British Orthopaedic Association

PATRON: H.R.H. THE PRINCE OF WALES

THE MANAGEMENT OF NERVE INJURIES: A GUIDE TO GOOD PRACTICE

First published by the British Orthopaedic Association, 2011

The Management of Nerve Injuries:
A Guide from the British Orthopaedic Association

Preface

British orthopaedic surgeons have made immense contributions towards the treatment of all aspects of injuries to peripheral nerves. During the First World War Robert Jones established the principles and practice of rehabilitation and the treatment of paralysis by musculotendinous transfer. Five Special Hospitals dedicated to the treatment of nerve injuries were established soon after the onset of the Second World War. At Oxford, Seddon and his colleagues (Seddon 1954) carried out much fundamental and clinical research. This included nerve grafting , the rate of nerve regeneration, the effects of disuse, the regeneration of proprioceptors and emphasised that cover by healthy full thickness skin was essential for successful regeneration after nerve suture or grafting. During the1950's, George Bonney and his colleagues defined the nature and the prognosis of lesions of the supraclavicular brachial plexus and in 1956 he introduced, at St Mary's Hospital, a policy of emergency repair of artery and of nerve in severe injuries.

Our material is drawn from the study of 3600 cases of compound nerve injury operated at St Mary's and Royal National Orthopaedic Hospitals during the years 1965 to 2007 and from the many patients referred to the clinics at those hospitals. Many colleagues, from Plastics and Neurosurgery, as well as Orthopaedics in other British units have provided important and extensive experience. It is notable that the best results that we have seen after repair of the radial, the sciatic and the common peroneal nerves were achieved by orthopaedic surgeons during emergency operations, often working in circumstances which were not ideal.

This Blue Book has three objects. The first is to provide advice and assistance, and no more than that, to the fracture surgeon faced with a nerve injury complicating skeletal injury. The book is not prescriptive; there are no flow charts, no algorithms, the decision must always be left to the judgement of the surgeon on the spot.

The second purpose is to assist towards the prevention of iatrogenous injuries. One hundred and eighty six patients from the 2330 seen during the years 1965-1998 suffered iatrogenous injury to a peripheral nerve, that is 8%. There were 323 such injuries amongst the 1271 patients seen since 2000, that is 25.4%. About one half of nerve palsies in fractures or dislocations of the elbow in children were inflicted during treatment. There has been an increase in the numbers of cases of avoidable post ischaemic fibrosis affecting the leg and foot from unnoted injury to an artery or from a neglected compartment syndrome (Birch 2007).

The third purpose of the Blue Book is to emphasise the importance of rehabilitation. Lesions of the radial and of the common peroneal nerves are particularly disabling, they may cost younger patients their jobs and imperil the independence of older patients. It is the central responsibility of the fracture surgeon to ensure that the cause of neuropathic pain is diagnosed and treated adequately, that fixed deformity is prevented, that appropriate functional splints are provided and that the progress to recovery is carefully monitored so that the nerve injury can be corrected or the appropriate musculo tendinous transfers may be performed at the right time.

INTENDED READERSHIP

This booklet is intended *mainly* for trauma and orthopaedic surgeons dealing with orthopaedic trauma and elective orthopaedic surgery where nerve injury may occur. It is also intended as a referral guide for *any* surgeon dealing with such injuries.

ORGANISATION OF THE BOOK

- This booklet is deliberately short to give easy access to information.

- The main sections are:

1. Urgent Nerve and related Vascular Injury Management-in the first 48 hours

All staff, medical and nursing, should have a high index of suspicion to detect nerve injury – and a possible associated vascular injury - after an injury or after an operation.

Examination at First Review

A good knowledge of nerve anatomy is important. All clinicians should use 'Aids to the Examination of the Peripheral Nervous System' 4th edition (Elsevier).

Careful examination and recording of nervous and vascular system findings is crucial and mandatory prior to intervention.

Sensation is best tested by comparing light touch with the normal side. Any difference, even slight, suggests an injury.

Using the phrase 'does it feel *the same* as the normal side?' is important. If the answer is 'no' then presume nerve injury.

- Seemingly normal sensation distal to a recent wound does not exclude a nerve injury.

- Impairment due to alcohol or drugs, or partial conduction across a short gap or haematoma can give an incorrect impression of normal sensation; where there is doubt, repeat examination in 24-48 hours is indicated.

- Tinel's sign, which can usually be detected on the day of injury in closed lesions, implies that the axons are ruptured. A Tinel sign which progresses distally in the ensuing weeks shows that axons are regenerating (Kato and Birch 2006)

- Skin which is red and dry indicates interruption of sympathetic fibres in the nerve supplying that skin. The lesion is one of degeneration (axonotmesis or neurotmesis) and cannot be one of conduction block.

- If a laceration is deep and near a nerve, exploration of the nerve, preferably in an operating theatre should be undertaken.

- Capillary refill does NOT exclude a vascular injury that could require urgent operation. Only a palpable pulse or a positive Doppler signal comparable to the opposite side can exclude a vascular injury. If there is a difference from the normal side, arterial exploration must be considered. A normal pulse does not exclude proximal bleeding nor a compartment syndrome.

- Weak palpable pulses or Doppler signals may persist after major arterial occlusion. The hand or foot may appear to be viable in the presence of critical ischaemia of proximal compartments. A deepening neurological deficit, signifies critical ischaemia.

Initial Management of a Patient with an Associated Vascular Injury:

- Wounds or injuries with a possible vascular injury need urgent liaison with a surgeon competent in vascular reconstruction in the limb. Muscle death can occur in 3-4 hours if circulation is not restored. Collateral circulation is rarely adequate in the acute situation.

- If an experienced surgeon is not immediately available, insertion of a silastic vascular shunt will temporarily restore circulation. This should be discussed with the definitive surgeon.

