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# A practical approach to nerve injuries post regional anaesthesia

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Over the past 10 years, the interest in regional anaesthesia and its advantages has grown, with the use of ultrasound-guided techniques and catheter insertion becoming ever more popular.[1] This increased interest in regional anaesthesia has led to an increased number of peripheral nerve blocks (PNB) performed and therefore an increased number of complications[1]; improved reporting methods and registries may have also played a role.[2] Although the incidence of neurological damage after regional anaesthesia is rare, the effects may be devastating with resultant permanent disability.[2-5]

## Incidence of nerve injury after regional anaesthesia

The incidence of perioperative nerve injury is difficult to determine accurately. Postoperative neurological symptoms (PONs) are common after PNB, but are usually transient and rarely result in permanent disability.[1,2]

Initially all data regarding nerve injuries associated with the use of PNB were obtained from the closed claims analysis. Multiple reports have shown a varying range, most estimating an incidence of 0.5–1%.[5] A report by Cheney, et al.[6] in 1999 showed that 16% of claims resulted from nerve injury, with the ulnar nerve most frequently injured (28%), followed by the brachial plexus (20%), lumbosacral nerve roots (16%) and the spinal cord (13%).[6] In 2004, the same group published that permanent nerve injuries accounted for 19% of regional anaesthesia claims with lumbosacral nerve root injuries and paraplegia being the most common.[7] Studies have shown that peripheral nerve injuries (PNI) after regional anaesthesia are low at 0.21–0.4%.[1,8] NYSORA suggests that anatomic location of the PNB plays a role in the risk of PNI – 0.3% for femoral blocks and up to 3% for interscalene blocks.[4]

Of interest, the risk of nerve injury may be more common after general anaesthesia; Lynch, et al.[9] observed an incidence of 4.3% for severe neurological complications.[9] These studies show that patient positioning is perhaps the most important risk factor for neurological complications during anaesthesia. Interestingly, the reported incidence of long-term neurologic symptoms using ultrasound guidance is similar to the incidence using peripheral nerve stimulation, 2–4 per 10 000 blocks.[2]

The Second ASRA Practice Advisory on Neurologic Complications Associated with Regional Anaesthesia and Pain Medicine[2] has added a section on the rate of neurologic complications related to common orthopaedic surgical procedures; a reminder that PNI may be multifactorial, associated with direct nerve trauma, positioning, stretch, retraction or compression.[2] Arthroscopic shoulder surgery is associated with nerve injury in 0.1–10% of cases, usually from surgical traction.[2] Seventeen percent of patients having shoulder replacement surgery may develop a transient, diffuse brachial plexus injury.[2] An incidence of 1% has been reported in patients undergoing total hip arthroplasty, usually from compression and traction retractors and intraoperative manipulation.[2] The incidence of PNI following total knee arthroplasty is significantly higher, 0.3–9.5%, with prolonged tourniquet times playing a role.[2]

## Histology of peripheral nerves

Nerves are formed by a collection of fascicles, comprised of nerve fibres or axons, that are supported and surrounded by the semipermeable perineurium, a tough squamous epithelial sheath. The epineurium, a loose collection of collagen fibres, surrounds the perineurium and is easily permeable.[4,5]

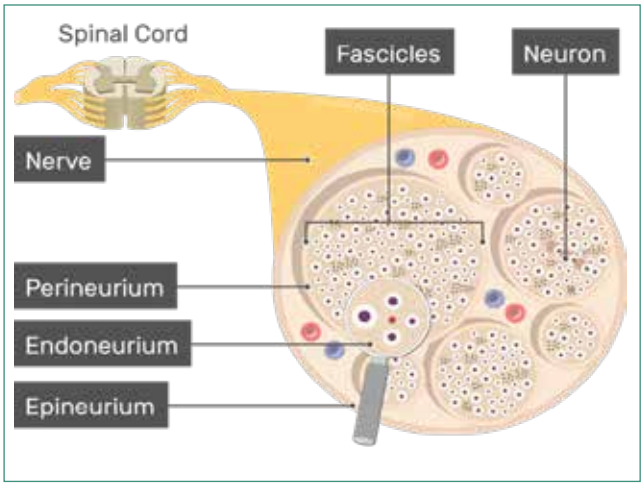



**Figure 1.** The structurte of a peripheral nerve

## Pathophysiology

Multiple mechanisms are involved in causing neural damage with the aetiology incompletely understood. PNI can occur when the nerve is exposed to stretch, compression, hypoperfusion, direct trauma, exposure to neurotoxic substances, pressure effects of the injected local anaesthetic or a combination of these.[4,10] The resultant histopathological disruptions range from impaired axoplasmic transport, axonal degeneration, Schwann cell damage, myelin destruction, segmental demyelination and complete Wallerian degeneration.[10]

