Review Article

Pitfalls in regional anesthesia for shoulder surgery

André P. Boezaart

ABSTRACT

Surgeons are often reluctant to support regional anesthesia for shoulder surgery and other orthopaedic surgery. This is because the sometimes true, but usually perceived "slowing down" of operating room turnover times, and the perceived potential for added morbidity. The former (time issue) can only be solved by proper management, while the potential for added morbidity can be minimized by doing appropriate blocks for appropriate surgery at the correct times, when really indicated, with the correct equipment and techniques, and avoiding situations that are prone to causing morbidity. This article discusses in detail when it is appropriate to do blocks for shoulder surgery, but more important, when is it not appropriate to do blocks, and how to carefully calculate a risk-benefit ratio and avoid added morbidity.

Key words: Shoulder surgery, upper limb surgery, regional anesthesia, continuous peripheral nerve block, complications, acute pain management

Department of Anesthesia and Orthopaedic Surgery, University of Iowa, Iowa City, Iowa, USA

Correspondence:
Professor of Anesthesiology and Orthopaedic Surgery, University of Iowa, 200 Hawkins Drive, 6-JCP Iowa City, IA, 52242, USA.
E-mail: andre-boezaart@uiowa.edu

While regional anesthesia (RA) is undoubtedly the most effective and efficient modality for the management of acute postoperative pain following not only shoulder surgery but also most orthopedic and other surgery, it is not without pitfalls. The first important step in avoiding these pitfalls is to acknowledge its existence.

Because the shoulder joint is such a complex joint and the brachial plexus has to accommodate the complex movements of the upper limb, there are various pitfalls in RA for shoulder surgery. This article is based on the existing literature and also on the opinion of the author following experience of over a number of years dealing with patients undergoing shoulder surgery and medicolegal challenges. Some of the author's opinions may be perceived as controversial, but readers will hopefully find a few concepts that are useful - even if it is only to provoke them into identifying potential sources of complications based on their own training and experience.

To be successful with RA, there are four absolute requirements:

1. Hard (definitive) indications for nerve block
2. The correct block(s) for the surgery
3. The correct technique
4. The correct equipment

Ignoring any one of these factors will most likely lead to complications.

INDICATIONS

Indications for RA are often the subject of debate, but if lawsuits are reviewed and the subject is discussed with people with vast experience in dealing with medicolegal challenges, it often becomes clear that the patient did not need the block in the first place. Although there are many examples and opinions vary greatly, a few common misconceptions exist. The two surgical procedures that most commonly fall in this category are subacromial decompression (SAD), or acromioplasty of the shoulder, and arthroscopy and meniscectomy of the knee joint. These are typically not painful procedures; they do not require major nerve blocks and often lead to dissatisfaction because of minor complications of the blocks. Furthermore, the indications for SAD are not always pure, and patients scheduled for this operation may actually have shoulder pain due to a nerve condition, such as existing brachial plexopathy. In such cases a brachial plexus block, if anything, will make the condition worse.

THE CORRECT BLOCK

Hilton's law

Hilton was a British surgeon and anatomist, born in 1804 in

Please cite this article as: Boezaart AP. Pitfalls in regional anesthesia for shoulder surgery. Int J Shoulder Surg 2007,1:1:30-38.

Castle Hedingham, Essex, and died in 1878. Hilton's law states, *"The nerve trunk innervating a joint also supplies the overlying skin and the muscles that move that joint."* Conversely, when a nerve innervates the muscles that move a joint or the overlying skin of the joint, that nerve also innervates that joint. For RA it is important to understand this law of anatomy.

For example, even the perfect interscalene block will not provide anesthesia and analgesia for wrist pain, as the perfect femoral nerve block will not provide complete anesthesia and analgesia for pain due to total knee arthroplasty. There are many other examples. For the upper limb, the most common inappropriate blocks are interscalene blocks for anything other than shoulder surgery (because the C8 and T1 dermatomes are often not blocked). Other examples are supra- and infraclavicular blocks for shoulder surgery, suprascapular nerve block for glenohumeral surgery, incomplete axillary block for any upper limb surgery, elbow block not involving the musculocutaneous or antebrachial cutaneous nerves for lower arm surgery and continuous infraclavicular nerve block for elbow and wrist surgery. The entire brachial plexus innervates all the large joints of the upper limb. Unlike lower jaw surgery, for example, where a single block of the mandibular nerve will provide analgesia for lower jaw surgery, there is no single nerve block that will take care of any orthopedic surgical procedure - the entire brachial plexus needs to be blocked to provide anesthesia or analgesia to any of the major joints of the upper limb.