- Vein grafts must not bypass major pedicles to muscle groups. Collateral circulation will not develop in time, even if distal circulation is restored.

- The need for fasciotomy must be considered once circulation is restored.

Initial Management of a Patient with a Nerve Injury

- If a nerve injury is present with an unstable fracture or dislocation, *the urgent priority is reduction and fixation of the skeleton.* This will resolve many cases where nerve injury is caused by compression or instability.

- It is necessary to explore any clinically injured nerve that is intimately associated with a fracture to be fixed (eg. radial nerve / humerus, peroneal nerve/knee dislocation). The possible exception is the isolated axillary nerve in low energy gleno humeral dislocations. A disposable motor nerve stimulator is cheap and may aid identification of nerves.

- The Gustillo concept is useful; if there is a high-energy mechanism, gross soft tissue stripping, clinically, operatively or on imaging, then nerve rupture and need for early repair is likely. Equally, at exploration, it may be that the nerves are in continuity. Repair is then not needed but the point is at least proven. If recovery is slow, then at least it is known for sure that the nerves are not ruptured.

- When there is a sensory or motor deficit, advice from a surgeon experienced in nerve surgery may be helpful but should not delay fracture treatment.

- When a nerve is exposed at operation and observed to be injured, the extent of surgery depends on the experience of the surgeon, the complexity of the nerve injury and the surrounding wound, and the general condition of the patient.

- If the surgeon does not have the experience to carry out a definitive repair on a particular nerve injury, the nerve ends should be gently apposed with coloured sutures - or if not apposable the ends should be 'tagged'. The injury should then be discussed with or urgently referred to a surgeon experienced in nerve repair.

Management of a Neural Deficit after an Operation

- After an injury or an operation, regular and recorded examinations for nerve and vascular deficiency are essential.

- Awareness of whether a nerve block or a long acting local anaesthetic has been given is important. This should be clearly recorded in the operation notes

- All nursing staff and junior doctors should be aware of the importance of detecting a nerve compression or injury at an early stage; and how to carry out measures such as loosening bandages, dividing Plaster of Paris splints [to skin level] and gentle repositioning of a limb.

- If these measures are ineffective, an experienced member of staff should be alerted at once to decide whether urgent re-exploration is required.

2. Non-acute Nerve Injury Management: presenting after 48 hours: General principles

- Most nerve injuries in the upper limb associated with closed fractures recover spontaneously (Gelberman 2001). The prognosis is worse after dislocations, worse still if there is a wound and worst of all in complete palsies in the lower limb.

- Many favourable lesions are incomplete or they are a mixture of conduction block and axonotmesis and clinical evidence of regeneration or recovery is usually evident by six weeks.

- Seddon (1975) gave good advice about nerves injured in the arm and at the elbow. Recovery may be awaited if two conditions are met: "the first is reasonable apposition of the bony fragments and the other complete certainty that there is no threat of ischaemia of the forearm muscles" He also advised that sciatic palsy in fracture of the femoral shaft should always be explored.

- If the surgeon elects open reduction and internal fixation of a fracture or dislocation in the presence of nerve palsy then the affected nerve must be exposed. The surgeon who does not do this is asking for trouble. The nerve may be trapped within the fracture or displaced into the joint and it will certainly be displaced from its normal position by bone fragments or haematoma.

- Nerve injury should always be suspected whenever a laceration, traction injury or a fracture occurs near a nerve.

- Careful sensory and motor examination including, the static and advancing Tinel's Test, should be carried out and recorded (see addendum section).

- After operation whenever a newly diagnosed sensory or motor loss is diagnosed - and does not resolve quickly – the possibility of a per-operative nerve injury or postoperative compressing haematoma should be considered. This indicates a need for early or urgent exploration and release or repair of a nerve. The painful nerve deficit is even more urgent than the painless one; treatable compression is the likely cause.

- *Where recovery is likely but not certain*, appointments should be made to ensure that regular examinations are carried out so that undue delay is avoided if surgery is required.

- If there is no clinical recovery by 6 weeks, neurophysiological investigations (NPI) are indicated within the following 2 weeks with a view to early exploratory or reparative surgery.

3. The Timing of Nerve Surgery

- There is strong evidence that very early surgery, either direct repair or grafting, promotes target reinnervation, nerve regeneration and neuromuscular function.

- Nerve transection causes distal axonal death and loss of retrograde neurotrophic support (from the distal stump as well as target organs). Extensive sensory neuronal death ensues, beginning within hours and peaking after 2 weeks. 30 to 70% of first order neurons will be lost within 2 months (Hart et al 2008). Motor neurones are particularly vulnerable in preganglionic lesions of the brachial plexus. Up to 80% of the relevant neuronal cell bodies have died by two weeks after injury ((Carlstedt 2007, Birch 2010)

- Repair or grafting is the only clinically applicable neuroprotective strategy currently available but must be performed early to be of any real benefit (Hart et al 2008). The earlier the cell body and proximal axon is reconnected to the Schwann cells in the distal stump, the better.

- For sensory neurons, the beneficial effect is halved by delay of more than 7 days. The window of opportunity is slightly longer for motor neurons. Surviving neurons also begin to lose their regenerative capacity after 6 weeks of disconnection from their end organs.

- In the near future, there may be a place for use of neuro-protective agents in the immediate emergency management stage. Recent animal studies suggest that acetyl - L- carnitine and N-acetyl cysteine reduce CNS cell death prior to nerve repair (Hart et al. 2008). Clinical trials are likely to start soon. The motor neurons may also be protected by similar strategies (Bergerot et al 2004)

- A delay of 2 months halves the number of axons crossing a repair and halves their rate of growth. This deteriorates further with longer delay. Motor end plate loss progresses even after repair and is near total after 1 year after proximal repair.

- Animal model studies have mainly involved low order species and sharp cut nerve lacerations, rather than crushing injuries; but these results have been confirmed on higher species with crushing injuries.