### *Pathology of peripheral nerve lesions*

There are three recognised types of peripheral nerve injuries, classified according to the degree of functional disruption:

1. Neuropraxia (axonal sideration): a mild, reversible degree of neural insult with intact axons and connective tissue structures.[1,4]
2. Axonotmesis (axonal interruption with sheath preservation): physical disruption of the axon with preservation of the endoneurium and other supporting connective tissues. Regeneration usually begins after six weeks. This injury is most commonly associated with positioning and stretching of the plexus, but may also be associated with use of toxic drugs or a high concentration of local anaesthetic.[1,4]
3. Neurotmesis (fascicular interruption): completely severed nerve including disruption of the axon and all the supporting connective tissues with a poor recovery.[1,4]

### *Mechanisms of nerve injuries*

The development of PNI appears to be multifactorial; a combination of mechanisms is usually required for nerve damage to occur.

1. *Needle trauma and injection site*

   The site of local anaesthetic injection within the nerve may damage the microarchitecture to varying degrees, with intraneural and intrafascicular injection the most damaging.[10] This is due to exposure of the axons to an inflammatory process, local anaesthetic-induced toxicity and harmful direct mechanical damage.[11,10] However, studies suggest that intraneural needle placement does not lead to an imminent neurological injury.[4] The perineurium is a tough, poorly distensible multilayer epithelial sheath that does not compensate to an increased intrafascicular pressure and therefore may result in ischaemia and inflammation.[2,4] Several studies comparing blunt versus sharp needles showed that blunt needles were less likely to enter the fascicles, but would cause more damage once entering the fascicle.[4,5,12-14]

2. *Neurotoxicity of local anaesthetics*

   The mechanism of action of a neural block demonstrates that all local anaesthetics are potentially neurotoxic[15,16] with the ability to reduce neural blood flow.[4,17,18] Risk factors include a high concentration of local anaesthetic and the use of adrenaline.[1,18] Several animal studies report the neurotoxic potential of local anaesthetics.[11,19-21] Proposed mechanisms for this toxicity involve altered calcium homeostasis with increased cytoplasmic calcium concentration reaching toxic levels,[1,4] disturbance in mitochondrial function, disruption of the membrane phospholipids and cell apoptosis.[4] The various local anaesthetics have different potential for neurotoxicity with ropivacaine having the least potential.[1]

3. *Physical stress and ischaemia*

   Nerves are fragile structures and must be handled with care. Rat studies have shown that local anaesthetics decrease blood flow to nerves.[5] Some of the most important risk factors for neurological complications during anaesthesia are patient positioning and manipulation.[22] Chowet, et al.[23] showed that leaving the wrist in extension after intra-arterial catheter placement for 30– 60 minutes resulted in a transient conduction block of the median nerve.[23] It is of the utmost importance to prevent stretching, traction and compression of nerves during any procedure.

4. *The role of additives*

   A common practice used to prolong the duration of a PNB and to decrease the concentration of local anaesthetic is to add adrenaline.[4] The addition of adrenaline 1:100 000 has been shown to reduce nerve blood flow by 35%[18] and increases the penetration of local anaesthetics into the nerve.[1] Another concern is that the effects of combining the local anaesthetic with adrenaline are additive with the potential to decrease neural blood flow by 80%, but the clinical effects are unknown.[4,17]

## Risk factors[10]

The risk factors for the development of PNI can be divided into anaesthetic, patient and surgical factors. Several large retrospective reviews have shown that postoperative neurological symptoms are independently related to both patient and surgical risk factors and not to the PNB itself.[2,10,24]

Intrafascicular injection should be avoided, despite poor evidence of resultant nerve injury.[2] Nerves with an increased neural tissue to connective tissue ratio e.g. proximal plexuses versus distal nerves are more susceptible to injury.[2,4]

