nerve has been avulsed directly from the muscle or, in the case of circumflex, the distal stump of the nerve is wrecked by fibrosis. The proximal stump is prepared in the usual way and two lengths of graft, usually the MCNF, are united to the proximal stump and then implanted into the muscle through short incisions through its sheath. The grafts are passed subcutaneously, and the

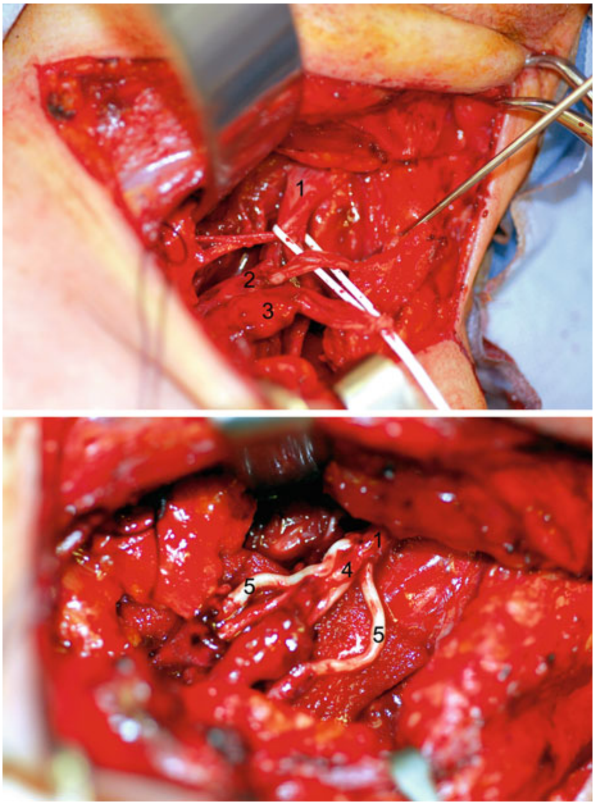


Fig. 5.27 Reinnervation of the avulsed ventral roots of C6 and C7 from the proximal stump of C5. The ventral root of C6 is apposed to the stump of C5. Grafts were passed to the ventral root of C7 and to suprascapular nerve. C5 (*1*), C6 (*2*), C7 (*3*), the ventral root of C6 (*4*) and the grafts (*5*) are seen

portal of entry is exposed by a short incision of the skin at those points. About ten portals of entry are fashioned using the terminal branches of the graft or by subdivision of the distal stump. The entry points of the implanted nerve are sealed with fibrin clot glue (Fig. 5.29).

5.4.4 Other, Non Neural, Material for Grafts: Entubation

Surgeons have for many years sought a source of material for graft to supplement or to replace the rather meagre stock provided by dispensable cutaneous nerves.

The freeze thawed muscle graft (*FTMG*) has been used extensively in laboratory and clinical studies. It has a place in the treatment of painful cutaneous neuromas [27]. Pereira et al. [22] treated the leprotic hand and foot by replacing the damaged segment of the median or tibial nerve with FTMG. Most patients recovered protective sensation; their ulcers healed. Doubtless, a number of amputations were prevented. One intriguing finding was the improvement in the condition of the skin in one third of the contralateral feet.

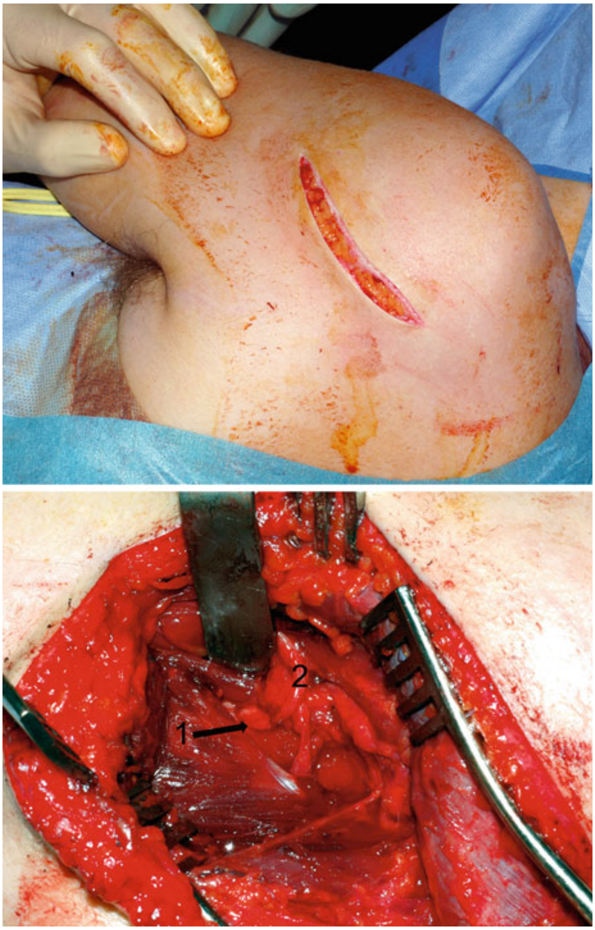


Fig. 5.28 Reinnervation of part of the circumflex nerve (*1*) by a nerve to long head of triceps (*2*)

The stumps of the nerve are prepared and the gap measured. A segment of adjacent muscle, of equivalent calibre, is excised. This should be at least two and a half times the length of the measured defect in the nerve. The muscle is then enveloped by a piece of aluminium foil and immersed in liquid nitrogen for about 60 s. The packet is then placed in distilled water for a couple of minutes. The prepared muscle graft can then be trimmed to appropriate length and breadth and it may be secured to the nerve stumps by suture and then sealed by fibrin clot glue. Fragmentation is usual with muscle grafts more than 3 cm long.

Entubation: In 1997 Lundborg and his colleagues [18] published a significant paper describing a prospective randomised trial comparing silicone entubation and suture of median and ulnar nerves in the forearms of 18 patients. Recovery was studied most thoroughly and no significant difference in outcome between the two groups was noticed. The proposed advantages following placing of nerve stumps within a silicone tube, so providing a “chamber” separate from the surrounding tissues,

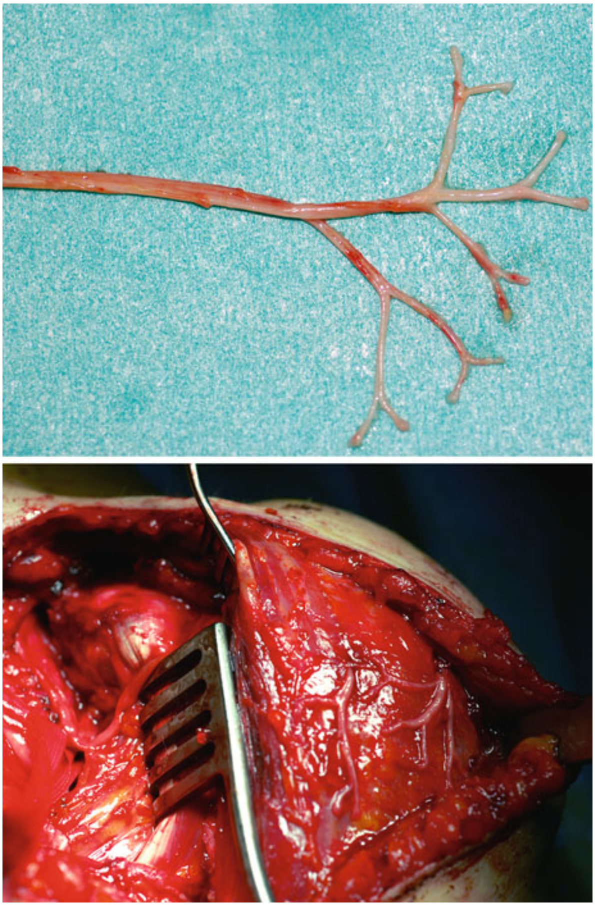


Fig. 5.29 Muscular "neurotisation". *Above*: the nerve graft is prepared. *Below*: it is passed from the proximal stump of the circumflex nerve and implanted into the muscle

include: the local accumulation of neurotrophic factors; the longitudinal orientation of fibrin matrix within the tube; and the possibility for the regenerating axons to be better guided into distal Schwann tubes across the gap. The tube must not be too tight. Silicone entubation may cause constriction and fibrosis of a sutured nerve.

It seems that the upper limit of a defect reparable by these methods is 3 cm. Repair of the long gap by means other than autogenous graft remains elusive. De Ruiter et al. [8] conclude that there is, as yet, little evidence demonstrating the superiority of empty, hollow biodegradable nerve tubes over suture or autografting.

5.4.5 Immobilisation

Repaired nerves need protection during at least the first 3 weeks after repair. In most cases, a simple plaster slab gives sufficient protection. Only in the case of extensive

Fig. 5.30 Sling for control of the fore quarter after repair of the brachial plexus. Note the check on lateral rotation at the gleno-humeral joint

proximal lesions of the whole sciatic nerve is elaborate protection required. Narrowing of the gap to permit end to end suture or adequate repair by graft requires flexion of the knee and avoidance of flexion of the hip. The necessary position of immobilisation in a hip spica is awkward and uncomfortable; further, gradual extension of the knee after 3 weeks may be necessary in order to protect the line of the repair. Usually, it is sufficient when the splint is removed to warn the patient about the danger of excessive movement of related joints, and to rely on the patient steadily to restore movement of those joints. There is particular difficulty in protecting repairs of the brachial plexus. At present, in adults, a sling with straps is used, which secures the arm across the body supplemented with a soft cervical collar. A plaster of Paris "cocoon" is applied after repair of the plexus in infants (Fig. 5.30).

The method used in the post operative care of severe wounds at the wrist is as follows (Fig. 5.31).

- The splint holds the elbow at 90° of flexion, the wrist at between 30 and 40° of flexion, the metacarpophalangeal (MCP) joints at about 70° of flexion, and the proximal interphalangeal (PIP) joints at no more than 30° of flexion. The dorsal splint extends to the tips of the fingers and the palmar splint to the PIP joints only. The splints are bandaged so that there is restriction but not rigid immobilization. Gentle, active flexion of the fingers and the thumb is encouraged from the

Fig. 5.31 Protection after repair. *Above*: plaster after repair of both nerves and flexor tendons at the wrist. *Below*: hinged plaster with adjustable check

outset. The arm is supported in a sling, but there should be encouragement of gentle active lateral rotation and of elevation of the shoulder to 90° from the first postoperative day.

- At 3 weeks the splints and the sutures are removed. The next splint does not restrict the elbow. The wrist is splinted to prevent extension beyond 20°. The dorsal hood, which again extends to the tips of the fingers, blocks the MCP joints to 30° of flexion and the PIP joints to 30° of flexion. Increasingly, vigorous active flexion of the fingers and the thumb is now permitted and gentle active flexion at the wrist is also encouraged within the confines of the splint, bandaged as it is to the forearm and hand.
- In direct sutures of nerves in the elbow region a hinged splint is applied at 3 weeks from operation (Fig. 5.31). This permits active flexion but blocks extension. The range of permitted movement is increased at weekly intervals by adjusting the hinge.
- By 6 weeks, splints are discarded and vigorous active flexion work against resistance is introduced. Now, gentle passive stretching work can be introduced for the fingers and the thumb.

It is of course very important during the period of recovery to maintain the mobility of the joints some or all of whose governing muscles are paralysed and to warn the patients of the danger, especially in cold weather, of accidental damage to the anaesthetic skin. Most of the work on passive movements of the joints can be done by the patient or by his or her parents, but weekly supervision by a physiotherapist is useful in keeping the mind concentrated on the work during the long march towards recovery. In the case of the metacarpo-phalangeal joints of the fingers and the carpo-metacarpal joint of the thumb, “lively” splints are useful, but the problem of the stiff metacarpo-phalangeal joint in the paralysed hand persists. Accurate diagnosis is the foundation of rehabilitation and operations for repair of the nerves should be seen as but the first stage in that process. It should be superfluous to add that the sooner the diagnosis is established the better, and that urgent efforts must be made to improve the prognosis.