- *Numerous clinical series strongly support better results after surgery within 7 days, versus late repair (2 months or more).*

- The above applies to complete or partial nerve division, rather than axonotmesis. Clearly, in the clinical situation, it may not be easy to distinguish rupture from axonotmesis. In cases of high velocity injury and extensive soft tissue stripping (Gustillo grade 3), nerve rupture along its length or at its origin is much more likely.

- *The most common valid reason for delayed repair is associated major injury. Operation should be performed as soon as reasonably possible.*

4. Specific Upper limb nerve injuries

a) Cervical and other Spine Injury:

- A cervical spine injury takes priority over a brachial plexus injury. If both co-exist, care should be in collaboration with a spinal surgeon.

- A careful neurological examination is mandatory.

- Any suspicion of fracture or of any cord lesion requires urgent CT and or MRI scanning.

b) Brachial plexus nerve and possible vascular injury.

- A brachial plexus injury should be suspected after any motorcycle injury or severe trauma.

- Associated vascular injury should be suspected if there is bruising or significant swelling above or below the clavicle, *even if the hand has apparently good circulation.*

- Urgent vascular and nerve repair may be needed, preferably at the same operation.

c) Brachial plexus injury without vascular injury.

- Careful examination especially of the shoulder region is important.

- For brachial plexus injuries – especially those involving high-energy trauma or severe pain or muscle paralysis - early operation is usually required. Discussion with a plexus/complex nerve injury specialist within 2 days, or sooner if possible, is recommended.

d) Clavicle Fractures.

- Isolated clavicle fractures rarely cause injury to the brachial plexus.

- If a sensory or motor loss is present with a likely impinging fragment, urgent reduction and fixation of the fracture is indicated. As spontaneous recovery is usual, *reduction of the displacement should not be delayed* if a specialist surgeon is not available to explore the plexus at the same time.

- If recovery does not occur 48 hours after reduction, specialist advice should be sought.

e) The Floating Shoulder.

- There is a high risk of vascular and plexus injury in this uncommon injury. If present, urgent operation with internal fixation, vascular and nerve repair is indicated.

f) Shoulder dislocation and/or upper humeral fracture with an associated axillary nerve or plexus injury

- *Careful and recorded* examination of the deltoid muscle and all plexus innervated muscles, by testing for static contraction on admission, *and again* before and after MUA or operation is important.

- If a nerve injury is present when the patient is first examined and there is an associated dislocation, there should be no delay in reduction.

- If an urgent open reduction and fixation is being considered then ideally a surgeon experienced in nerve repair should be consulted; but this should not unduly delay reduction of the dislocation. The majority of isolated axillary nerve injuries in low energy dislocations recover. Exploration of the nerve is not usually needed unless there is neuropathic pain suggesting entrapment. If recovery is not progressing at 6 weeks, electromyography (EMG) of teres minor and the posterior deltoid is helpful. High energy injuries or those involving more of the plexus nerves are better explored acutely.

- It is important to examine for nerve injury again in the follow-up clinic: in particular for active contraction of the deltoid and the supraspinatus muscles (see addendum section), as complete rotator cuff tears can mimic deltoid paralysis. If there is doubt an urgent ultrasound or MR scan is required in case an urgent cuff repair is needed.

- Suprascapular nerve injury may occur in isolation or accompanying a rotator cuff tear and axillary nerve palsy. It is difficult to distinguish from an isolated cuff tear, as there is no sensory component. Ideally, the nerve should be explored as well as the above two structures (see section 6 for technique).

g) Humeral shaft fracture *with* radial nerve palsy.

- Careful and recorded examination for a radial nerve injury before MUA, or operation, and again afterwards is important in order to detect whether a new injury has occurred.

- The site of fracture is important. A mid shaft fracture is often associated with a recoverable lesion. Nerve rupture is more likely in a displaced distal shaft fracture because of tethering from the lateral septum.

- If operative exposure of a fracture is required the nerve should always be visualized and protected throughout the exposure. This must be checked before closure and documented in notes. It is only too easy to trap the nerve beneath a plate or damage it with a drill or screw. Urgent re-exploration is indicated in cases where the radial nerve stops working after operation, <u>unless the nerve was exposed and protected.</u>

- Exploration is wisest when the nerve stops working after an MUA, when there is neuropathic pain, or if the bone fragments are not apposed.

- If no MUA or operation is required, a ‘wait and see’ policy is reasonable in the first instance *as many radial nerve palsies will recover.*

- Regular examination by assessing whether there is an advancing Tinel’s sign and appropriate recovery in the proximal muscles.is indicated. Brachioradialis is usually the first muscle to recover.

- If there is no recovery at 6 weeks an EMG of the lateral head of triceps, brachio-radialis and extensor carpi radialis longus can reassure. If there is no EMG evidence of recovery at 6 weeks, and if Tinel's sign remains static at the level of lesion exploration of the nerve is indicated. The surgeon must ensure that adequate functional splints are provided.

h) Supracondylar fracture with vascular and/or nerve injury.

- A careful neurological and vascular examination is important.

- Capillary refill does not exclude a vascular injury.

- If there is impaired circulation ideally a surgeon with vascular experience should be advised before an MUA or operation in the unlikely event of normal circulation not returning after reduction of the fracture. *This should not delay fracture reduction.*

- If there is no radial pulse, the brachial artery may need exploration. Most often the artery requires only decompression of overlying fascia. Only very rarely is brachial artery repair needed. Mini fasciotomy of the forearm and direct examination of deep forearm muscles can be useful to reassure that there is no compromise of deep muscle circulation. This does not of course replace full therapeutic fasciotomy if this is considered necessary.