Preexisting neuropathies and other neurologic conditions increase the risk of PNI 10-fold, whether hereditary, metabolic, toxic or entrapment syndromes[2]; they are more vulnerable to an increased block duration and local anaesthetic toxicity.[5] The "double-crush" theory suggests that preexisting neuropathies result in an increased susceptibility for further nerve damage from a secondary, albeit low-grade, insult.[2] Other anaesthesia- and patient-related factors include established peripheral neuropathy, preexisting subclinical peripheral neuropathy, profound hypothermia, hypovolaemia, hypotension, hypoxaemia, electrolyte disorders, malnutrition, small or large body mass index, tobacco use, anatomical variations e.g. cervical ribs.[10] Peripheral vascular disease, smoking, vasculitis, hypertension are independent risk factors.[2]

Certain surgical procedures can result in nerve damage from direct nerve trauma, manipulation or positioning with stretch and compression of nerves.[2] Surgical duration and the use of

pneumatic tourniquets, especially if of prolonged duration (> 120 minutes), can lead to diffuse sensorimotor deficits.[2]

## Presentation

Although many patients who have suffered a PNI may experience abnormal pain, weakness or sensation immediately following anaesthesia, nerve injury may only become apparent at a later stage, days to weeks after the procedure.[10] Typically, patients will only be aware of symptoms when the block has worn off, usually within 48 hours and may present with a range of symptoms, from light intermittent tingling to complete sensorimotor deficit,[3] either more marked than expected, recurrent or progressive.[2] Patients usually complain of decreased power and/or altered sensation such as paraesthesia, pain or persistent anaesthesia.[10] Minor symptoms may resolve within a few weeks, whereas severe nerve damage could result in permanent disability.[3]

Consider other potential causes of neurological symptoms, such as peripheral neuropathy secondary to diabetes mellitus, alcohol, hypothyroidism, nutritional deficiency, myelopathy, radiculopathy, spinal cord trauma or infarction and muscle disease.[10]

## Practical management – What do you do?

A few principles to remember when confronted with a postoperative motor or sensory deficit that outlasts the expected duration of the PNB performed are:

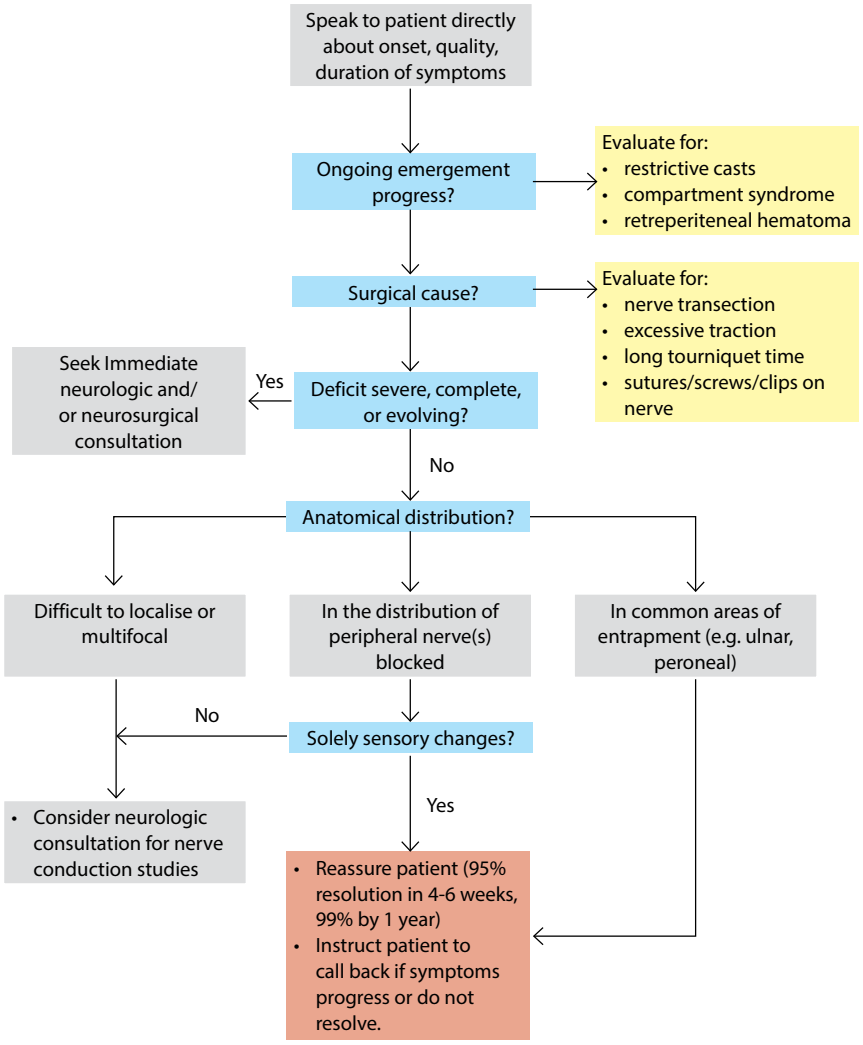
1. Good communication with the patient is of paramount importance. Support, reassure and inform the patient.[3,4,10]
2. Correct the underlying pathology, including surgical decompression if a space-occupying lesion is present. Surgical referral is recommended if there is severe axonal loss on EMG and no recovery at 3–6 months.[3, 10]
3. Alleviate symptoms using pharmacological agents, physiotherapy and orthotic measures such as splints and limb supports. These adjuncts will help prevent muscle atrophy and preserve range of motion and some function of paralysed joints.[3,10]