5.5 Approaches to Individual Nerves: Neck and Upper Limb

5.5.1 The Transverse Supraclavicular Approach: (Anterior, or Anterolateral)

This is used for exposure of the supraclavicular part of the brachial plexus. Its disadvantage is that the vertebral artery stands between the operator and the most proximal parts of the nerves. The risk of skin necrosis is negligible. The scar is reasonable. The length and the level of the incision are modified according to the lesion. In the urgent case the incision extends from beyond the mid line to beyond the anterior fold of the trapezius and is placed just above the clavicle. For lesions of the upper trunk of the brachial plexus the incision is shorter and is placed about two fingers breadth above the clavicle. The exposure of Fiolle and Delmas [10] is achieved by adding a vertical limb to the transverse supraclavicular wound. The transclavicular approach [5] is, in effect, a medial extension of the transverse supraclavicular approach and it gives excellent access to the first part of the subclavian artery, the first part of the vertebral artery and the whole of the brachial plexus.

The operation: The patient lies supine in a semi-sedentary position, with the head elevated to about 30° and the neck in extension. After placing recording electrodes to the scalp and the skin of the neck, the head is bandaged to a neurosurgical rest. The neck is extended but not rotated. The area of skin preparation includes the whole of the forequarter, extending to the jaw line and the ear, beyond the mid line to the inferior rib margin.

The skin flap is developed deep to the platysma (Fig. 5.32). This is easier to identify at the posterior margin of the sternocleidomastoid muscle. Below, the flap is developed to reveal the inferior margin of the clavicle; above as far as the greater auricular and transverse cervical nerves crossing the anterior face of ster-

Fig. 5.32 The transverse supraclavicular approach to the brachial plexus. Note the position of the patient and the line of incision

nocleidomastoid (SCM). The incision is deepened in the plane between external jugular vein and the SCM, displacing the supraclavicular nerves posteriorly. The lateral part of the insertion of the muscle can be elevated from the clavicle. The fat pad and the omohyoid muscle are now seen. The omohyoid is divided between stay sutures and reflected. The fat pad may present as two leaves, split by branches of the transverse cervical vessels. These must be preserved in cases of rupture of the subclavian artery because of their contribution to the collateral circulation (Fig. 5.33).

The scalenus anterior is exposed and the phrenic nerve is seen coursing obliquely across it. It is mobilised and held in nerve sling. Access to bony structures behind the plexus should be achieved by separating the component nerves rather than by forward retraction of the plexus. Following the phrenic nerve cranially brings the surgeon to the fifth cervical nerve and it is sometimes helpful to work on the medial side of the phrenic nerve to expose a ruptured stump at C5 or C6. The upper trunk and the suprascapular nerve are traced. After traction injury it may be easier to identify the suprascapular nerve first and follow it back to the upper trunk. The seventh cervical nerve can now be seen behind the upper trunk. Division of scalenus anterior

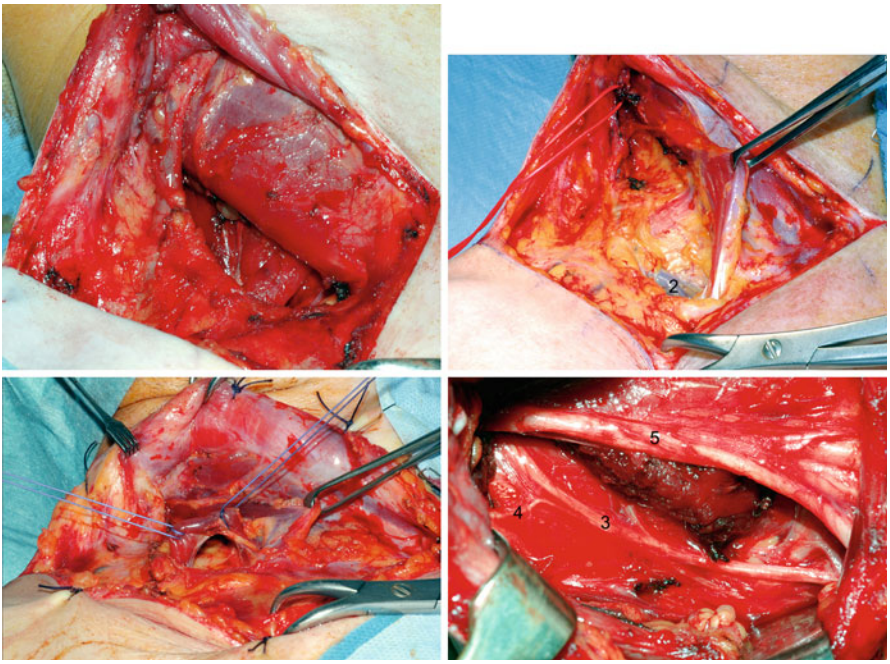


Fig. 5.33 *Above left*: the posterior margin of sternocleidomastoid is defined, anterior to the external jugular vein and supraclavicular nerves (*1*). *Above right*: this is retracted to display the fat pad and transverse cervical vessels (*2*). *Below left*: the omohyoid is divided between stay sutures. *Below right*: the nerve to serratus anterior (*3*) is displayed by section of scalenus medius deep to the upper trunk (*5*). The largest ramus comes from C6. There is often a communicating branch from the dorsal scapular nerve (*4*)

reveals the subclavian artery; the plane between the muscle and the subclavian artery requires careful definition. We have seen the subclavian artery crossing anterior to scalenus anterior in three cases and through it in seven more. The eighth cervical and first thoracic nerves are traced by following the plane between the artery and the lower trunk. The nerve to serratus anterior lies lateral and deep to the upper trunk, behind the suprascapular nerve and posterior to scalenus medius. The rami forming this nerve are displayed by dividing scalenus medius. There are usually three, usually that from C6 is the largest. The spinal accessory nerve, is identified running in a vertical and sinuous manner on the deep face of trapezius. The dorsal scapular nerve can be found passing posteriorly away from C5.

Some key points:

- Neck and head should be extended but not rotated
- Place towels to expose the whole of the posterior triangle, including manubrium, the mandible, the lower part of the ear, the upper margin of trapezius and the whole of the upper limb.
- Skin flaps include the platysma
- Define the posterior margin of SCM and work between it and the fat pad. This protects the supraclavicular nerves
- Identify and reflect omohyoid and ligate the transverse cervical vessels.
- Identify the phrenic nerve in front of scalenus anterior.
- For the exposure of C8, T1, and the proximal subclavian artery divide scalenus anterior WITH GREAT CARE

Extension by the operation of Fiolle and Delmas [10]: This affords full display of the supra, retro and infra clavicular plexus, of the second part of the subclavian to the terminal axillary artery and of the subclavian and axillary veins deep to the clavicle. The originators said "the exposure of the vessels can be achieved in three minutes" and this is possible in an emergency. There is no doubt that the operation secures rapid access to and control of major vessels from the scalenus anterior to the lowest part of the axilla. The plexus itself is exposed from the spinal nerves above to the terminal branches below. It is especially valuable in fresh cases of laceration or rupture of the great vessels deep to or below the clavicle and in later cases of false aneurysm, and is often necessary for the delayed exposure of ruptured nerves after primary vascular repair. It is the exposure of choice in the closed infraclavicular rupture of vessels and nerves. The incision is T-shaped, the vertical limb running in the delto-pectoral groove, retracting the cephalic vein medially, then curving into the apex of the axilla underneath the fold of pectoralis major. In urgent cases a Gigli saw is used to divide the clavicle at the lateral edge of SCM: otherwise, a hole is drilled and prepared for a compression screw, inclined at 45° to the long axis of the clavicle. Subsequent fixation is made easier by contouring a plate to the bone and drilling and preparing one hole in the lateral fragment. The clavicle is cut at 90° to the axis of the hole for the compression screw. It is possible, in some cases, to avoid cutting the clavicle. The bone can be drawn upwards or downwards by a nylon tape (Figs. 5.34 and 5.35).

Fig. 5.34 The Fiolle Delmas exposure. The incision at the shoulder was made for the purpose of inserting an intramedullary nail. The wound, caused by the fracture, has been left open

The fascia at the root of the axilla is divided and the finger develops a plane between pectoralis major and minor in front, and the axillary bundle behind. Pectoralis major is detached from the humerus. Pectoralis minor is reflected taking care for the musculocutaneous nerve. The limb is rolled into lateral rotation so that the trunks, divisions and cords of the brachial plexus are displayed with their accompanying vessels. The exposure has been used in more than 250 cases. There have been nine cases of non union of the clavicle; infection complicated three of these.

Some key points:

- Identify and preserve the cephalic vein
- Identify the groove between pectoralis major and deltoid which is often easier close to the clavicle
- Use a malleable retractor between the clavicle and subclavius muscle before dividing it.
- The subclavius muscle is cut between clamps. LOOK OUT FOR THE SUPRASCAPULAR VESSELS

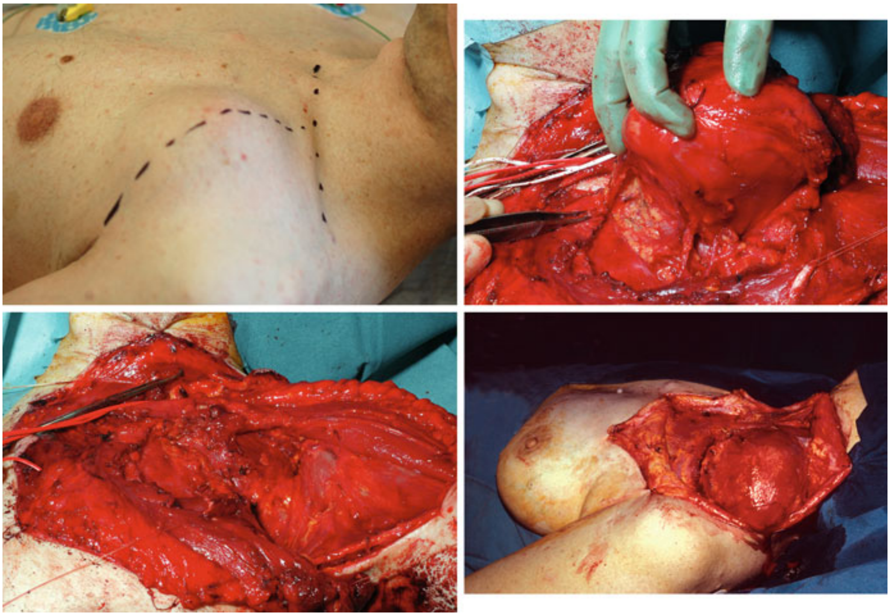


Fig. 5.35 Two large neurofibromata exposed through the approach of Fiolle and Delmas. *Top left*: the skin incision. *Bottom left*: the tumour exposed and, *top right*: removed. There was no loss of function. *Bottom right*: another neurofibroma arising in the posterior triangle of the neck. It was not necessary to divide the clavicle in either of these cases

- The easiest way to define the interval between the pectoralis minor and the coraco brachialis is to pass the index finger behind the upper margin of pectoralis minor and feel for the interval.