THE CORRECT TECHNIQUE

It is important to choose a technique, become familiar and confident with it and stay with this technique. It probably does not matter whether one routinely uses nerve stimulation, ultrasound, paresthesia or a combination of these techniques, as long as the technique is sound.

CORRECT EQUIPMENT

This author joins Chelly in his plea for blunt large-bore needles for nerve blocks.[1,2] This is especially true for blocks around the dura and other fascia layers like the pleura. The Tuohy needle has been specifically designed not to penetrate tissue like the dura, and it has certainly stood the test of time. Anesthesiologists have been using these needles successfully for many decades now, and most anesthesiologists would feel very uncomfortable in using anything but a 16-18-guage Tuohy needle around the dura. Yet, the same anesthesiologists will not hesitate to use a 22-guige B-beveled needle to perform a single-injection paravertebral block, whether at the cervical, thoracic, lumbar or sacral level. This ignores the fact or perhaps signifies ignorance of the fact that the dura extends well down the nerve roots into the paravertebral space. Paravertebral blocks are performed just outside the dura or extradural or peridural or epidural, and the same rules applying to epidural blocks (large-bore Tuohy needles, lidocaine test dose, fractionated injection, etc.) should therefore apply to any paravertebral block. Neglect of this fact has led to many tragic complications in RA, mainly spinal cord injuries,[3,4] although most of these cases seldom or ever reach the anesthesia or surgical literature, since they are engulfed by the legal system and usually settled out of court. Defense lawyers generally do not encourage their clients to publish the cases in fear of incrimination; and because these cases do not reach closure in the courts, they do not reach the 'closed claim' studies and publications.

Where not to do blocks

There are four areas in the upper limb where blocks are traditionally done but which may be wise to avoid for routine approaches.

Injury to a nerve can be due to direct trauma to the nerve, toxicity or due to ischemia of the nerve.[5-7] Ischemia, in turn, may be due to pressure or traction on the nerve or vasoconstriction. We should therefore avoid direct trauma to the nerve and avoid doing blocks in places where the nerves are in a confined space or closed compartment. Furthermore, we should be careful to avoid intra-operative traction to the nerves. This is especially applicable to shoulder surgery.

With blocks in a relatively confined space, we add volume to the space in which the nerve is situated by injecting local anesthetic agent into that space. We may also cause some bleeding and hematoma in the area. If we now cause vasoconstriction by adding epinephrine to the injected anesthetic, we have the potential for nerve ischemia and nerve injury.

The places that we need to avoid are:

1. Intervertebral neuroforamen

This is the area between vertebrae where the nerve roots exit the spinal canal. Unlike chronic pain medicine, it is never necessary in RA for upper limb surgery to place a needle or catheter into the intervertebral foramen.

Intraforaminal placement of a needle is possible during interscalene block if the technique is not correct. Using the interscalene block as Winnie's described it in 1970,[8] it is not likely to enter the neuroforamen. According to this technique, the needle should be advanced mesiad, posteriorly and caudally. If the needle enters perpendicular to the skin in slender people and the caudal direction is ignored, it is conceivable that the neuroforamen may be entered. This incorrect approach may have originated from the later description of Winnie[9] in which he described the same technique as in his previous publication but added *'perpendicular to the skin in all plains'* and the latter became the standard of practice for some practitioners. This is

unfortunate, sine the 1975 description was never intended to apply to interscalene block but was meant to apply to cervical plexus block.

When doing interscalene blocks, one has to be careful to follow the original description of mesiad, posterior and caudal direction when inserting the needle. To avoid entering the intervertebral foramen, most practitioners have converted to the longitudinal[10] or lateral[11] approach to the interscalene space.