As with any complication, document the history of the symptoms, perform and document the findings of a complete systemic examination with a motor and sensory examination of all four limbs and the cranial nerves.

An attempt to exclude the differential diagnoses should be made; haematological investigations include a full blood count, renal and liver function tests, a blood glucose, and vitamin $B_{12}$ and thyroid stimulating hormone.[10] Ruling out potentially reversible causes e.g. compression from haematoma or dressings and casts and compartment syndrome is a priority.[2]

Referral to a neurologist and neurophysiologist who will investigate further is helpful and advisable; investigations may include targeted serum plasma analysis, ultrasound to exclude haematoma, nerve conduction studies (NCS), electromyography (EMG), magnetic resonance imaging (MRI) and nerve biopsy.[3,10] Nerve conduction studies and electromyography can give falsely reassuring results in the two weeks after the injury as neuronal degeneration is incomplete.[25,26] However, an early exam within 2–3 days of the onset of the injury can serve as a baseline and help determine prognosis and the duration of the lesion i.e. if the lesion was present before the nerve block was performed.[4] Electrophysiological changes are usually obtained four weeks after the injury.[4]

**Practical approach to management of a patient with neurologic deficit after peripheral nerve block**



A multidisciplinary approach to management should include early decompression of space-occupying lesions, pharmacological treatment of neuropathic pain, rehabilitation involving physiotherapists and occupational therapists, and referral to neurosurgeon/plastic surgeon if persisting at 3–5 months.[2] There is currently no pharmacological agent that effectively stimulates nerve regeneration.[3] Regeneration is a slow process; it occurs at a rate of one mm per day.

Electroneuromyography, incorporates NCS and EMG, is the standard to assess nerve damage after regional anaesthesia.[3] These investigations will help determine the presence of a deficit, localise the responsible lesion and define its severity and prognosis. However, they provide no information on the direct cause of the damage, but may help differentiate between the possible causes.[3]

## Interpreting electroneuromyography/ electrodiagnostic studies

NCS allows functional assessment of motor and sensory nerves with the ability or inability of the nerve to conduct an impulse. A conduction block occurs when there is loss of conduction across a lesion, usually a demyelinated area.[3] A demyelinated nerve is an axon that was previously myelinated; this is different to an unmyelinated nerve. If immature myelin has started regenerating, there will be a return of conduction but at a slower velocity.[3]

The action potential is a summation of many potentials. On a recording of action potentials, a few variables are assessed.[3]

a. *Latency:* The time it takes from stimulation of the nerve to measurement of the beginning of the action potential.
b. *Conducting velocity:* Shows how fast the nerve is propagating an action potential.
c. *Amplitude:* The amplitude is dependent on axonal integrity, as well as the muscle fibres it depolarises.
d. *Duration:* The time from onset latency to termination latency.

Clinical information obtained from NCS evaluates the localisation of a focal nerve lesion, severity of a nerve lesion (with possible prognosis), presence of underlying polyneuropathy and suggests whether the underlying pathological process is due to axon loss or demyelination.[3] Abnormal recordings may be seen within the first few days after a nerve injury.

Several different types of lesions can be identified. A complete lesion shows no elicited response in the muscles distal to the lesion. A smaller elicited response is noted in a partial lesion. If there is axon loss, the conduction velocity is minimally affected. A significant slowing of nerve conduction velocity or a conduction block indicate denervation or demyelination.[3]

EMG evaluates the electrical activity of skeletal muscle and measures the electrical activation of the muscle fibres.[3,26] The structure assessed is the motor unit, comprising of one anterior horn cell, its axon and all the muscle fibres innervated by that motor neuron.[3] It is useful in differentiating between myopathic and neurogenic muscle weakness.[26]

Clinical information obtained indicates whether weakness has a neurogenic basis, the extent of the nerve injury and the severity grade is defined. It also provides a guide to the onset time of the lesion.[3] EMG is useful in distinguishing between radiculopathies, plexopathies and neuropathies involving one or several nerves.