5.5.2 The Transclavicular Exposure

The approach was designed to give adequate exposure and control of the venous trifurcation, the first part of subclavian artery, the vertebral artery and the recurrent laryngeal nerve. the intervention remains an extensive and difficult one calling for a high degree of anatomical knowledge and practical versatility. The exposure rests on the elevation of the osseo-muscular flap comprising the medial portion of clavicle with the sterno clavicular joint based on the sternocleidomastoid muscle (SCM). The whole of the brachial plexus can be displayed after some lateral work; the cervico dorsal spine can be seen from C3 to T3 by developing the plane between the carotid sheath and the visceral axis (Fig. 5.36).

The transverse limb of the incision runs from the fold of the trapezius on the side of operation to the mid point of the opposite posterior triangle. This limb can be extended to increase the exposure. The vertical limb runs to the sternal angle.

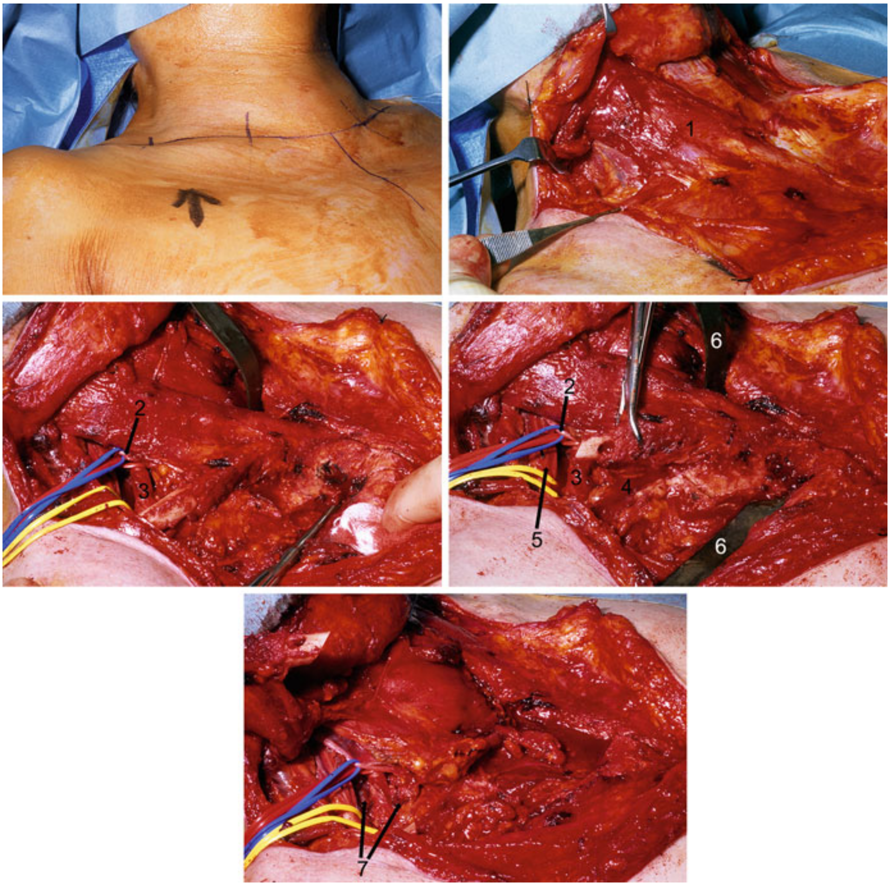


Fig. 5.36 The transclavicular exposure. *Top left*: the position of the patient and line of incision. *Top right*: elevation of the skin flaps with platysma and definition of sternocleidomastoid muscle (*1*). *Middle left*: the clavicle exposed and the phrenic nerve (*2*) and subclavian artery (*3*) traced. *Middle right*: the bone flap is elevated, taking care for the subclavian vein (*4*). The trunks of the brachial plexus (*5*) are seen. Malleable retractors (*6*) are inserted deep to the manubrium before section of the first costochondral junction and division of the manubrium. *Bottom*: the tumour (*7*) is seen deep to the subclavian artery, where it enveloped the vertebral artery

The flaps are widely elevated to include platysma. The SCM is defined anteriorly and posteriorly from its insertion below to the uppermost limit of the wound above. The accessory nerve is identified. The clavicle is displayed subperiosteally at its middle point. The subclavius muscle and suprascapular vessels are divided. The omohyoid muscle is divided and reflected. Pectoralis major is detached from the inferior portion of the medial clavicle revealing the subclavian vein. The strap muscles are released from the notch of the manubrium and the plane deep to this developed carefully using a dental Howarth elevator and a curved Adson's dissector. The plane is enlarged with the finger and a malleable retractor passed. The first costochondral junction is defined after detaching pectoralis major from the adjacent manubrium and the interval between the first and second sternocostal junction is developed deep to the sternum by the means outlined above. A malleable retractor is passed to meet its fellow from above. The first costal cartilage is cut with a scalpel, a fine osteotome is used to divide the manubrium with an L-shaped cut. The clavicle is now divided and the medial clavicle, sternoclavicular joint and upper corner of the manubrium are elevated on the SCM. The residual strap muscles are released. The internal jugular vein is now seen and traced to its junction with the subclavian vein. The brachiocephalic vein is traced and lightly held in a vascular sling. The phrenic nerve is elevated from scalenus anterior and the muscle divided. The first part of subclavian artery, the vertebral artery and the recurrent laryngeal and vagus nerves are seen. To display the whole of the plexus pectoralis major and pectoralis minor are detached from the humerus. When it comes to closure, the manubrio-clavicular fragment is reattached to the manubrium with wires, and to the clavicle with a plate and screws. The soft tissue layers are carefully closed. This exposure has been used on 80 occasions, chiefly for tumours of the brachial plexus. One patient, a 62 year old man, with a malignant neurofibroma complicating neurofibromatosis type 1 died of consumptive coagulopathy. Osteomyelitis of the clavicle occurred in two cases, and non union in four more. The recurrent laryngeal nerve is more vulnerable on the right side. Damage to the thoracic duct can usually be avoided, except in a scarred field and is usually recognised because of the leak of milky fluid. It is best to identify and repair the lesion, because if the pleura has been opened, there is a real danger of formation of a chylothorax. If the hole cannot be repaired, it can be plugged with a muscle graft.

Some key points:

- This is a major intervention and each step should be carried out with care under direct vision.
- Use malleable retractors behind the clavicle and deep to the manubrium.
- Detach pectoralis major from inferior clavicle with care, to expose subclavian vein crossing the first rib.

5.5.3 The Postero-Lateral Route

This, the posterior subscapular route, provides very good access to the most proximal parts of the nerves and in particular to the nerves in the intervertebral foramina [15]. The patient is almost supine, with the limb on the affected side resting on a separate table. The incision is convex medially, truly parascapular. The scapula is freed by the division of the trapezius and rhomboid muscles and, if necessary, the levator scapulae and it is retracted laterally so that the upper ribs are exposed. The first rib is defined and removed extra-periosteally, if necessary after the second rib has been removed sub-periosteally to facilitate exposure. The scalenus medius muscle is partly liberated during the removal of the first rib, and further mobilisation permits its upward retraction to display the brachial plexus. It is necessary to avoid damage to the nerve to serratus anterior during this process. By medial retraction of the posterior paravertebral muscles the foramina can be opened by hemi-laminectomy. Closure after completion of the procedure is by re-uniting the muscles carefully over a drain or drains.

There are three *potential* complications:

- winging of the scapula,
- instability of the cervical spine if more than two facet joints are removed,
- damage to various related structures.

The approach is firmly indicated in:

- the thoracic outlet syndrome: prior operation by the transaxillary or supraclavicular routes for removal of the first thoracic or seventh cervical rib, when the posterior third of the rib remains;
- tumours of the plexus: tumours with intraforaminal and extra foraminal lateral components;
- radiation neuropathy when there is extensive change in the skin and deep tissues of the neck and chest wall;
- traumatic lesions when the evidence is that a reparable lesion is in or near the foramen.

The approach described affords a less extensive view to the more distal (lateral) part of the supraclavicular plexus than does Kline's [15] (Fig. 5.37). The patient is put in the lateral position, the affected side uppermost, and the limb is included in the field. The incision, convex laterally, is centred over the seventh cervical vertebral spine. The flaps are raised. The trapezius is divided close to the midline and the muscle is retracted laterally. The next layer then comes into view: the upper part of the rhomboids, and the lower part of the splenius capitis. The levator scapulae, running from the scapula to the upper cervical transverse processes, and the splenius cervicis, running from the third to the sixth thoracic vertebral spines to the upper cervical transverse processes, are rather lateral. The upper part of the rhomboids and the lower part of the splenius capitis are divided near the mid line and the erector spinae group is exposed. Lateral to this, the transverse processes of the first thoracic and lowest four cervical vertebrae can be felt. The transverse processes and lateral masses are exposed by blunt dissection, with medial retraction of the erector spinae group. The back of the first rib is exposed at the lower end of the field, and the scalenus medius is cleared from its upper surface. That muscle is detached from its origin on the posterior tubercles of the lowest three of four cervical transverse processes. The nerves are then shown distal to the transverse processes, the proximal branches of the fifth, sixth and seventh nerves going into the scalenus medius to form the nerve to the serratus anterior. Now the posterior tubercles of the fifth and sixth vertebrae and part of the transverse process of the seventh are nibbled away to show the most proximal parts of the nerves. If necessary, the first thoracic transverse process and the first rib can be removed to increase the exposure of the lowest part

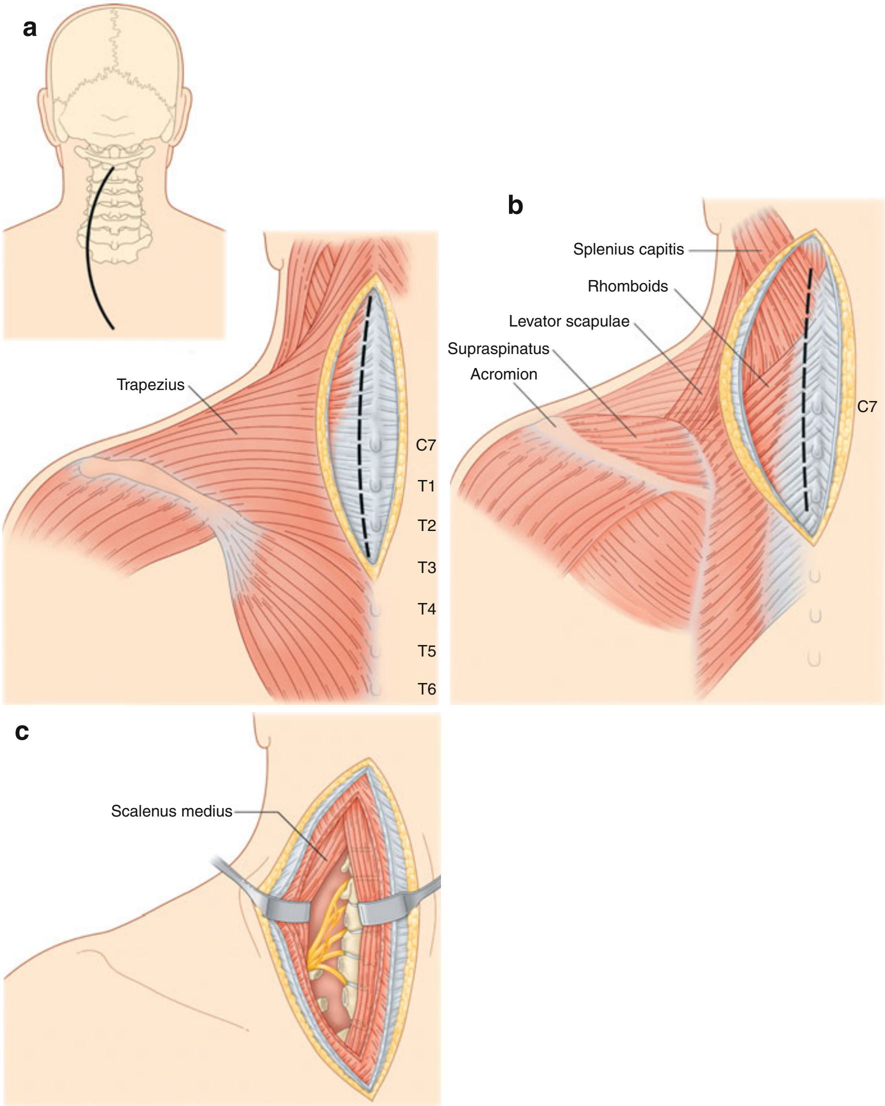


Fig. 5.37 Posterior approach to the left brachial plexus. (**a**) The incision. (**b**) The division of the trapezius. (**c**) Removal of posterior elements and detachment of scalenus medius to expose the proximal part of the plexus. Note that the nerve to serratus anterior is shown. In many cases of proximal injury to the plexus, it will have been damaged with the main nerves

of the plexus. Later, if necessary, one or two interfacetal joints can be removed to show the nerves in their dural sheaths in the foramina.