It is also practically possible to place a catheter into the neuroforamen during continuous paravertebral block.[12] Intraforaminal catheter placement during thoracic, lumbar or sacral paravertebral block may also be possible.

2. Supraclavicular area

Large studies have shown no problems with the supraclavicular block[13] and have proven it to be very easy and successful and relatively free of complications, but because the supraclavicular block does not usually include the suprascapular nerve, it is not often used for shoulder surgery - especially if the surgery involves the rotator cuff. The reason for not advocating this block as a routine block is that the nerves are all bundled together where they cross the first rib deep to the clavicle. The middle and anterior scalene muscles are posterior and anterior to the nerve bundle and further anterior is the subclavian artery. While this confined space may be the very reason why this approach is so successful, it may also be the cause of volume-induced pressure and ischemia to the nerve.

Although the above argument has not been tested by research and this block has stood the test of time, it seems prudent to perform the supraclavicular block when a fast onset and dense block are sought and probably not to use it as routine block. In the infraclavicular area, the cords of the brachial plexus are situated in a wide-open space, and the infraclavicular block should be a better alternative for distal upper limb surgery.

3. Sulcus ulnaris

It is obvious that the nerve here is in a very confined compartment, and performing a nerve block here almost always leads to ischemic nerve injury.

4. Carpal tunnel at the wrist

This is where the median nerve crosses deep to the retinaculum at the wrist. The median nerve is a large nerve in a very confined space, and local anesthetic agent injected here may result in ischemic nerve injury if the 'roof' of the carpal tunnel is not immediately removed as is often done following this block by hand surgeons when performing carpal tunnel release surgery.

To summarize, the places to avoid doing blocks routinely are anywhere where the nerves are bundled together in a tight compartment. These locations are the very places where blocks are usually easy to do and successful due to the very fact that the nerves are in a tight compartment. Furthermore, ultrasound studies have taught us that it is difficult to place a needle intraneurally if the nerve is not fixed. In these tight compartments, the nerves are usually fixed.

Patients are especially vulnerable to nerve injury after shoulder surgery. It is now becoming clear that the nerve block is very seldom the cause of nerve injury.[14-17]

Epinephrine (Adrenaline)

Addition of 1/200,000 to 1/400,000 epinephrine to the local anesthetic solution shortens the onset time of the block, makes the block last longer when short-acting drugs are used and increases the density of the block. The reason for this is nerve ischemia.

In a classical experiment on rat sciatic nerve, Selander[18] demonstrated in 1985 that intraneural injection of saline or 0.5% bupivacaine caused no permanent axonal degeneration. On the other hand, bupivacaine 1% without epinephrine or bupivacaine 0.5% with 1/200,000 epinephrine caused axonal degeneration in most instances. These experimental findings have been verified subsequently.[19,20]

Because ischemia is the main cause of nerve injuries, it seems logical that whatever the reason for using epinephrine, it does not do anything good for the nerve. If a shorter onset time and denser block are required, more appropriate drugs can be used. And if a longer-acting block is needed, a continuous nerve block can be placed. Apart from being potentially dangerous to the nerve, epinephrine is therefore not really necessary. This should provide a strong incentive not to use it routinely.

Existing neuropathy

The issue of existing brachial plexitis or neuropathy is poorly understood and under-appreciated. The obvious causes of neuropathy, such as diabetes, Charcot-Marie-Tooth disease (SMT) and trauma, are well understood. These conditions and others where the pathology is well documented are not contraindication to nerve block. However, undocumented and undiagnosed neuropathies can cause embarrassment.

When a nerve is already injured or under pressure in a tight compartment or area of impingement or traction, further pressure often causes persistent clinical symptoms of neuropathy. This often ranges from persistent numbness to severe neuropathic pain that is often blamed on the block.

Existing brachial plexopathy

Patients with clinical or subclinical brachial plexopathy may present with nondescript pain in the shoulder and arm. This can vary from severe shoulder pain, to paresthesia or

dysesthesia in the arm and hand. The patient is usually referred to a shoulder surgeon, who schedules the patient for arthroscopy of the shoulder. Patients with existing brachial plexopathy typically present with pain distal to the elbow, which is not usually a symptom of *bona fide* shoulder pathology.