Features assessed are nerve response amplitude and conduction velocity along the course of the nerve. Sensory conduction studies are generally more difficult than motor conduction studies. Sensory neurons are excitable for up to 11 days after the injury, whereas motor nerves are excitable for up to seven days.[25]

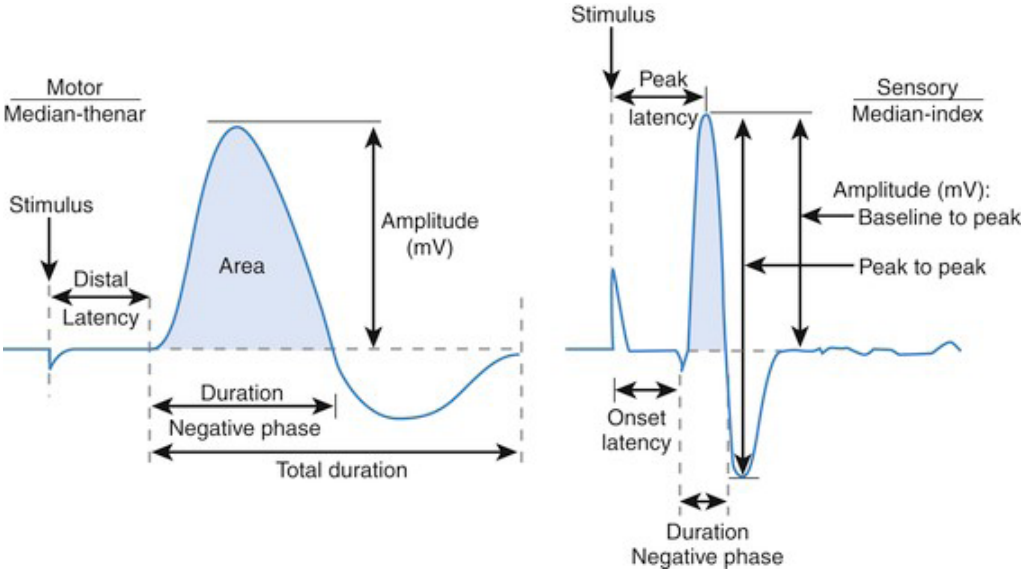



**Figure 2.** The action potential

**Table I.** Pathophysiology of nerve damage and neurophysiological findings[3]

| Pathophysiology | Key neurophysiological finding |
|---|---|
| Neuropraxia (conduction block) | MEP/SSEP altered<br>NCS and EMG remain normal over time |
| Axonotmesis (axonal degeneration) | MEP/SSEP altered<br>NCS and EMG show signs of partial damage |
| Neurotmesis (nerve degeneration) | All neurophysiologic recordings become completely abolished |

*Abbreviations:* EMG, electromyography; MEP, motor-evoked potential; NCS, nerve conduction study; SSEP, somatosensory-evoked potential.

## Prevention

There are multiple modifiable factors and techniques that may influence the risk of nerve injury following PNB. It is important to note that no single technique can prevent PNI and that several techniques should be used in combination.[2]

1. ***Nerve localisation***

   Clinical trials have failed to scientifically demonstrate the superiority of any single nerve localisation technique during needling; whether it is ultrasound guidance, nerve stimulation or elicited paraesthesia.[2,10, 27] Traditionally, pain on injection was said to be an effective and reliable clue.[4] This can be problematic as patients receiving regional anaesthesia may already have pain and discomfort in the area,[4] comorbidities may restrict pain perception e.g. diabetes mellitus,[4] and there is little evidence that this technique is sensitive or specific.[4] Further problems with relying on paraesthesia as a clue include terminating the injection once nerve damage has likely already occurred by the time the patient verbalises pain; needle-to-nerve contact is not reliably excluded, nor does it reliably predict PNI[2]; patients may be unable to verbalise pain e.g. heavily sedated, anaesthetised, paediatrics and mentally impaired patients.