  A neural deficit alone, without vascular compromise is a difficult area. The nerve may be entrapped within the fracture and a deepening deficit suggests vascular compromise, even if not obviously apparent. Exploration of the nerve is a good option. On the other hand, some of these deficits recover spontaneously. If the surgeon elects to treat the injury by closed manipulation this must be followed by careful serial clinical examinations. If the surgeon elects internal fixation then the nerve which is not working MUST be exposed.

- The ulnar nerve is at risk when inserting (or removing) wires, or during fixation on the medial aspect of the elbow. Visualisation of the ulnar nerve is important during insertion or removal of K wires or metalwork.

- Care must be taken to distinguish between critical ischaemia and compartment syndrome in the upper limb with a supracondylar fracture of the humerus. They have an equivalent final common pathway of muscle death. However, fasciotomies in an ischaemic limb will not restore the circulation and brachial artery decompression alone will not save muscle and nerve at risk from compartment syndrome.

i) Forearm Fractures and nerve injuries

- Any nerve injury can occur but posterior interosseous nerve palsy is the most common. It occurs either at the time of injury or during surgical exposure of the proximal radius. If a motor deficit is present before a planned operation the nerve should be explored.

- If a motor deficit is present immediately after operation and does not recover with elevation of the limb and release of bandages and splints within two hours, re-exploration is needed, unless the nerve was explored and found to be intact at operation.

- Anterior interosseous nerve paralysis is relatively common after high energy proximal forearm fractures. It may be associated with ischaemia or compartment syndrome and can be one of the first warning features. Most isolated cases recover and those that do not can be treated by musculotendinous transfer. An observant approach is therefore reasonable.

j) Median nerve palsy associated with wrist or carpal injury.

- If a median nerve deficit is present on admission, reduction of the fracture and decompression of the nerve should be carried out urgently. After operation high elevation is important. If sensation does not begin to return within a few hours (taking into account a possible pre-operative nerve block) then urgent median nerve decompression should be carried out.

k) Lacerations over the superficial radial nerve at the wrist or forearm; palmar cutaneous branch of median nerve and dorsal branch of ulnar nerve:

- Lacerations of these cutaneous nerves can cause severe pain. Evidence of sensory loss distal to a laceration should always be carefully sought. These nerves should be repaired.

l) Digital nerve injuries.

- Injuries proximal to the trifurcation of the nerve should be repaired. Injuries distal to the trifurcation can be repaired using magnification but conservative treatment is a reasonable option. There is no reliable surface marking for the trifurcation but it is usually in the locality of the DIP joint.

5. Lower limb Injuries

General comments

- In general, lower limb nerve injuries have a poorer outlook than upper limb ones and are more sensitive to the effects of acute compression.

- Although their incidence is lower (as fewer nerves lie adjacent to bone), when they do occur, exploration and decompression is recommended.

- The sciatic nerve functions as 2 separate anatomical nerves running together. The physical bifurcation occurs anywhere from pelvis to distal femur. The common peroneal nerve (CPN) is more sensitive to injury. Isolated CPN deficit does not exclude injury at the hip.

a) The pelvis and lumbosacral plexus

- Neurological injury is present in around 8% of cases of unstable pelvic and acetabular fractures.

- These fractures should be reduced and fixed as soon as is practicable, accepting that a high proportion will require delay for stabilization of general condition.

- Accurate reduction, will often decompress the pelvic plexus and sciatic nerves. No extra attempt is usually made to decompress or perform neurolysis on the injured nerves.

- Reduction of complex ring and acetabular fractures requires accurate fixation which can not always be performed immediately after injury.

- -Closed reduction of a dislocated femoral head should be performed immediately, without delay or transfer. If a sciatic nerve paralysis or neuropathic pain persists after reduction, consideration should be given to entrapment of the sciatic nerve within the reduced joint. This is a complication requiring urgent sciatic nerve exploration.

- The vast majority of pelvic nerve injuries are in continuity and at least partial recovery occurs in 50 % of cases, where good fracture reduction can be obtained. Outlook is worse in cases where reduction is poor or delayed. (Rodgers et al 2009a&b). Equally, a neurological. deficit should not force urgent fixation in non ideal circumstances, or by an inexperienced surgeon. The morbidity from poor fixation could easily be greater than that of a delayed intervention on a nerve.

b) The hip

The committee has studied the serious problem of neurological and vascular complications of arthroplasty of the great joints. We recommend this matter is considered within a Blue Book dedicated to these and other early complications, and that such events be recorded in the National Joint Registry.

c) The knee

- Dislocation of the knee has a high incidence of common peroneal nerve injury *and associated arterial injury* - which can present with intact capillary refill.

- The arterial injury is often an occult intimal tear that has a tendency to thrombose during prolonged procedures under tourniquet.

- If arterial imaging is not performed prior to bony or soft tissue reconstruction surgery, it is important to check doppler pulses immediately after surgery.

- For the acute presentation of dislocations with common peroneal nerve paralysis, we recommend formal exploration of the nerve at the time of ligament repair as soon as practicably possible.

- Nerve ruptures with loss of nerve length generally require nerve grafting. Delay before repair is particularly damaging. However, so much of the common peroneal nerve may have been damaged that grafting is not practicable. Nerve transfer is sometimes valuable, using the nerve to lateral head of gastrocnemius.

- *Lesions in continuity* may recover well without surgery to the nerve. Neurolysis may be required if there is no evidence of recovery clinically or by EMG by about 6 weeks. There may be a case for nerve grafting lesions where there is severe disruption and probable rupture within the epineural sleeve.
-
- Recovery following traction injury of the common peroneal injury progresses very slowly. Electromyography is useful in detecting early regeneration. Prevention of fixed deformity, of skin ulceration and appropriate splinting is the responsibility of the surgeon.
- *Posterior tibial nerve injuries* are rare. In cases presenting late, monitoring of Tinel's sign is useful; failure of progression being an indication for intervention.