The mechanism of the brachial plexopathy is usually not clear but is thought to be due to pressure, and consequently ischemia, to the brachial plexus where it crosses the first rib and where the clavicle may impinge it. This condition is thought to be more common in females than in males. The space between the first rib and the clavicle is larger in males than in females, and this probably explains the difference in the rate of its incidence with respect to gender. The impingement is chronic and low grade, usually just enough to cause pain in the shoulder, arm and hand. It usually involves the more inferior trunks of the brachial plexus than the upper trunks or divisions. In interscalene or supraclavicular blocks, injection of a large volume of local anesthetic agent where the brachial plexus crosses the first rib and is already under potential stress may cause problems. If epinephrine is added, it may aggravate nerve ischemia. A small hematoma in the area would increase the pressure even more.

Since *bona fide* shoulder pathology typically does not cause pain distal to the elbow, it may be wise to ask the patient about the distribution of the pain and other symptoms. If the patient admits to these symptoms distal to the elbow, it should be a reason to be cautious and rather offer patients postoperative blocks once the pathology is clear. Patients with existing brachial plexopathy sometimes end up getting subacromial decompression surgery, while subacromial impingement was not the original pathology.

It is relatively easy to perform continuous or single injection blocks postoperatively. If a nerve stimulator has to be used, it can be painful to evoke a motor response after surgery. It is then helpful to use 0.3-0.5 μg/kg Remifentanil as a bolus intravenous injection at 1- to 3-min intervals as required.[21] Propofol can also be used.

If a cervical paravertebral block is used, a single injection or a continuous block can be done, with 'loss of resistance to air' as indicator of correct placement. An 18-G insulated Tuohy needle is used for continuous or single-injection CPVB and preferably not a 22-G stimulating needle designed for peripheral nerve block. A cervical paravertebral block is not a peripheral nerve block but is performed just outside the dural sleeve covering the nerve roots and is therefore extradural or peridural or epidural.[2] An interscalene block can also be done postoperatively, if needed, without nerve stimulation by using ultrasound.

FROZEN SHOULDER

Frozen shoulder, or adhesive capsulitis, is a common condition of which anesthesiologists should have some understanding. It is classified as primary (idiopathic) or secondary adhesive capsulitis. The secondary form is caused by trauma, surgery, infection, etc., to the joint and is due to adhesions in the glenohumeral or subacromial joints. Because the capsule of the joint is not involved, the glenohumeral joint does not 'freeze' in the anatomical or functional position. Primary adhesive capsulitis, on the other hand, is due to a fibroblast proliferation of the joint capsule. Microscopically there are collagen deposits similar to that in Dupuytren's contracture of the hand. But while Dupuytren's contracture is common in males, primary frozen shoulder is more common in females.[22-25] The shoulder 'freezes' in the functional anatomical position of abduction, flexion and internal rotation.

Primary adhesive capsulitis is the most common and the least understood form of frozen shoulder. Lloyd and Lloyd,[26] Hill[27] and Reeves[28] have all suggested three phases of primary adhesive capsulitis, based on clinical observations.

Phase I: Phase I is characterized by localized shoulder pain. The patient develops painful range of motion and exhibits progressive loss of motion.

Phase II: Phase II is characterized by diffuse shoulder pain with progressive loss of motion secondary to pain or to the development of a capsular pattern described by movement limitations. Most restricted is external rotation, followed by abduction and internal rotation. This phase slowly progresses to phase III.

Phase III: The patient continues to have decreased range of motion. Patients with phase III adhesive capsulitis do suffer pain, but placing the arm in the functional position of abduction, internal rotation and flexion relieves this pain.

A patient may consult a shoulder surgeon at any stage of the progression of the disease, which is a self-limiting disease that usually subsides after 3 to 5 years.[22-28] The personality profile of patients with primary adhesive capsulitis is typical with 75% being women of whom 84% falls into the 40-59 years age group. Most patients (66%) have no other medical problems.[29] Hand dominance seems to have no role in the development of primary adhesive capsulitis.