It is necessary to proceed carefully and methodically in this exposure, securing good haemostasis at each stage. It is not an easy exposure, but it is the preferred route when there is a very proximal lesion and access by the anterior route is barred by the sclerosis of a previous intervention. Two muscle layers and one subcutaneous layer are closed over a suction drain. A description of the approaches for the roots of the spinal nerves after avulsion is available [3].

5.5.4 The Spinal Accessory Nerve

The incision is often dictated by the site through which the nerve was originally damaged. Often enough, the original incision can be extended either as a "Z" or in the direction of the lines of skin tension. The usual site of injury is in the posterior triangle between the sternocleidomastoid muscle (SCM) and trapezius muscles, though occasionally the nerve is wounded in its course through the former muscle or proximal to it. The greater auricular nerve is the key to the exposure of the proximal stump which emerges from behind the SCM about 5 mm cephalad. The nerve emerges from deep to the muscle as one trunk, and at this point a fine branch is seen which innervates the uppermost part of the upper one third of the trapezius. This must be respected. The course and relations of the nerve are remarkably constant (Fig. 5.38).

The incision extends to the anterior face of the SCM, displaying the greater auricular and transverse cervical nerves. Exposure of the accessory nerve should begin in unscarred tissue, and the lesion defined after proximal and distal trunks have been found. The proximal stump may have retracted deep to the SCM. It can be identified anterior to the muscle or branches to the SCM are identified with a nerve stimulator. The distal part is found beneath the anterior part of the upper fibres of the trapezius where it must not be confused with branches of the supraclavicular plexus which pass obliquely or horizontally in front. Atrophy of the distal trunk is a common finding because of the long delay before diagnosis. There is no point in attempting end-to-end suture after resection: the gap is usually too great, and in any case, the mobility of the forequarter on the axial skeleton forbids the use of such a

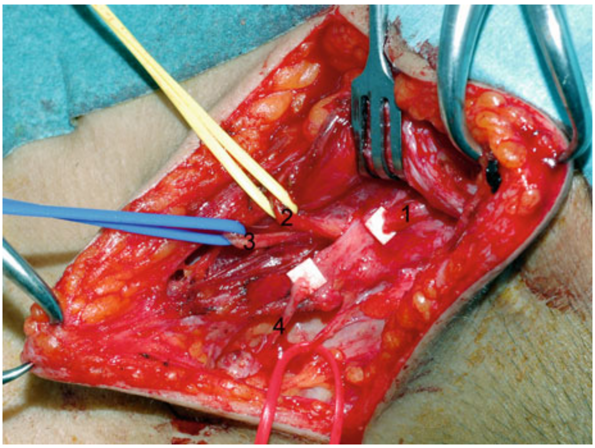


Fig. 5.38 The spinal accessory nerve emerges, as one trunk (*1*), from deep to sternocleidomastoid about 5 mm cephalad to the greater auricular (*2*) and transverse cervical (*3*) nerves. In this case the nerve had been transected 15 months earlier and there is atrophy of the distal stump (*4*)

method because of the hazards of disruption. If the proximal stump is inaccessible part of the lateral pectoral nerve may be used to reinnervate the distal trunk.

Some key points:

- Find the anterior face of SCM and identify the greater auricular and transverse cervical nerves.
- Inferiorly the nerve has a characteristic sinuous course, deep the fascia covering the inner face of the trapezius. It is accompanied by a vein which can prove troublesome.

5.5.5 The Suprascapular Nerve

The lateral position and a transverse incision is preferred. The flaps are raised, and the supraspinous part of the trapezius muscle is detached from its origin and raised to show the supraspinatus muscle, or the fibres of trapezius can be split to show the underlying supraspinatus, which is lifted from its scapular origin to reveal the suprascapular nerve traversing the notch. The accompanying artery is usually superficial to the transverse ligament or bony bridge. Ochiai et al. [20] showed that the suprascapular nerve might be seriously damaged in several places and describe an exposure which exposes the nerve along its entire course as far as the infraspinatus and which can be extended to display the circumflex nerve anteriorly.

5.5.6 The Infraclavicular Part of the Brachial Plexus

With the full opening of the delto-pectoral interval the pectoralis minor muscle is exposed crossing the field to its attachment on the coracoid process. Below and above it is the neurovascular bundle, covered by a layer of fascia and, in the lower part of the field, by the flat reflected tendon of the sternal part of the pectoralis major. The easiest way to define the interval between the pectoralis minor and the coraco brachialis is to pass the index finger behind the upper margin of pectoralis minor and feel for the interval. The tendon of pectoralis minor is divided. The muscle is drawn medially, care being taken of the medial pectoral nerve piercing it and going on to the pectoralis major. Now the fascia over the plexus is divided above and below the former site of the pectoralis minor. If it is absolutely necessary, the flat reflected tendon of the pectoralis major too can be divided. Thus the whole neurovascular bundle is displayed. The lateral cord is the most prominent component, the axillary artery is behind it and the axillary vein medial to it. In the lower part of the field the median nerve is formed from the contributions from the medial and lateral cords. Just at the formation of the lateral cord the lateral pectoral nerve arises to pierce the clavipectoral fascia and enter the pectoralis major. The posterior cord lies deep to the lateral cord and axillary artery; the medial cord is deep to the axillary vein. Some mobilisation of both great vessels is necessary for the full display of the cords (Fig. 5.39).

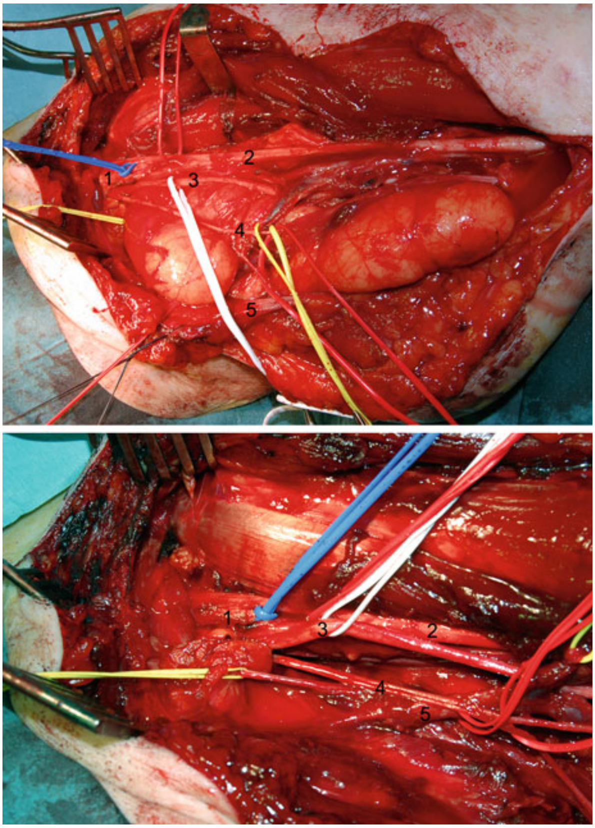


Fig. 5.39 The infraclavicular brachial plexus splayed over a massive lipoma. The axillary artery (*1*) is marked by the blue sling, the median nerve (*2*) by a red sling and the ulnar nerve (*3*) by a white sling. The medial cutaneous nerve of forearm (*4*) is seen and the radial nerve (*5*) lay deep to the tumour. The appearances before (*above*) and after (*below*) removal of the tumour

The musculocutaneous nerve arises from the lateral cord above the level of the coracoid process and runs laterally into the coraco-brachialis muscle. It may be a single branch but can consist of several branches arising at different levels from the cord.

The posterior cord and its lateral and terminal branches are exposed between the lateral cord and the axillary artery. The three subscapular nerves are seen, and in the lower part of the field the separation of the trunk into radial and circumflex nerves is visible. Reflection of coracobrachialis from the tip of the coracoid process improves exposure of the anterior "door" of the quadrilateral space and permits exposure of the distal stump of a ruptured circumflex nerve. This display may be extremely difficult in the late case, especially after arterial injury.

Some key points:

- Identify and preserve the cephalic vein.
- Definition of the delto pectoral groove may be easier just below the clavicle.
- Variations in the course of the axillary artery and the musculocutaneous nerve are common.
- This exposure can be extremely difficult in delayed cases with arterial injury. Do not hesitate to extend the incision.

5.5.7 The Circumflex Nerve

In cases of rupture the anterior (proximal) stump is almost always found just below the coracoid process and repair sometimes requires exposure of the posterior (distal) stump through a separate posterior incision. Repair has to be effected by graft, and it is certainly easier to secure good placement and attachment through two incisions than through one giving limited access. The posterior circumflex artery is often ruptured by the head of humerus, in anterior dislocation. This can lead to serious bleeding, or to a false aneurysm. The distal stump of the nerve may be strangled in fibrosis and in these cases direct muscular neurotisation is useful as it is when the nerve has been avulsed from the muscle (Fig. 5.40).

5.5.8 Median and Ulnar Nerves in the Arm and the Axilla

The incision crosses the anterior axillary fold and the axilla, and descends the medial side of the arm. The flaps are raised and the axillary fat displaced downwards. The neurovascular bundle is found in its sheath in the lower part of the axilla: most medial is the axillary/brachial vein; the nerves are grouped around the lower part of the axillary and the brachial arteries. In the upper arm, the medial cutaneous nerve of forearm (MCNF) lies anterior to the brachial vein and is the most superficial of the nerves within the neurovascular bundle. The nerve perforates the deep fascia in the middle part of the arm. The slender medial cutaneous nerve of the arm (MCA) runs outside and posterior to the neurovascular sheath. Communicating branches between the MCNF and MCA are common. The axillary artery is embraced by the two roots of the median nerve, which starts on its lateral side and crosses it in the arm. The musculocutaneous nerve most commonly arises as a single branch from the lateral cord at or below the level of the coracoid process, but it may consist of several branches arising at intervals along the line of the lateral root of the median nerve. It passes laterally into the coracobrachialis muscle and the flexors of the elbow. The ulnar nerve and the medial cutaneous nerve of the forearm are on the medial side of the artery. The former passes posteriorly about half way down the arm to pierce the medial intermuscular septum and to lie between it and the medial part of the triceps muscle, to which it usually gives a branch. Deepest of all is the radial nerve, which crosses anterior to the tendon of latissimus dorsi and then passes posteriorly between the long and medial heads of triceps. The nerve runs behind the humerus deep to the lateral head of the triceps and gains the lateral aspect of the lower part of the arm by piercing the lateral intermuscular septum. The neurovascular bundle can be traced up into the axilla to expose the cords and the origin of the circumflex and radial nerves.