   The use of paraesthesia and peripheral nerve stimulation to detect needle-to-nerve contact is difficult with a 38% and 75% chance respectively.[10] However, needle repositioning is required if there is paraesthesia or pain during needling or injection. Although not highly sensitive in detecting intraneural needle tip position, electrical nerve stimulation is highly specific when a motor response is elicited at $\leq 0.2$ mA[4]; however, intraneural needle placement and the intensity of the stimulating current, between 0.2–0.5 mA, to elicit a motor response do not correlate.[5]

   Ultrasound-guided regional anaesthesia is becoming standard practice providing real-time imaging of the target nerve and needle tip possible. The use of ultrasound increases the rate of success, the onset and quality of PNB and reduces the complications associated with regional anaesthesia[5]; however, it does not completely eliminate them.[2,27,28] A video analysis of ultrasound-guided blocks performed by trainees showed several reasons including failure to recognise the maldistribution of local anaesthetic, failure to identify the needle tip before injection, poor needle visualisation due to incorrect site insertion and angle and limited ability in identifying nerves and connective tissue[2]; showing that the use of ultrasound is operator-dependent and requires a good knowledge of anatomy. A more recent study of over 1 000 ultrasound-guided PNB showed similar results.[29] Research also suggests that the use of ultrasound reduces the total dose/volume of local anaesthetic required for the block. Research has shown that despite intraneural injection, neurologic damage may not occur.[4]

2. ***Timing of peripheral nerve block***

   The authors of a recent review article recommend performing PNB in conscious patients where possible,[10] despite paraesthesia reported by patients lacking sensitivity and specificity as a warning of nerve injury. The ASRA Practice Advisory, both in 2008 and 2015, recommend not routinely performing regional anaesthesia in anaesthetised or deeply sedated adult patients as they are unable to ascertain and verbalise any concerning sensations.[2,30] The benefit of a cooperative and immobile child likely outweighs the risk.[2]

3. ***Needle design and needling techniques***

   Direct trauma to the nerve fascicles may lead to nerve injury. Long-bevel sharp point needles may not produce paraesthesia as early as short-bevel blunt point needles; however, the histological damage is more severe with short-bevel needles.[10] Short, blunt-bevel needles are less likely to penetrate the tough perineurium.[5] Although most experts prefer short-axis, in-plane needling for most PNB, there is insufficient data to support the use of any specific technique.[10]

4. ***Injection pressure monitoring***

   In animal models, intrafascicular needle-tip placement is reliably shown with high injection pressures, greater than 170 kPa.[10] Histological findings of severe axonal damage are seen with high pressure injections.[4] Despite using the resistance to injection as standard clinical practice to evaluate injection pressure, evidence shows that anaesthetists are poor at judging injection pressure[2] and therefore in-line manometer devices have been developed, but not yet adopted.[4,10] Until such time, it is recommended to use large volume syringes (20 ml) when performing PNB,[10] a technique that appears to be more valuable as a negative predictive monitor.[2]

5. ***Local anaesthetic choice and adjuncts***

   Microscopic nerve fibre injury and oedema occur in a concentration-dependent manner when a local anaesthetic is applied to a nerve.[10] Local anaesthetics reduce neural blood flow and with the addition of adrenaline, this blood flow is reduced further with the potential of ischaemic axonal injury.[1,10,18] Ropivacaine is likely less toxic than other local anaesthetics[5] but has, however, been shown to cause histological damage in rodent sciatic nerves.[31] The addition of dexmedetomidine to bupivacaine appears to reduce neuronal toxicity – in rats.[10] Other adjuncts which have been shown to not increase neurotoxicity when used with ropivacaine are clonidine, buprenorphine and dexamethasone, whereas the addition of midazolam increases the neurotoxic potential.[10] The least concentrated solution of local anaesthetic to achieve an efficient block should be administered.[1]

6. ***Comorbidities***

   In a patient with imminent anticoagulation and/or the use of multiple anticoagulants avoid performing deep blocks.[2]

Avoid PNB if an improper aseptic technique is to be used or if the block will be performed in an area of active infection.[2] In patients with preexisting neuropathies, the risks and benefits need to be weighed for each patient. Careful documentation is required.