- If arteries are explored in Gustillo grade 3 fractures, it makes sense to examine the accompanying nerves. Decision to amputate or reconstruct is rarely if ever influenced by the nerve injury.

d) The foot and ankle

- Nerve injuries are unusual in foot and ankle trauma. The principles relating to other body areas apply. Nerve palsy may result from intrinsic muscle compartment syndrome.

6. Operation-Related Nerve Injury

- Fractures, haematomas, chronic deformities and fibrosis can displace nerves from their normal positions. A motor nerve stimulator is useful.

- The relative inexperience of training and junior surgeons, sub-specialisation and a low priority for teaching detailed anatomy contribute to operation related nerve injury.

- It must be accepted that nerve injury during operation may occur in spite of due care. Early Recognition and prompt remedial action after the event are the keys to a good outcome.

- The supposed benefits of limited access surgery need to be balanced against the increased chance of nerve injury. Surgeons carrying out such operations should always bear in mind the proximity of main nerves and vessels which may have been displaced from their usual position.

- Cross sectional limb anatomy charts should be placed in operating theatres.

- Detailed training of regional nerve anatomy and safe approaches should be included in those courses that address techniques of fixation and implant design.

- Organisers of undergraduate training must be made aware of the effects of reduced anatomy training for all future doctors.

- Safe positioning and protection of limbs during operation and other manoeuvres is needed to avoid injury.

- Injury to cutaneous nerves is often not recognised, delaying effective treatment.

- If a nerve is cut during surgery, immediate repair will often lead to a good recovery. Simple epineural suture should be performed. If this is not possible, then it is the responsibility of the operating surgeon to seek urgent assistance.

- *Painful* postoperative paralysis must be explored urgently. Release of a bone fragment, suture or implant compression can be highly effective. Any delay can have serious long-term consequences. Equally, the risk of sepsis, resulting from early re-exploration must be balanced against the benefit for the nerve. Documentation of exploration and status of nerves at primary surgery, particularly prior to wound closure is critical. If it is clear that a nerve has been explored, released and is not impeded by metalwork but is still paralysed post operatively, expectant repeat observation is reasonable in the absence of neuropathic pain.

- In minimal access surgery, incisions should be big enough to ensure that a nerve is not in the field. Exploration and identification of the nerve itself is not essential but should be carried out where a nerve is at particular risk from displacement by a fracture or an unusual anatomical position.

- Short incisions are long on difficulty.

- It is all too easy to strangulate small cutaneous nerves with sutures. Subcutaneous closure in areas where small superficial sensory nerves are known to occur is best avoided unless they have been specifically identified.

- Recognition of operation related nerve injury in the post-operative period is essential. Surgeons must insist upon adequate post operative review and follow up. (Cannon 2009).

Specific Nerves

a) Axillary nerve

- Arterial bleeding inferior to the humeral neck implies damage to circumflex vessels and that the quadrilateral space has been entered. This acts as a warning that the axillary nerve is in imminent danger. It's position can be confirmed just inferior to the lower border of subscapularis. If in jeopardy, it can be visualized, rather than just palpated.

- Be wary of deltoid splits more than 4 cm distal to the acromion. A deltoid split is not extensile, if distal access is needed, a second deltopectoral approach is possible and safer. The terminal branches can be visualized by partially releasing the distal insertion of deltoid.

- Plating the upper humerus is now popular. It is necessary to pass the plate deep to the axillary nerve that can be visualized as above.

b) Suprascapular nerve

- The suprascapular nerve is at risk from extensive efforts to repair the rotator cuff tendons. It is not often necessary to explore it but if needed, it can be found by sub-periosteal elevation of the trapezius from the upper border of the clavicle 2 cm lateral to mid shaft. The scapular notch is then palpable through investing fascia. The nerve enters the notch and can be traced proximally up to the upper trunk of plexus.

c) Musculocutaneous nerve

- This can be palpated deep to the conjoined tendons (via lateral border) and an abnormally high take off may be identified. The nerve is not actually visible, but can be palpated and it's position confirmed. Blind passage of slings deep to the coracoid or placement of deep retractors without this manoeuvre will not ensure that nerve injury is avoided. The origin and course of the nerve is variable. It arises from the lateral cord at different levels – it may even spring from the median nerve.

- The brachial plexus is vulnerable to injury in the dislocated / unstable shoulder. If possible, reduce and stabilise the joint before exploring the nerves.

d) Radial nerve

- This may be interposed in the fracture when it is at risk during closed nailing of the humerus. If in doubt, an adequate exposure will identify this, closed nailing will not. Its fascial constraint is often ruptured in trauma and it may cross the lateral humerus well proximal to its normal relation to the lateral intermuscular septum.

- It can be difficult to find in the distal arm — if it cannot be identified, find the top end of the superficial radial nerve below the elbow and trace it proximally.

e) Posterior interosseous nerve

- Hold the forearm in pronation. Subperiosteal elevation of supinator (Boyd approach) protects the nerve and it is not essential to view it. If you want to see it, use an anterior approach and find it lateral to biceps tendon, deep to recurrent radial artery.

f) Ulnar nerve at elbow

- It is easier to palpate in acute trauma when it looks like a stick of stewed rhubarb. The best place to find it is postero-superior to the medial epicondyle deep to the deep fascia, posterior to the medial intermuscular septum.

g) Superficial palmar branch of median nerve

This lies on the ulnar side of the sheath of FCR tendon—dissection through and deep to the sheath protects it. The majority of anomalous sensory and motor branches of the median nerve lie on the radial side of the main nerve—perform neurolysis or deep dissection on the ulnar side of the main nerve.

h) Radial digital nerve to the thumb

It crosses the thenar eminence obliquely. The same area holds the palmar arterial arch and the motor branch of median nerve. This hazardous area can often be avoided by passing fixation devices / soft tissue grafts deep to the plane of the neurovascular bundles.