Some key point:

- Take time to identify the medial cutaneous nerve of forearm, an important guide.
- If there is difficulty with the median nerve trace the brachial artery.

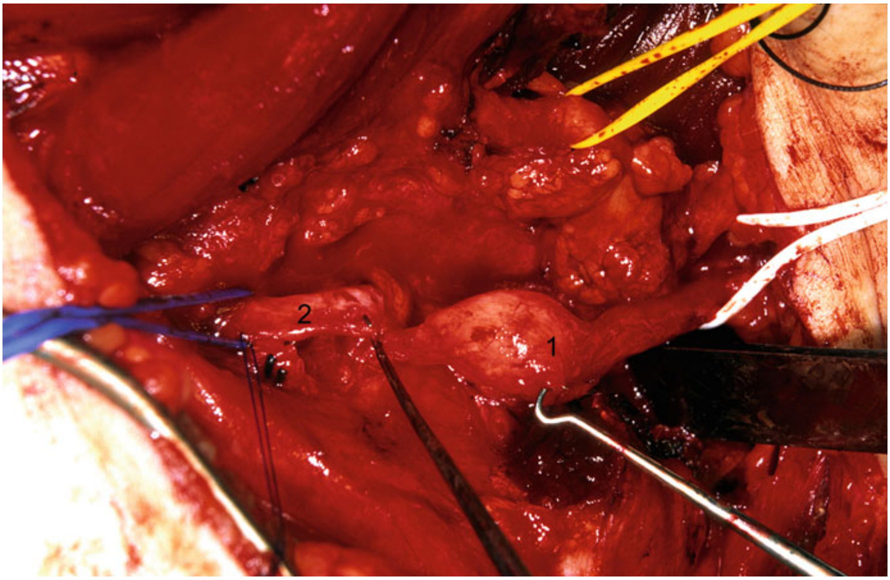


Fig. 5.40 Rupture of the circumflex nerve at the entrance to the quadrilateral tunnel. The proximal stump (*1*) and, somewhat unusually the distal stump (*2*) are visible

5.5.9 The Radial Nerve

The proximal part of the radial nerve is quite easily displayed in the upper part of the axillo-brachial incision; the distal part is easily found through an anterolateral incision in the lower part of the arm and by entering the interval between the biceps and brachialis medially and the brachioradialis and extensor carpi radialis longus laterally (Fig. 5.41). Finding the middle part – the part most likely to be in trouble – is rather more difficult. It is to be found through a posterior incision, and by separation of the superficial part of the triceps (the long and lateral heads) from its deep part (the medial head). The flaps are raised and the lower part of the deltoid muscle and the superficial part of the triceps muscle are exposed**.** The V-shaped interval between the upper parts of the long and lateral heads is now defined, by locating the upper part of the long head and following its lateral border distally. The "seam of the half sleeve" [13] – that is, the junction of the long and lateral heads of the triceps – is now opened from the top towards the olecranon (Fig. 5.42). Further exposure of the radial nerve is anterior to the lateral head of the triceps muscle, by entering the interval between the biceps/brachialis and the brachioradialis/extensor carpi radialis longus. If there is difficulty in bridging a gap after resection, some length can be obtained by re-routing the distal stump towards the upper medial aspect of the arm deep to the biceps and brachialis muscles. For exposure of the more distal parts of the nerve the incision may be extended round the side of the arm to the medial side of the brachioradialis. Thence it runs across the anterolateral aspect of the elbow into the forearm. With

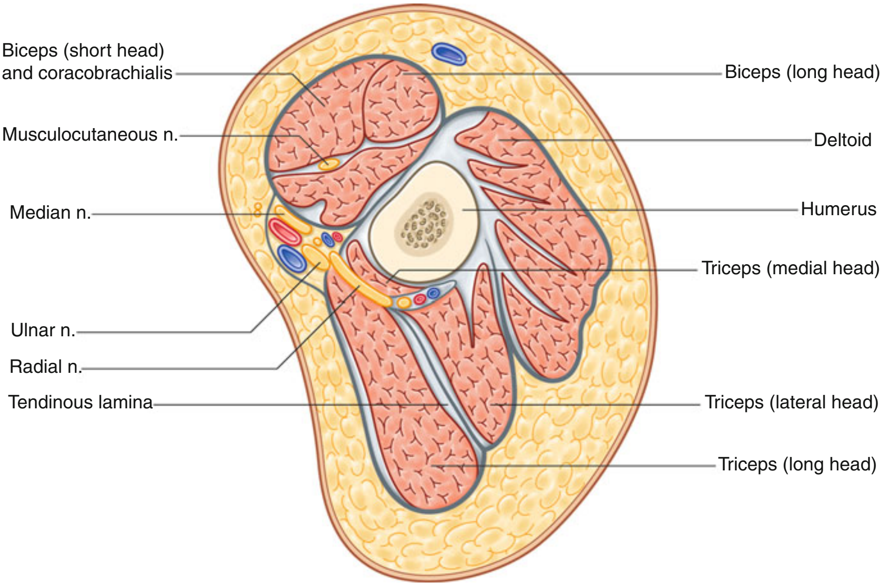


Fig. 5.41 Transverse section through the arm above the level of the insertion of the deltoid muscle, just below the level of the posterior movement of the radial nerve

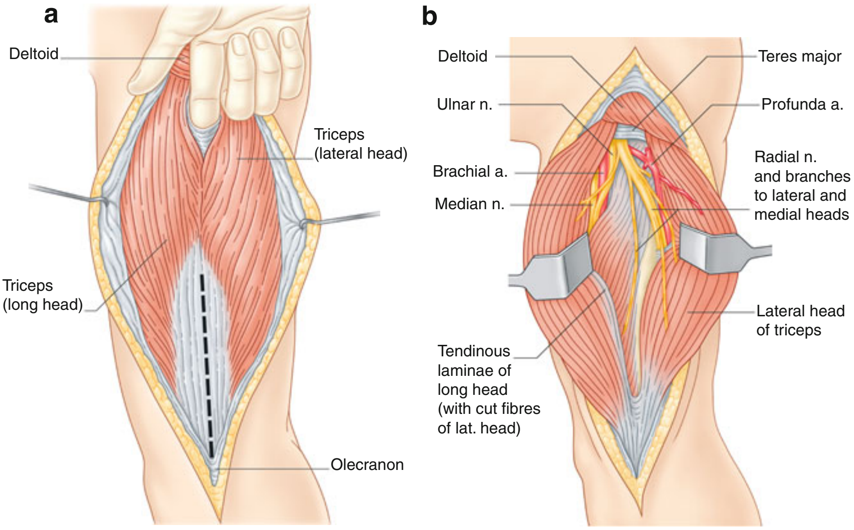


Fig. 5.42 The exposure of the radial nerve in the arm. (**a**) The "seam of the triceps". The finger is introduced between the long and lateral heads which are separated. (**b**) The opening of the "seam" reveals the radial nerve from the start of its course on the back of the humerus to the piercing of the lateral intermuscular septum

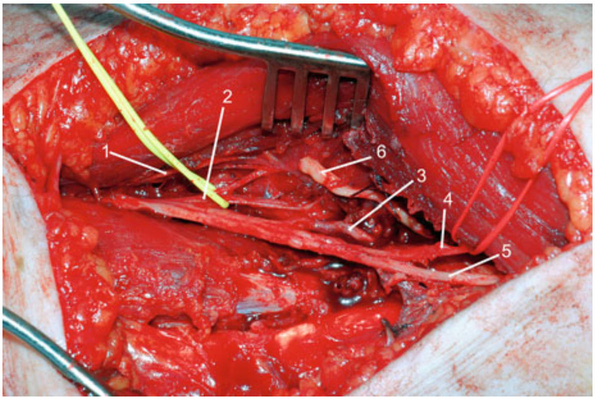


Fig. 5.43 The radial nerve at the elbow exposed during repair of posterior interosseous nerve cut during operation for fracture of radial head. *Above*: the nerve is seen in the valley between brachioradialis and biceps lying on fibres of brachialis. *Left*: the nerves to brachioradialis (*1*) to extensor carpi radialis longus and brevis (*2*) the proximal part of the posterior interosseous nerve (*3*) a further branch to extensor carpi radialis brevis (*4*) and the superficial radial nerve (*5*) are shown. A segment of the lateral cutaneous nerve of forearm (*6*) has been prepared as a graft

this anterior approach the radial nerve and its terminal branches are found in the interval between the biceps/brachialis and the brachioradialis/extensor carpi radialis longus. There are important branches from this segment of the nerve. The nerve to brachialis, passing antero-medially is often seen about five finger breadths above the lateral epicondyle. The nerve to brachioradialis passes postero-laterally about 2 cm more distal. More distally still, is the branch to extensor carpi radialis longus and then, after that, branches, usually two, to extensor carpi radialis brevis (Fig. 5.43).

Some key points:

- Note the posterior cutaneous nerves of arm and forearm emerge from the interval between lateral head of triceps and brachioradialis.
- The plane between brachioradialis and brachialis is sometimes obscured: do not hesitate to extend distally to the cubital fossa and work from below.

5.5.10 The Posterior Interosseous Nerve

In the Henry [13] approach, the incision is made on the posterolateral aspect of the upper forearm between the mobile mass of the brachioradialis and the radial extensors of the wrist, and the extensor communis digitorum. The interval between the extensor carpi radialis brevis and the extensor communis digitorum is then opened and the supinator muscle exposed. The posterior interosseous nerve passes between the superficial and deep parts of this muscle, to emerge at the lower margin of the superficial part and to run for about 4–5 cm before breaking up into its terminal (motor) branches. The point of emergence can quite easily be found, and the

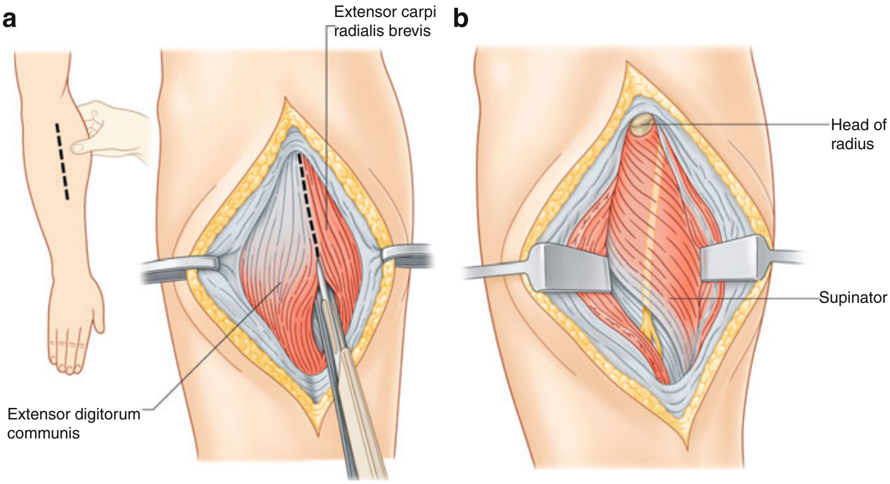


Fig. 5.44 The exposure of the posterior interosseous nerve. (**a**) The incision (*left*) and the separation of the extensor carpi radialis brevis from the extensor communis (*right*). (**b**) The posterior interosseous nerve and supinator exposed

nerve then followed proximally by division of the superficial part of the muscle along its line (Fig. 5.44).