7. ***Blood pressure control***

   Avoid prolonged hypotension during neuraxial anaesthesia; this is defined as a decrease of baseline mean arterial pressure (MAP) by greater than 20–30% for 20 minutes or longer.[2] The risk of spinal cord injury is increased with certain surgeries e.g. aortic, cardiac spine, and with other risk factors e.g. atherosclerosis, hypertension, smoking.[2] Aim for a MAP of 60–65 mmHg to maintain spinal cord perfusion.[2]

8. ***Arterial tourniquets***

   If tourniquets are applied, they should be inflated to the minimal pressure that will provide the surgical field advantage: the patient's systolic blood pressure plus 100 mmHg for the upper limb and plus 150 mmHg for the thigh. The tourniquet should be deflated for 10–15 minutes after two hours. These are only guidelines and should be tailored to each patient.[10]

NYSORA provides an algorithm for monitoring while performing peripheral nerve blocks.[4]

## A short note on continuous peripheral nerve catheters

A new trend in pain control, continuous peripheral nerve catheters (PNCs), provides better pain control, higher patient satisfaction, dramatic reduction in postoperative nausea and vomiting, decreased side-effects of systemic opioids, faster functional recovery, shorter hospital stay and positive effects on surgical outcome.[1,5] However, there are few studies assessing the complications and management of PNCs. Gasparini, et al.[32] showed that operator skill is necessary to limit the number of attempts.[32] Complications of PNCs include catheter kinking, knotting and looping; entrapment requiring surgical removal; localised inflammation and infection, bacterial colonisation, abscess formation and sepsis; and accidental vascular puncture, bleeding and haematoma formation.[5] The American Society of Regional Anesthesia has recently published the fourth edition of their guidelines on regional anaesthesia and anticoagulation therapy – deep and non-compressible plexus/peripheral nerve blocks should be treated the same as neuraxial blocks.[33]