Finally and perhaps most important to anesthesiologists, because of difficulty in the physical examination of frozen shoulder, a coexisting neuropathic process may go undetected.[30] Patients with primary frozen shoulder will often, when asked how they relieve the pain, say that they keep the arm on pillows in the functional position. When the arm is then carried at the side, the scapula rotates externally and pseudo-winging of the scapula develops. The net effect of this is that the distance from the cervical vertebrae to the coracoid increases,[31] resulting in chronic light traction on the brachial plexus-most severe where the brachial plexus crosses

the first rib. As a result, the patient presents with pain in the shoulder and arm. Doing nerve blocks, especially blocks in the area of the first rib (interscalene and supraclavicular), may cause more pressure and more ischemia to the brachial plexus, especially if epinephrine is added to the local anesthetic agent. It may therefore be prudent to avoid doing blocks in the area of the first rib in the case of primary adhesive capsulitis. There should be no problem doing blocks in the case of secondary capsulitis, because the shoulder does not freeze in the functional position but freezes with the arm at the side of the patient. There is thus no rotation of the scapula in secondary adhesive capsulitis and consequently no traction on the brachial plexus.

Because of our poor results with continuous interscalene blocks in patients with primary adhesive capsulitis, we employed the continuous cervical paravertebral block (CCPVB).[32] Since starting to do CCPVB for capsulotomy and physical therapy for primary adhesive capsulitis, we have had excellent results. In theory, that could be attributed to the fact that the CCPVB is done more proximally, away from the area where the brachial plexus crosses the first rib.

Subacromial decompression

Subacromial impingement is probably over-diagnosed and over-treated. Although this possibility has not been proven by research, there is a strong suspicion that a substantial number of patients that present for SAD actually have existing brachial plexopathy causing the pain in their shoulders. The diagnostic test for subacromial impingement is to inject local anesthetic agent into the subacromial space. If the pain then subsides, it presumably provides 'proof' of subacromial impingement, and the patient is scheduled for SAD.

It has been demonstrated some time ago[33,34] that in the majority of patients, if an invasive procedure, such as an injection, is performed for pain, the pain will subside, even if the origin of the pain is remote from the site of injection. This has been demonstrated by immediate improvement of pain when a local anesthetic is injected around the supraspinatus muscle in patients with referred shoulder pain due to liver pathology. It is therefore fair to assume that referred shoulder pain caused by brachial plexopathy will, like pain due to subacromial impingement, also subside after subacromial injection of a local anesthetic agent. This notion has not been evaluated by clinical research but it may be prudent for anesthesiologists not to assume that all patients with positive subacromial injection tests have subacromial impingement. We have to assume that some of these patients have existing brachial plexopathy. At the very least, anesthesiologists have to be careful with these patients especially if they present with pain and neurological symptoms distal to the elbow.

Because of this uncertainty, it may be wise to adopt the following practice:
Subacromial decompression is generally not a very painful surgery and therefore does not routinely require major nerve blockade. When confronted with patients scheduled for SAD with no proof of other shoulder pathology, the patient should be asked about pain, dysesthesia, paresthesia, numbness or any other neurological symptoms distal to the elbow. If the patient does have these symptoms or any other neurological symptoms, it may be wise to offer a postoperative block to this patient. Postoperative brachial plexus root or trunk blocks are easy to perform.

Some practitioners may prefer to use a nerve stimulator for these blocks, which is perfectly acceptable, but the patient may suffer extreme pain during a stimulated motor response. Remifentanil 0.3-0.5 μg/kg can be used as a single bolus intravenous injection. If the choice is a single injection or continuous interscalene block, it can be done with ultrasound assistance, while CCPVB can be done with ultrasound or 'loss of resistance to air' techniques.