Lower Limb

- Percutaneous surgery around the knee for tendon graft harvest is commonplace. Surgeons must be familiar with detailed regional neuro-anatomy.

- The infra-patellar branch of saphenous nerve is vulnerable from knee arthroscopy portals or hamstring tendon harvest; oblique or transverse portal incisions made with the knee in flexion reduce chance of injury.

- Meniscal repair can damage saphenous nerve / branches (medial) or common peroneal (lateral). All inside techniques are safer. If outside assisted sutures are used the relevant nerves should be identified and protected.

- In high-energy knee injuries, the common peroneal nerve is often stripped from its attachments and may lie surprisingly superficial within the subcuticular fat. It is vulnerable in the skin incision.

- The posterior tibial nerve and artery, superficial and deep peroneal nerves are more vulnerable in the distal end of deep posterior tibial compartment, where they lie close to the overlying fascia. Care is needed during percutaneous lateral tibial plating, fasciotomy and ankle surgery.

- Most of the vulnerable cutaneous nerves in the foot lie immediately adjacent to veins. The vein is more obvious than the nerve. Examples are: sural nerve and short saphenous vein, medial branch of saphenous nerve and vein over the first metatarsal.

- The superficial peroneal nerve may be palpable on passive flexion of the 4^{th} toe and should be identified for planning ankle arthroscopy portals.

7. Compartment Syndrome

- The diagnosis and management of pure compartment syndrome, uncomplicated by arterial or nerve injury is well documented.

- A mixed picture with arterial and or nerve injury is much more challenging diagnostically and therapeutically.

- Nerve injury may mask ischaemic pain and arterial injury may cause deepening of the initial neurological deficit. Equally, vascular injury causes deepening neurological defect which may mask compartment syndrome. Diagnosis can be difficult and a high index of suspicion is essential.

- Compartment syndrome must be considered in any case of neurological deficit after trauma. Detailed motor and sensory examination (in the conscious patient) must be performed and compared with the initial index assessment.

- If the nerve deficit deepens or is more generalised than the initial nerve deficit, secondary compartment syndrome is highly likely. This is of particular relevance if the plan is to refer the case to a specialist centre, as delayed decompression could lead to loss of a limb.

- Pulses are preserved and present in a pure compartment syndrome. We recommend supplementary assessment of pulses with Doppler ultrasound in this type of case. Any partial diminution of signal, compared to other uninjured limbs indicates reduction of arterial flow and perfusion.

- If in doubt, the safe option is stabilisation of the fracture, exploration of the relevant neurovascular bundles and compartment fasciotomies.

- Compartment pressure measurement or monitoring is of great use, particularly when the conscious state is reduced. Readings must be taken in context of the clinical picture and current blood pressure.

- Limited diagnostic fasciotomy of the forearm compartments may be of use, particularly for children's supracondylar fracture, where the hand is pink but pulse pressure diminished. If the deep muscles are healthy and contractile, this reassures that arterial exploration is not immediately needed. Subcutaneous fasciotomy of the forearm in cases with a marginal indication for fasciotomy is also reasonable, with very close post-operative observation.

- In the lower limb, formal fasciotomy of all 4 compartments through 2 incisions is the reliable safe option.

8. Blast Injury: The Military Experience

Modern war wounds are predominantly caused by explosive devices and 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 the norm and meticulous attention to debridement as a part of time limited resuscitative surgery is essential.

- Surgery of the ballistic wound is a phased process. The first operation is critical for the removal of contaminated and devitalised tissue and it profoundly influences the outcome. A low threshold for decompression of muscle compartments is adopted. Vascular injuries are repaired or temporarily shunted and fractures are stabilised using external fixation, skeletal traction or plaster immobilisation. Divided nerves and tendons are trimmed and tagged to the adjacent wound bed with a fine suture to aid the later identification and repair.

- Once haemostasis is obtained, the wounds are dressed with dry, fluffed gauze and left for up to five days, when delayed primary closure (DPC) of the wound may be possible. Essential elements of modern battlefield orthopaedic surgery include:
    - Time limited procedures – operations are restricted to the identification and correction of life and limb threatening injuries
    - Rapid fracture stabilisation
    - Control and repair of major vessels and extensive decompression
    - Early and vigorous resuscitation with blood products
    - Control of pain by high doses of opiates and continuous peripheral nerve block by the infusion of local anaesthetic through catheters placed adjacent to main nerves proximally.

More than one half of nerve injuries are prolonged conduction block. Recovery of plantar sensation through lesions in continuity of the tibial nerve is usual. Anaesthetic plantar skin is NOT an indication for amputation. The principles governing the repair of transected nerves in these wounds include:

- Repair, whether by suture of by graft, is carried out as soon as the patient's general condition and the condition of the wound permits.
- Although recovery of function is limited by the extent of destruction of target tissues it is rather better than that seen following repair of nerves ruptured in closed traction lesions.
- The repair must be covered by healthy full thickness skin and the nerve operation may have to be deferred until this has been achieved. It is essential that the artery supplying the flap does not bypass the main arterial pedicle of any major muscle group.
- Complex reconstruction of the wounded limbs is usually necessary and this is undertaken within the framework of an early and vigorous programme of rehabilitation.

9. Special Investigations

Neurophysiological Investigations (NPI)

This is a most useful adjunct to clinical assessment. Both motor and sensory pathways can be assessed from CNS to end organs. It may also be used intra-operatively, either simple motor distal stimulation, or complex proximal sensory stimulation. It has the following, well defined indications but equally should not be used as an excuse for delaying surgery when it is clearly indicated on clinical grounds.