5.5.11 The Lower Part of the Median Nerve

The median nerve is easily displayed at and just below the elbow and in the lower part of the forearm through a sinuous incision winding down from the elbow. At elbow level it is found medial to the brachial artery (Fig. 5.45). It then descends between the superficial and deep heads of the pronator teres The median nerve can be traced down into this tunnel, and can to some extent be mobilised by division of the deep (ulnar) head of the pronator teres. Having negotiated the pronator teres, the nerve runs down the forearm between the deep and superficial flexor muscles, loosely attached by areolar tissue to the deep surface of the flexor digitorum superficialis. It can be exposed in this part of its course by separating the flexor superficialis from its radial origin and retracting the muscle. The anterior interosseous nerve is now displayed. The nerve enters the hand just deep to and between the tendons of the palmaris longus and flexor carpi radialis.

The carpal tunnel is formed posteriorly and laterally by the concavity of the carpus; in particular, the scaphoid, lunate, hamate, and pisiform bones. It is roofed by the flexor retinaculum and anchored medially to the pisiform and hamate bones and laterally, to the scaphoid and the trapezium. The width of the retinaculum is about 2.5 cm; its length is about the same. Proximally it blends with the ante-brachial fascia, and distally with the palmar aponeurosis. The tendon of the palmaris longus is attached to it anteriorly. A deep lamina on the radial side is attached to the medial

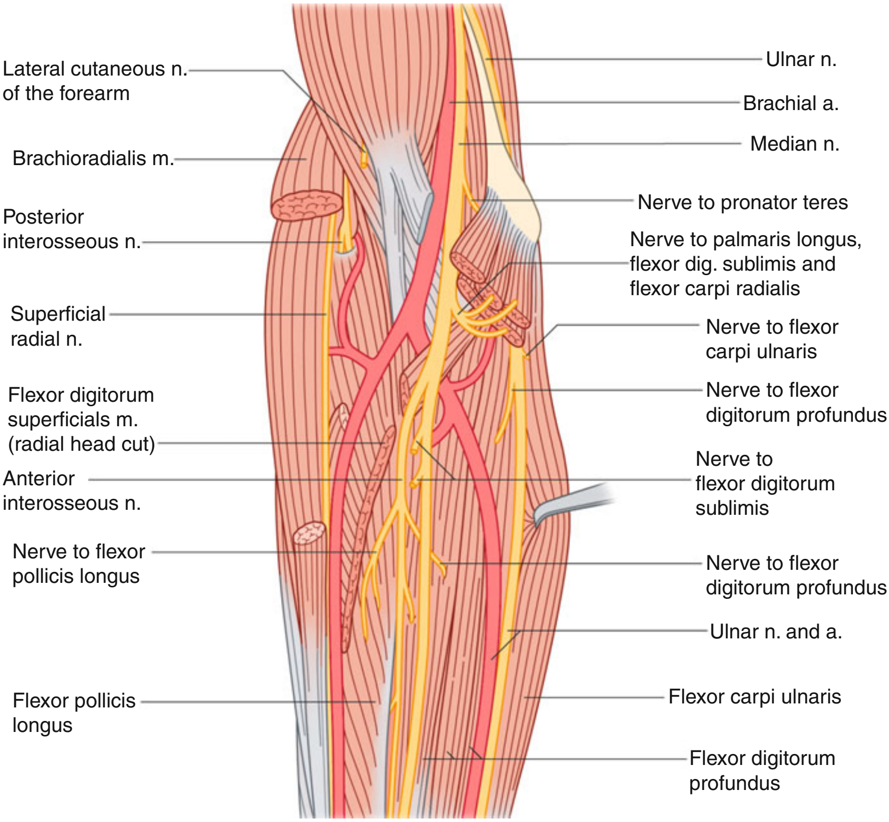


Fig. 5.45 The anterior aspect of the right elbow (see Fig. 1.15)

lip of a groove on the trapezium. Between this layer and the more superficial part lies the tendon of the flexor carpi radialis muscle in its synovial sheath. On the ulnar side a localised thickening of the ante-brachial fascia extends laterally from the pisiform bone as a superficial part of the retinaculum, passing superficial to the ulnar nerve and vessels to blend with the retinaculum lateral to them.

The positions of the motor and the palmar cutaneous branches of the median nerve are very important for the surgeon. In most cases the motor branch arises from the radial side of the nerve in the carpal tunnel and runs laterally, soon branching to supply the opponens and short abductors of the thumb, and often part of the flexor brevis. A particular hazard for the surgeon is produced by an origin from the ulnar side of the nerve and a course across it, either deep or superficial, to the retinaculum. The palmar cutaneous branch arises from the median nerve about 7 cm above the wrist crease and runs distally, medial to the tendon of the flexor carpi radialis to innervate the skin over the thenar eminence and the radial side of the proximal part of the palm. Damage to this can cause a profound, persistent painful state, with very troublesome hyperaesthesia and hyperalgesia, and even hyperpathia and allodynia (Fig. 5.46).

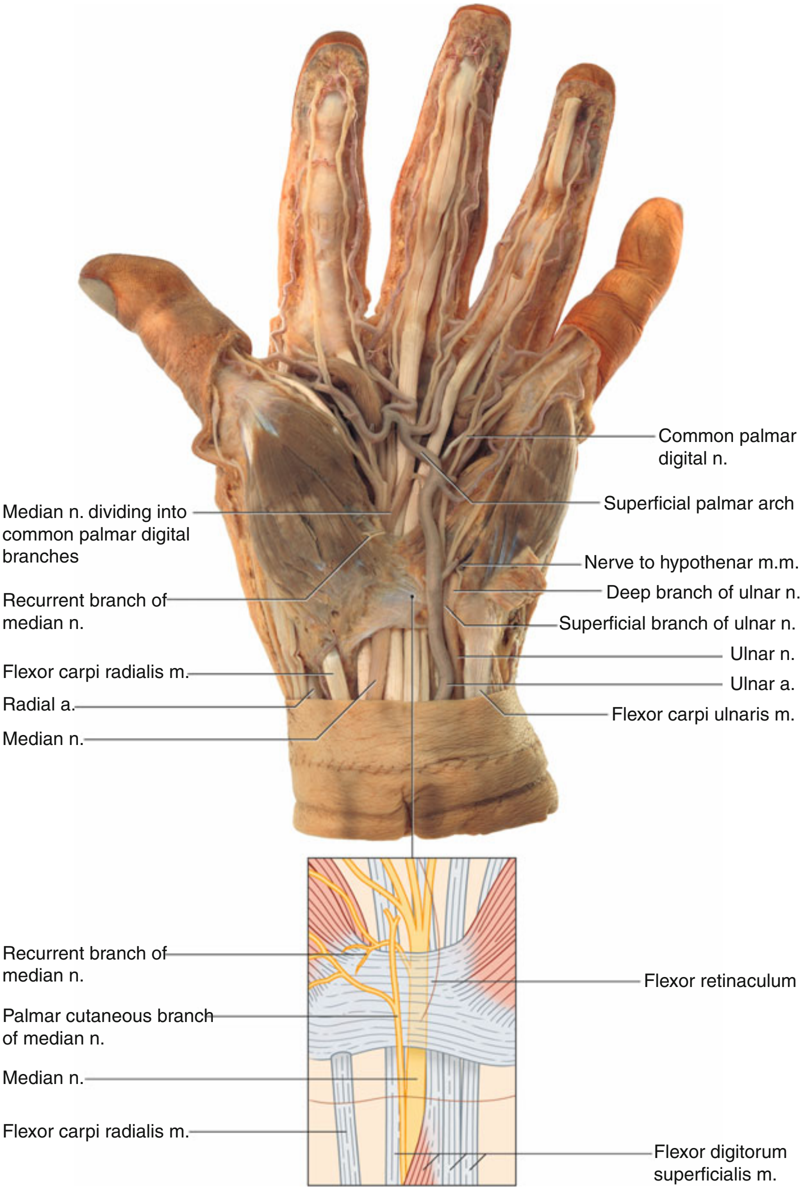


Fig. 5.46 The median and ulnar nerves in the left hand. *Inset* shows the normal course of median nerve at the wrist and also the palmar cutaneous nerve (see Fig. 1.16)

Two key points:

- Beware the palmar cutaneous nerve which arises from the radial side of the median nerve.
- Variations in the course of the motor branch are frequent.

5.5.12 *The Lower Part of the Ulnar Nerve*

As the ulnar nerve approaches the elbow, it runs behind the medial intermuscular septum and then passes subcutaneously behind the medial epicondyle of the humerus in the retro-condylar groove. It passes through the arcade of Struthers, a fibrous canal about 6 cm in length which terminates at about 4 cm proximal to the medial epicondyle [3]. The components of the arcade include not only the tough medial intermuscular septum of the arm but also the sheath of the medial head of triceps, which can be seen enveloping the nerve, as well as the internal brachial ligament. The ulnar nerve then passes superficial to the medial capsule of the elbow joint and deep to the arcade, joining the two origins of the flexor carpi ulnaris muscle (the arcuate ligament). This is the "cubital tunnel". A branch of the medial cutaneous nerve of forearm passes superficially here. The nerve then runs between the flexor carpi ulnaris and flexor digitorum profundus muscles, joining the ulnar artery in its course down the forearm. The muscular branches arise just below the elbow. The nerve is vulnerable to external pressure. It may be compressed between the arcuate ligament and the medial capsule and with relaxation of this ligament it may become hypermobile, dislocating forward when the elbow is flexed. Because of the excursion required of it during movement of the elbow, it may be stretched during flexion if its movement is restricted by changes due to damage by external pressure.

The ulnar nerve and artery pass down the forearm within a well defined sheath which is found deep to the anterior margin of flexor carpi ulnaris. The nerve and artery may become tightly compressed by swollen anoxic muscle and, later, by post ischaemic fibrosis. Arterial bleeding from a wound on the ulnar aspect of the forearm indicates damage to the ulnar nerve.

The ulnar nerve divides into its superficial (sensory) and deep (motor) components at about wrist level. Both components run into Guyon's space (Fig. 5.47). The superficial branch passes superficially to supply the palmaris brevis and the skin of the medial two digits; the deep branch runs between the abductor and the flexor of the little finger to pierce the opponens and then runs across the deep palmar space with the deep palmar arch, ending by supplying the adductor and flexor brevis of the thumb and the first palmar interosseous muscle. Deep as it is, the deep branch is vulnerable to wounds from glass or knife. The nerve is best followed by an incision beginning above the wrist, entering the ulnar side of the palm and curving across the distal palm in a crease. It is isolated in the upper part of the incision lateral to the tendon of flexor carpi ulnaris and medial to the ulnar artery and followed to its bifurcation. Then the deep branch is followed between the hypothenar muscles. Its deep course has to be revealed by mobilisation of the deep and superficial flexor tendons. The multitude of the motor branches of this nerve, to most of the intrinsic muscles of the hand, has to be borne in mind during this exposure, though it is impossible to avoid some of these in a scarred field.

Two key points:

- Beware the medial cutaneous nerve of forearm around the elbow. It is always in the way and damage causes intractable pain.
- Look out for the dorsal cutaneous branch of the ulnar nerve. It is best to formally expose this when dealing with fractures of the shaft of the ulna.