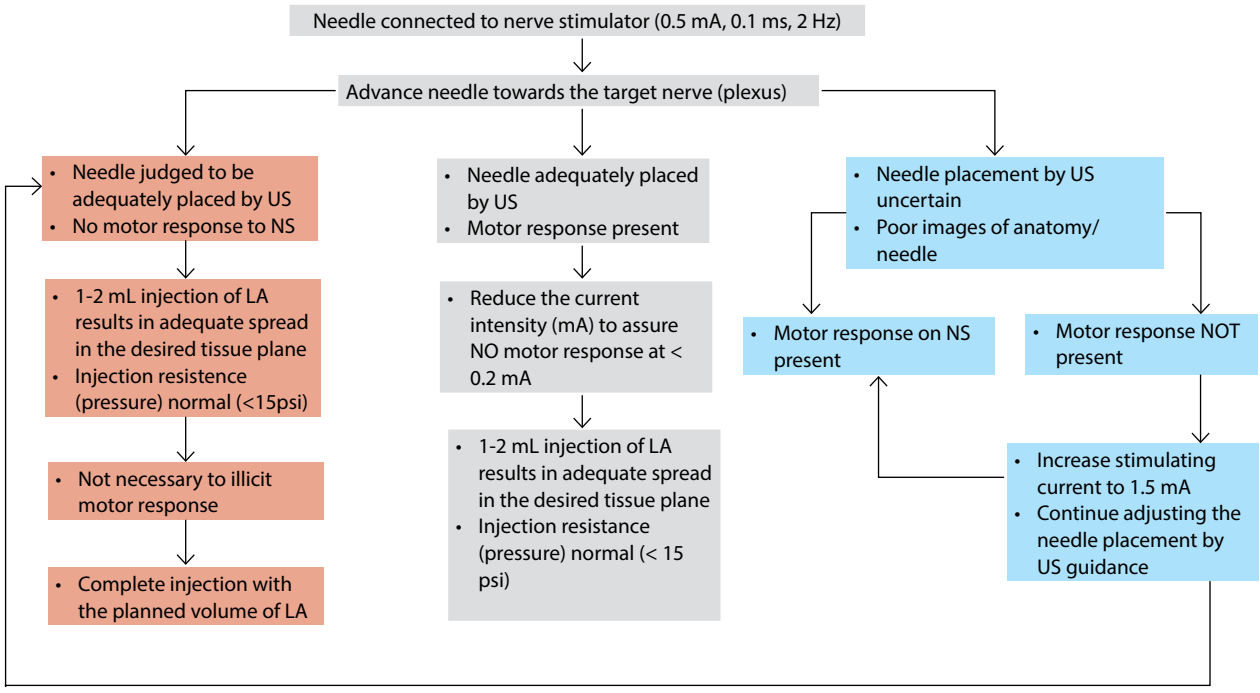
## Last but not least: Consent

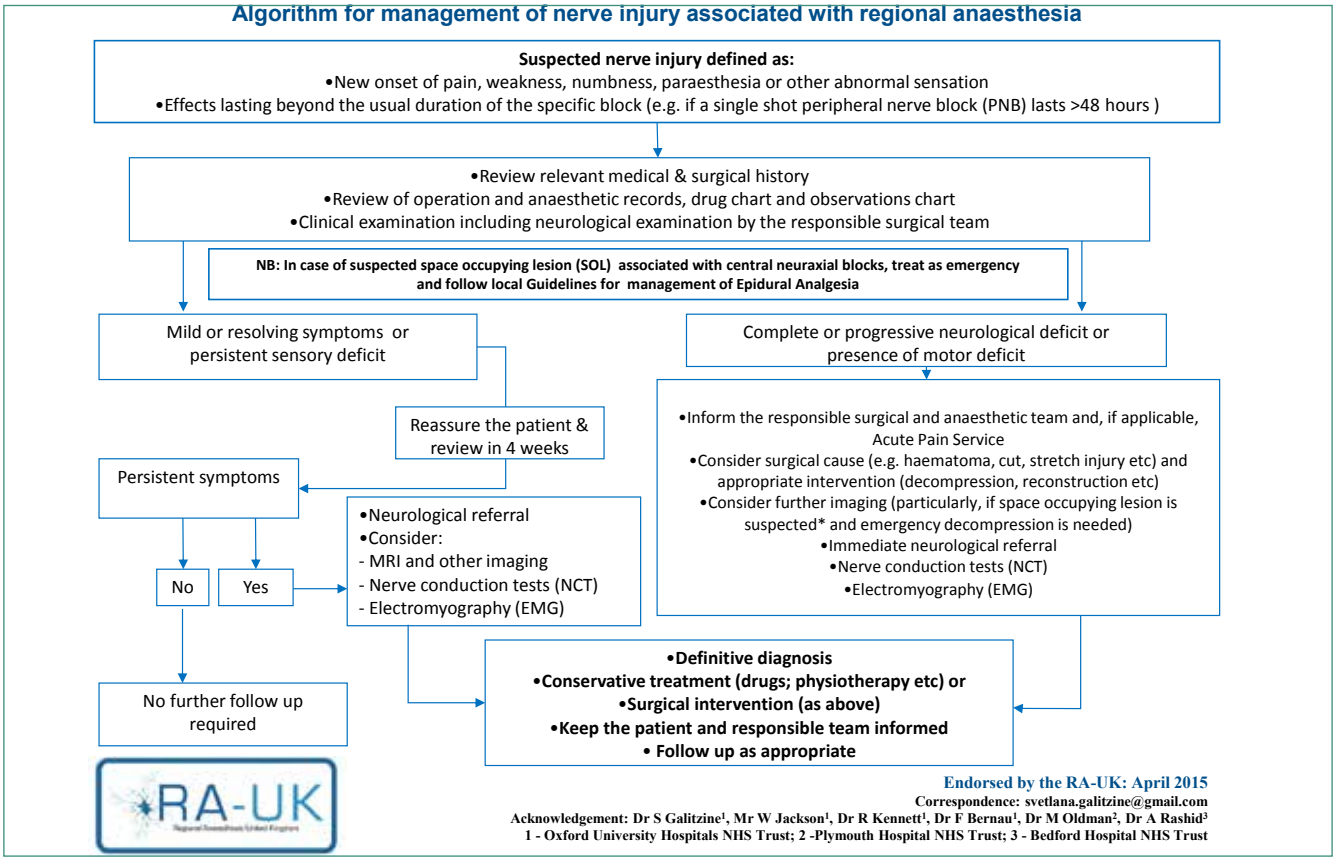
Consent should be obtained from the patient before their arrival in theatre and information provided before their elective surgical procedure e.g. pamphlet. Common complications should be listed and major complications that could result in death or disability should be thoroughly discussed. Provide information on the expected incidence and severity of nerve injury and inform patients with a pre-existing neuropathy of their increased risk. Discuss the risks and benefits of the procedure. Patient information leaflets are available from the SASA website.

## Conclusion

When performed properly, regional anaesthesia is safe and the benefits largely outweigh the risks. Patients need to be counselled about the common and life-threatening and disabling complications. Every effort should be made to minimise the risk of PNI in every patient.

**Monitoring during never blocks: Combining ultrasound (US), nerve stimulation (NS) and injection pressure monitoring**



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