- The demonstration of conduction across the site of the nerve lesion on the day of injury or at any time thereafter, indicates that some of the nerve fibres are intact.
- The persistence of conduction in the nerve trunk distal to the lesion at an interval of about seven days or more after the injury, that is after Wallerian degeneration has occurred, proves that the lesion is one of conduction block
- Examination by EMG of appropriate muscles at the appropriate time after injury may reveal reinnervation before that is clinically apparent. The investigation is best performed at about six weeks after injury. The teres minor and posterior deltoid are examined in cases of axillary palsy, the three heads of triceps in high lesions of the radial nerve and the brachio radialis in intermediate

lesions of that nerve, the peroneus longus and tibialis anterior in lesions of the common peroneal nerve.

- Examination by EMG is helpful in confirming the level of injury, particularly in distinguishing between injuries of the posterior cord and of the radial nerve and between high lesions of the common peroneal nerve and lesions of that nerve at the knee.

- NPI must not be used as a substitute for clinical examination nor should delay in obtaining them be used as an excuse for procrastination.

- Intraoperative studies of conduction across lesions may help in distinguishing those which will recover on their own from those which will not.

- The study of the central pathway, from the exposed nerve to the central nervous system is particularly helpful in the analysis of traction lesions of the supraclavicular brachial plexus.

MRI

- Recent improvements have led to greater accuracy of distinction between nerve injury in continuity and rupture (particularly in the brachial plexus), and to diagnose brachial plexus root avulsion.

- This is highly dependant on the type of scanner and reporter skills. MRI should not delay surgery but if clinically indicated may be useful for operation planning. Specifically, apparent continuity of nerves on MRI or root avulsion DO NOT preclude surgery.

- MRI may avoid the need for over extensive surgery. It will usually give a good indication of the linear extent of nerve damage, eg. above or below the clavicle (for plexus injury) and avoid routine exploration of uninvolved nerve segments.

- MRI will confirm muscle wasting from denervation when clinical examination is difficult but does not help with distinguish between axonotmesis and neurotmesis.

Ultrasound

- As with MRI, this is highly dependant on equipment (hockeystick probe) and reporter skills. As skills develop, it will undoubtebly have an increasing role in closed cases. Currently, it is of great use for relatively superficial nerves such as the common peroneal and radial. As yet, it is not applicable to deep nerves such as axillary or suprascapular. Ultrasonography may be very helpful in the detetction of expanding haematoma.

CT

- Diagnostically useful myelogram enhanced CT scanning is also equipment and operator dependent. Brachial plexus root avulsion, cervical cord haematoma or fractures may be demonstrated. CT scanning of pelvic and other complex fractures will often show bone fragment displacement at known areas of nerve compression eg. Sciatic notch, sacral foraminae and scapular notch.

Angiography

- Digital subtraction or MR angiography is especially valuable in the diagnosis of arterial injury

All of the above investigations aid decision-making but are of limited use. Apparently normal results should not distort clinical judgement. Equally, it is anticipated that further technical advances in imaging will further enhance the benefits from pre-operative MRI and ultrasound.

10. Epineural Suture

- Sharp lacerations of nerves if repaired early are usually apposable without tension.

- If there is there is delay of more than a few days the nerve may not be apposable without tension. A nerve graft may be needed. Protection of the distal suture line is secured by plaster of Paris splints.

- Direct repair of a nerve proximal to the elbow or knee needs protection for 3 weeks in a shoulder or hip spica, or appropriate sling. If there is doubt over tension, then a short nerve graft may be preferable.

- Sutures should be monofilament nylon or prolene with taper cut rather than round-bodied needles. 8/0 is good for digital nerves. Up to 5/0 may be needed for large proximal nerves with thick epineurium, such as the sciatic nerve. The first 2 sutures are placed at 3 and 9 o'clock positions of the nerve circumference. They are cut long, to be used as stay sutures to invert the nerve for repair of the posterior half of the circumference. The very first suture should be tied loose, to allow correction of mal-rotation with the second and subsequent sutures.

- Epineural repair alone is acceptable for proximal main nerves, such as the sciatic. Group fascicular repair, in which larger bundles or groups of bundles are coapted may by preferred in the median and ulnar and nerves at the elbow and wrist.

- Care is needed to avoid malrotation of ends, achievable by matching up epineural blood vessels. The principle is to close the epineural sleeve to allow axon sprouting and crossing of anastomosis without axonal escape through the epineurium leading to neuroma.

- Closed nerve ruptures need a graft with resection of the damaged segments back to healthy nerve tissue. There is usually reasonably clear demarcation between viable and traumatized nerve tissue in acute cases. If the demarcation is not clear cut in delayed cases, on table neurophysiology may help the decision where to resect. Many ruptures are very proximal or distal and very short stumps adjacent to the spinal cord or motor end plates permit little choice of level of resection.

- There are now many specialist techniques for the management of very proximal injuries. These include nerve transfers, vascularised grafts and implantation into the spinal cord (Carlstedt 2007, Birch 2010). These techniques are beyond the remit of this book.

Conclusions

We suggest that the following principles in the approach to nerves injured by skeletal injury:

- **Clinical examination and history of energy of injury often permits the distinction between lesions of conduction block (that will recover) from deeper, lesions that require surgery.**

- **A diagnosis of conduction block (neurapraxia) should not be made in the presence of significant neuropathic pain. Such pain suggests that a noxious agent is still at work upon the nerve and requires surgery.**

- **Deepening of the lesion whilst under observation indicates bleeding or arterial compromise until proven otherwise.**

- **The diagnosis of conduction block cannot be regarded as secure until the persistence of conduction in the distal segment of the nerve is demonstrated after about seven days from the injury.**

- **An advancing Tinel sign distinguishes axonotmesis from neurotmesis in the main nerves of the limb. This investigation should enable the clinician to come to a view about the likelihood of recovery at no later than six weeks from the injury. Unfortunately the axillary nerve cannot be examined by this method because it is so deeply seated.**

- **Lesions of the sciatic, the tibial and the common peroneal nerves are usually associated with high energy injuries. The likelihood of recovery in the untreated cases is generally low. These three nerves should always be exposed during operation upon the fracture or dislocation.**