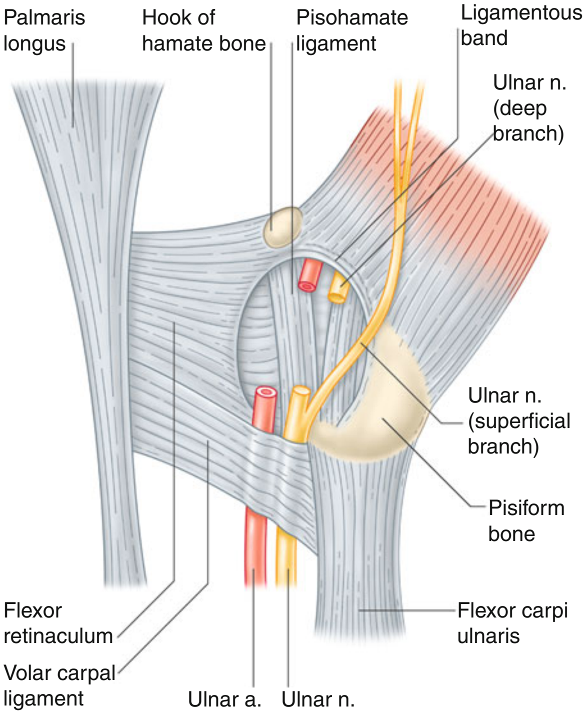


Fig. 5.47 Guyon's space. Note the possibilities for entrapment at, and distal to, the volar carpal ligament

5.6 Approaches to Individual Nerves: Abdomen, Pelvis and Lower Limb

5.6.1 The Lumbar Plexus

This is accessible through the lower quadrant of the abdomen, by the same transverse muscle cutting incision and extra-peritoneal approach that is used for lumbar sympathectomy [16]. The exposure may be helped by placing the patient in the lateral or semi-lateral position. The incision is made between the rib cage and the iliac crest. The external oblique split and the deeper muscle is cut, with opening of the lateral part of the rectus sheath. The underlying fascia is delicately opened and the peritoneum is swept away from the abdominal wall and vertebral column. The lateral cutaneous nerve of thigh, the ilio-inguinal nerve and the ilio-hypogastric nerve are encountered approaching the lateral and posterior margin of the psoas muscle. The femoral nerve lies in a gutter between the iliacus and the psoas major (Figs. 5.48 and 5.49). The obturator nerve runs medial to the psoas muscle. The lumbo-sacral trunk is closer to the mid line and deep to the great vessels. The spinal nerves passing to the femoral nerve run deep to the psoas muscle in much the same way as the cervical spinal nerves run deep to scalenus anterior and the muscle must be cut or reflected to display them. This approach gives good access to the lumbar plexus in the psoas muscle and to the femoral and obturator nerves on each side of the lower part of the psoas. Access to the lumbosacral plexus is rather restricted

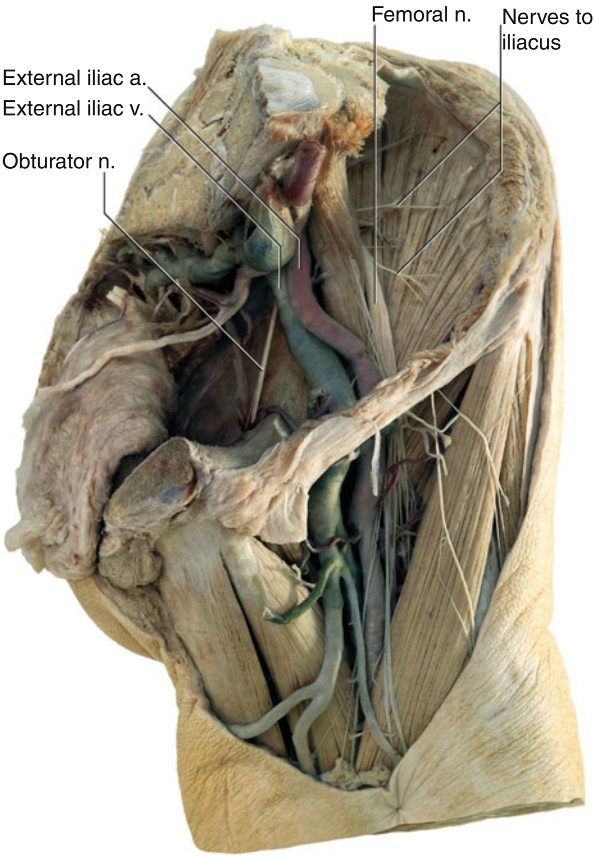


Fig. 5.48 The left femoral nerve (see Fig. 1.20)

through this extra-peritoneal approach. A trans-peritoneal approach makes access easier, but the viscera have to be mobilised with the consequent risks of ileus after operation and of late complications from adhesions. Injuries to the lumbosacral plexus are often associated with forbidding scarring.

5.6.2 The Femoral Nerve

This can be traced down to the level of the inguinal ligament from above through an abdominal incision and exposed again in the thigh through a separate anterior crural incision. Kline, Hudson and Kim [16] suggest that the crural incision can be extended laterally above the inguinal ligament and the lower abdominal muscles split to give an extraperitoneal approach.

Key point:

- Exposure of the nerve at the groin crease is enabled by identifying the common femoral artery and working lateral to it. The nerve lies in a slightly deeper plane.

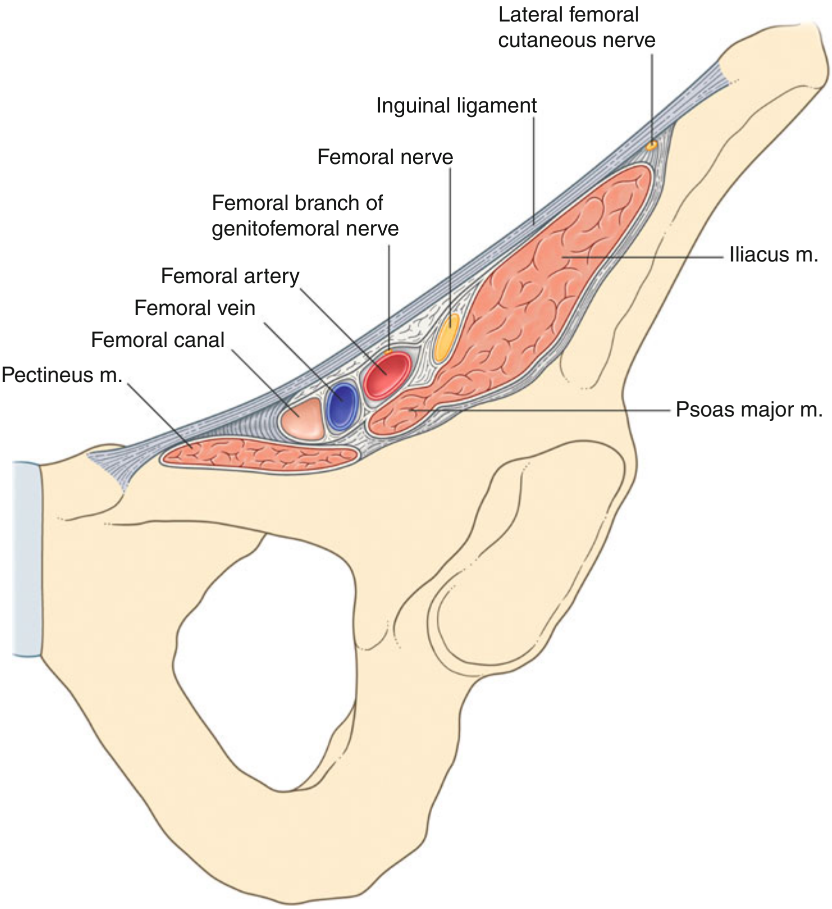


Fig. 5.49 The femoral nerve and vessels deep to the inguinal ligament. The drawing shows the left inguinal region (see Fig. 1.38)

5.6.3 The Sciatic Nerve

Two exposures are regularly used. In the first, the gluteus maximus muscle is split as in the posterior approach to the hip. This provides an adequate exposure of the sciatic nerve where it traverses the neck of the femur. Up to 15 cm of the trunk can be seen. A second, more extensive, approach is described by Henry [13]. The prone position is used for both.

Splitting the gluteus maximus: The incision runs obliquely about two finger breadths above the line drawn from the ischeal tuberosity to the tip of the greater tuberosity. The gluteus maximus is exposed and gently split along the line of its fibres noting and preserving branches of the inferior gluteal nerve and securing careful haemostasis. The muscle flaps are held apart with the large Deavers retractor.

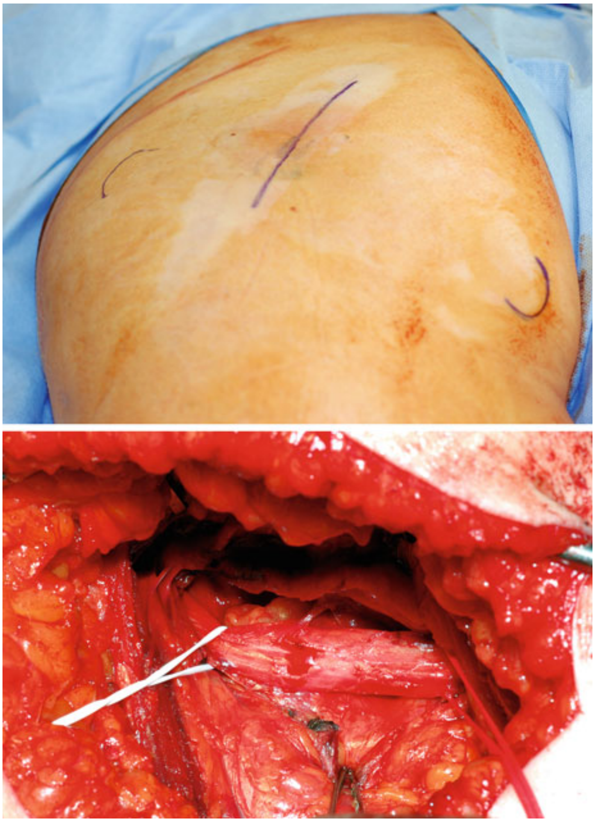


Fig. 5.50 Exposure of sciatic nerve by transgluteal approach. *Above*: the patient lies prone and the incision is made between the tip of the greater trochanter and the ischial tuberosity. *Below*: the nerve is exposed as it crosses the neck of the femur

The nerve is seen crossing the posterior aspect of the neck of the femur, and it can be traced up to the sciatic notch if necessary by division of the piriformis (Fig. 5.50).

The wound is closed by repair of the sheath of gluteus maximus, the fat and the skin. This approach is very useful in exploration of lesions of the sciatic nerve incurred during arthroplasty of the hip.

Key points:

- Haemostasis must be meticulous.
- The trunk is easily demonstrated by rolling the tip of the finger over it.

Full exposure of the sciatic nerve and of the superior and inferior gluteal nerves and vessels is achieved through the operation described by Henry [13], who compares the "gluteal lid" with a parallelogram whose shorter sides are almost longitudinal and whose longer (upper and lower) sides are oblique. The caudal edge is virtually unattached.

The incision can follow the "question-mark" shape advised by Henry, or can run from the iliac crest at the junction of the gluteus maximus and the iliotibial tract,

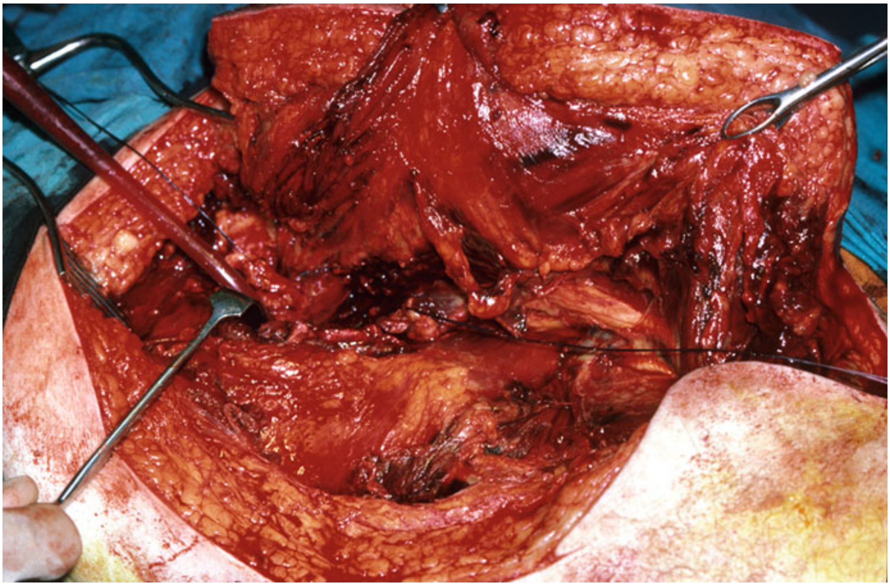


Fig. 5.51 The extended exposure of the sciatic nerve damaged by fracture/dislocation of the hip

obliquely down the back and lateral side of the buttock to reach the great trochanter and then turn medially to descend in the mid line of the thigh. It is necessary to look out for the posterior cutaneous nerve of the thigh, piercing the deep fascia in the upper part of the thigh and descending in the midline. It should be identified under the fascia below the lower border of gluteus maximus. Now, the gluteus maximus is detached from its insertion to the femur; the cephalic side of the muscle is separated from the ilio-tibial tract, and both tendinous and muscular insertions to the femur are divided**.** Then, with continued care for the posterior cutaneous nerve of the thigh, the gluteal lid is hinged back on its pelvic origin. Excessive traction upon the superior gluteal vessels must be avoided. The structures displayed are the gluteus medius and the short lateral rotators of the hip, the superior and inferior gluteal vessels and nerves, the pudendal nerve and vessels and the sciatic nerve. The sciatic nerve can be followed into and through the great sciatic notch by division of the tendon of the piriformis and retraction of the muscle. Downward extension of the vertical limb of this incision permits display of the whole of the sciatic nerve (Fig. 5.51).

Careful closure of the wound is essential. In particular, the gluteus maximus must be reattached laterally and cephalad. One or two suction drains should be used. The subcutaneous tissues should be closed.

Key points:

- Haemostasis must be meticulous.
- Avoid traction upon the formidable superior gluteal vessels.
- Reattachment of the muscle must be secure.

5.6.4 *The Tibial and Common Peroneal Nerves in the Popliteal Fossa and Below*

The incision starts above the back of the knee and skirts the crease to return to the midline below the knee, to descend in the midline for about 10cms. The flaps are raised. Care must be taken of the sural nerve arising from the tibial nerve and descending in the midline, at first just under the deep fascia and piercing that in the proximal part of the leg The tibial nerve and popliteal artery and vein are found above in the mid-line; the common peroneal nerve has at this level deviated laterally to lie close to the tendon of the biceps femoris. The gastrocnemius is split in the midline to expose the underlying soleus muscle, which also is split to show the nerve and vessels below the knee.

The tibial nerve in the leg and behind the ankle is exposed through a straight or sinuous incision over the medial head of the gastrocnemius and medial to the tendo calcaneus. The medial head of the gastrocnemius is exposed, freed and retracted laterally to expose the medial part of the soleus. Then, the medial part of the soleus is mobilised by division of the medial "pier" of its tendinous arch and of its medial origin. The soleus is then retracted laterally, to expose the deep compartment of the leg with the tibial nerve and vessels (Fig. 5.52).

Exposure of the common peroneal nerve necessarily takes the popliteal incision laterally, to descend on the lateral side of the leg and permit exposure of the deep peroneal (anterior tibial) and superficial peroneal divisions in which the nerve terminates just below the neck of the fibula. The operator must remember that the common peroneal nerve is very close to the surface behind the head of the fibula and lateral to its neck. It has been partly divided by the initial skin incision. The nerve is embraced by fascia enveloping the biceps femoris and is displaced with that muscle in dislocation of the knee.

Some key points:

- The sural and common peroneal nerves are the signposts in this exposure.
- The common peroneal nerve is close to the skin and will be displaced anteriorly by the biceps femoris after knee dislocation.
- As with all nerve work it is much easier to find these nerves in proximal healthy tissue.

5.6.5 *The Lower Tibial Nerve and the Plantar Nerves*

The lower part of the tibial nerve is easily found on the medial side of the ankle, under the flexor retinaculum, between the flexor tendons of the hallucis and the flexor digitorum. The terminal plantar branches are traced into the foot by division of the retinaculum and then by bringing back the abductor hallucis muscle after defining its superior edge and detaching it from its origin on the distal part of the

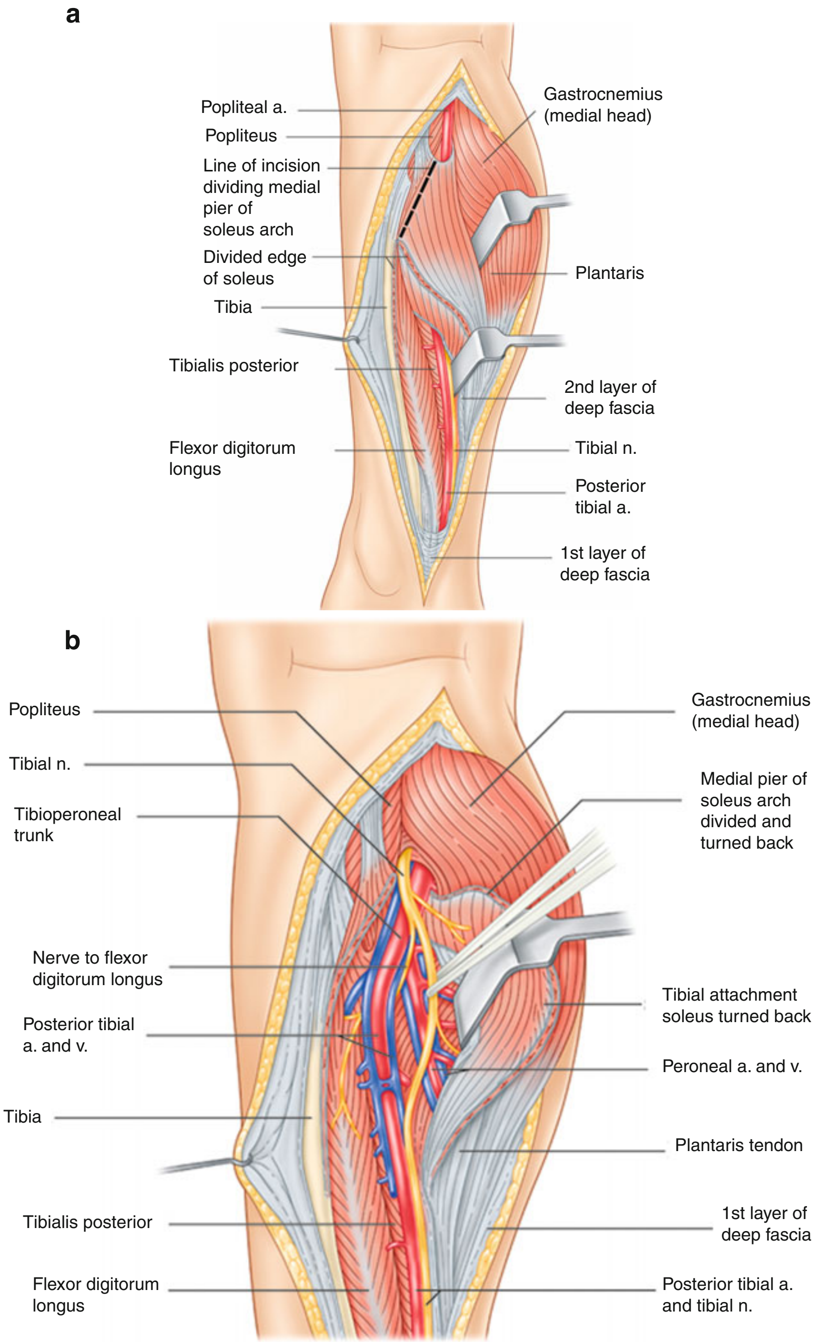


Fig. 5.52 Exposure of the tibial nerve in the leg. (**a**) The soleus exposed and the line for its detachment shown. (**b**) The tibial nerve and vessels revealed by the retraction of the soleus

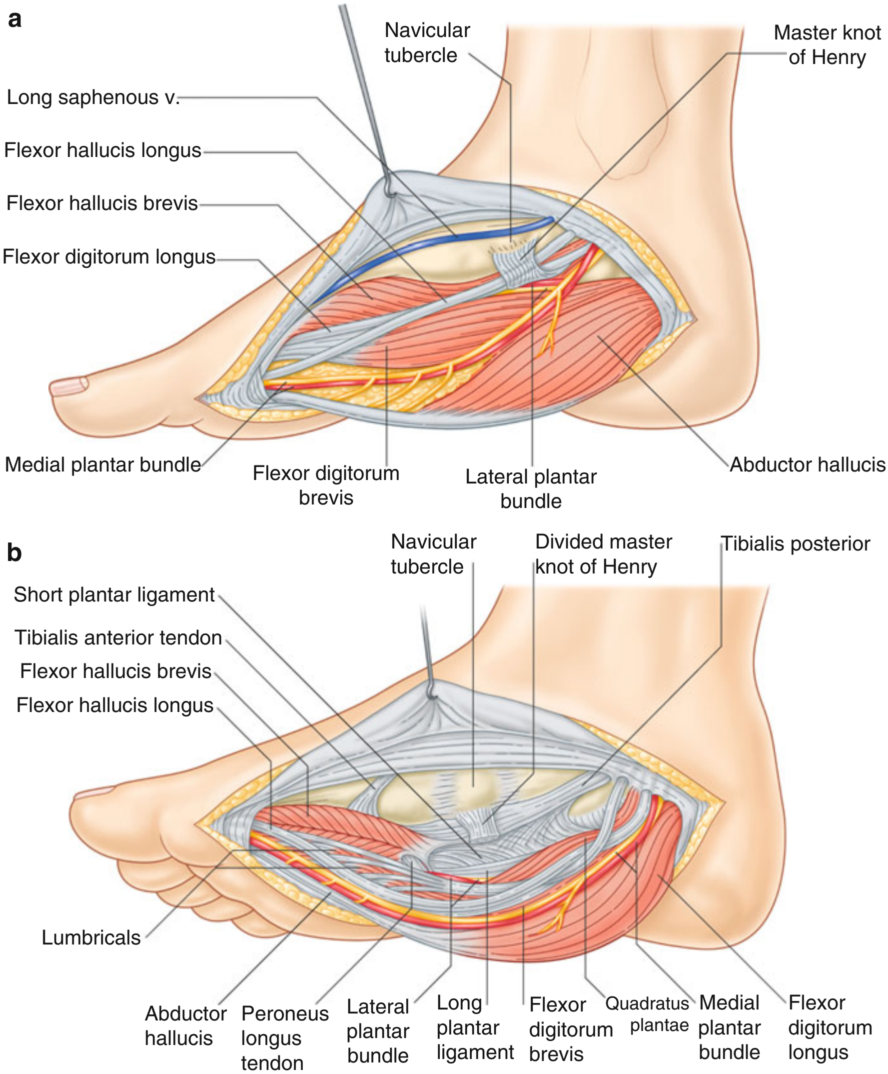


Fig. 5.53 Exposure of the plantar nerves through a medial incision. (**a**) Retraction of abductor hallucis reveals the medial plantar nerve. (**b**) Release of the tendon of the flexor longus hallucis gives access to the whole of the deep compartment of the sole

retinaculum. The plantar nerves are found between the deep and superficial layers of the plantar muscles in the plane between, on the one hand, the two abductors and the flexor brevis digitorum and on the other, the flexor accessorius and the tendons of the long flexors (Fig. 5.53).

Key point:

- Take care for the calcaneal nerves. Wounding these can prove most troublesome.

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