- **If a surgeon elects to fix a closed fracture by whatever technique, then the nerve which is not working preoperatively should be exposed. The nerve and adjacent artery may be in the fracture or in the joint. Both will certainly be displaced from their normal position.**

- **Whilst the presence of nerve palsy is not necessarily an indication for operation the presence of a complete lesion of the main nerve adds to the argument for open treatment of the fracture.**

- **If a nerve is inadvertently divided during any operation, immediate epineural repair is the ideal. If the operating surgeon is unable to perform this, then repair by a colleague is very urgent.**

11. References

1. Aids to the examination of the Peripheral Nervous System, 4th edition, Elsevier.Ed: M O'Brian
2. Bergerot A., Shortland PJ., Anand P., Hunt SJ., Carlstedt T. 2004. Co-treatment with riluzole and GDNF is necessary for functional recovery after ventral root avulsion injury. *Exp. Neurol. 187 359-366*
3. Birch R., Surgical Disorders of the Peripheral Nerves 2nd edition, Springer-UK, 2010.
4. Birch R. Brachial plexus injury: the London experience with supraclavicular traction lesions. Neurosurg Clin N Am. 2009 Jan;20(1):15-23.
5. Blakey C.M , Biant LC, Birch R. The pink pulseless hand complicating supracondyler fractures of the humerus in childhood JBJS J Bone and Joint Surg (Br)2009 91.B:1487-92
6. Cannon SR. Quality of elective surgery in Treatment Centres. JBJS 91B: 141-2 editorial 2009.
7. Carlstedt,T. Central Plexus Injury, Imperial College Press 2007.
8. Hart A.M., Terenghi G., Wiberg M. "Neuronal death after peripheral nerve injury and experimental strategies for neuroprotection." Neurological Research 2008 Dec;30(10):999-1011.
9. Jivan S, Kumar N, Wiberg M, Kay S. The influence of pre-surgical delay on functional outcome after reconstruction of brachial plexus injuries. J Plast Reconstr Aesthet Surg. 2009 Apr;62(4):472-9. Epub 2008 May 16.
10. Kato N., Birch R. 2006**.** Peripheral nerve palsies associated with closed fractures and dislocations. *Injury 37: 507-512*

11. Medical Research Council Special Report Series No. 282. 1954**.** *Peripheral Nerve Injuries.* Ed: Seddon H J.. HMSO
12. Rodgers B., Pearce R., Walker R., Bircher M. Incidence and outcome of neural injuries following acetabular fractures. British Orthopaedic Association Scientific Meeting, Manchester, September 2009
13. Rodgers B., Pearce R., Walker R., Bircher M. Incidence and outcome of neural injuries following pelvic fractures. British Orthopaedic Association Scientific Meeting, Manchester, September 2009
14. Seddon HJ 1954 Nerve grafting In: *Peripheral Nerve Injuries by the Nerve Injury Committee of the Medical Research Council MRC Special Report Series 282. London HMSO. 402-403*
15. Siegel DB., Gelberman RG. 1991 Peripheral nerve injuries associated with fractures and dislocations In: Ed: RH Gelberman. *Operative Nerve Repair and Reconstruction.* J B Lippincott, Philadelphia. 619-633

LIMITATIONS OF OUR ADVICE

Nerve injury, associated with trauma or surgery is a complex biological process that is not ideally suited to dogmatic or proscriptive protocols. We write this document on the basis that it gives some practical, evidence-based advice on what are often difficult decisions for the treating clinicians. Our advice cannot replace the judgment of the experienced clinician and does not take account of the vagaries of current healthcare, where surgeons capable of expert definitive management may not be available within the time limits advised, and where there is often unacceptable delay in access to supporting diagnostic services.

AUTHORSHIP GROUP

Chair: Rolfe Birch, Previously Orthopaedic Surgeon St Mary's Hospital 1979-1991, PNI Unit RNOH 1979-2007 Current position: Consultant in Charge, War Nerve Injuries Clinic, DMRC Headley Court.

Leela Biant, Consultant Trauma and Orthopaedic Surgeon, Edinburgh, Dalton Boot, Consultant Trauma and Orthopaedic Surgeon, Warrington, Guy Broome, Consultant Trauma and Orthopaedic Surgeon, Carlisle, Andrew Hart, Consultant Plastic Surgeon ,Glasgow.

CONTRIBUTORS

Martin Bircher, Orthopaedic Consultant, London, Thomas Carlstedt, Professor of Neurosurgery, London, Matt Dawson, Orthopaedic Consultant Carlisle, Roderick Dunn, consultant Plastic surgeon, Salisbury, Major Will Eardley, RAMC, Gail Ferrier, Orthopaedic Consultant Carlisle, Michael Fox, Orthopaedic Consultant, London, Alister Hart, Orthopaedic Consultant, London, Tim Hems, Orthopaedic Consultant Glasgow, Keith Ions, Orthopaedic Consultant Carlisle, Simon Kay, Professor of Plastic surgery Leeds, Simon Lambert, Orthopaedic Consultant, London,Chris Moran, Professor of Trauma and Orthopaedics, Nottingham, Major Arul Ramasamy, RAMC, Marco Sinisi, Neurosurgeon London. Georgio Terenghi, Professor of tissue engineering Manchester, Stewart Watson, Consultant Plastic and Hand surgeon, Manchester. Ahmed Malik, Keneth Mannam, Hesham Al-Khateeb, previous SPR's RNOH.

Formating, Kirstin Robinson SCP, Carlisle, Asef Alani, Northern Training Rotation.

British Orthopaedic Association
35-43 Lincoln's Inn Fields
London WC2A 3PE
Rel: 020 7405 6507
Fax: 020 7831 2676
secretary@boa.ac.uk
www.boa.ac.uk