Hereditary neuropathy with liability to pressure palsies

Hereditary neuropathy with liability to pressure palsies (HNPP) is a poorly understood condition, and most anesthesiologists are not aware of its existence.[35,36] It is an autosomal-dominant inherited disorder characterized by a tendency to develop focal neuropathy after trivial trauma (such as nerve blocks). Studies on teased nerve fibers show sausage-shaped myelin sheaths on ultrasound.[35,36] Diffusely enlarged peripheral nerves can be demonstrated outside entrapment sites with ultrasound. The incidence of HNPP has been estimated to be 1/100,000 of the population but it is probably significantly higher.[37] The patient often has associated hyporeflexia, talipes cavus and a family history of peripheral nerve palsies. The condition is suspected when electrodiagnostic studies show one or more entrapment neuropathies superimposed on a background of sensimotor polyneuropathy. There are no specific electrodiagnostic criteria, but predominant decrease of distal nerve conduction velocity may indicate underlying HNPP. The diagnosis is confirmed when the genetic defect responsible for the disease is demonstrated: a deletion of chromosome 17p11.2-12.[38] A high index of suspicion exists if there is a family history of multiple-pressure neuropathies such as carpal tunnel, tarsal tunnel, ulnar nerve entrapment or a personal history of multiple entrapment neuropathies.

The motor palsy following trivial trauma to the nerve (such as a nerve block) is usually permanent and there is no sensory loss. The nerve block is often blamed for this condition.

THORACIC OUTLET SYNDROME

There are several well-recognized peripheral neurological

syndromes that affect the upper extremities. These include:

1 Herniated disk and hypertrophic spondylosis of the cervical vertebrae
2 Brachial plexus compression by a cervical rib or elongated C7 transverse process
3 Ulnar nerve entrapment in the cubital tunnel of the elbow or Guyton's canal in the wrist
4 Median nerve entrapment by the pronator teres muscle in the forearm or the carpal tunnel. Each of these conditions has characteristic location patterns or radiating pain, tenderness and muscle weakness and some have diagnostic radiological and electrodiagnostic features. The correct diagnosis can usually be made by history, examination and ancillary tests, and the condition can be documented. These conditions should not pose contraindications to regional anesthesia if the areas where the nerves are under pressure are avoided.

However, there remains a group of under-diagnosed patients who present with moderate to severe pain, paresthesia, weakness and dysfunction of the arm and hand that does not fall within these specific clinical entities. The patients are usually young and predominantly female. The pain typically radiates from the scapula down the arm to the hand - again, distal to the elbow. The pain is often generalized. The theory, which has not been substantiated by research, is that the scalene muscles are developed out of proportion to the rest of the musculature in young females, and these scalene muscles compress the brachial plexus as it lies between them. (In a small but unreported series of 12 patients, excellent results were obtained by Botox injections into one of the scalene muscles. All the patients remained pain free for 4-6 months, and the first rib resection with good results was done after the third or fourth Botox injection. This needs further research.) Most of the arm and shoulder pains spontaneously disappear at the age of 25-30 years. Furthermore, these patients often have lax ligaments at an age of 18-25 years and present for capsulorraphy. This is usually the first of a series of shoulder surgeries.

Anesthesiologists should be careful when offering continuous or single injection brachial plexus blocks in young female patients scheduled for capsulorraphy, capsulotomy or other shoulder operations for which the indications are not perfectly clear. Surgery may not improve the shoulder pain, but because the primary cause of the shoulder pain and pain in the arm and hand is pressure on the brachial plexus, brachial plexus blocks are often afterwards implicated in the neurological symptoms. Again, young female patients with a history of multiple shoulder surgery and pain distal to the elbow should be approached with caution when considering brachial plexus blocks.[39-43]

Other considerations

Compartment syndrome: Compartment syndrome[44] occurs when excessive pressure develops within a closed fascial compartment and renders the tissue within the affected compartment ischemic. Orthopedic compartment syndrome occurs in the upper extremities, lower extremities and in the gluteal region. These syndromes have multiple causes, but they are most commonly due to trauma and fractures. Aggressive emergency treatment is essential to prevent the patient from losing a limb.

The most common cause of compartment syndrome is a fracture. The syndrome is often caused by higher energy, closed fractures but can also occur with lower-energy forces and open fractures. There is often a history of direct blunt injury to the limb, such as a tibia struck by the bumper of a car. They occur most commonly with closed tibia fractures and are particularly common in proximal tibia fractures.

Vascular injury can also lead to compartment syndrome. Arterial bleeding in a closed compartment can readily cause excessive intracompartmental pressure in it. Reperfusion after prolonged ischemia can cause excessive swelling leading to a compartment syndrome. This typically occurs after a revascularization procedure. Compartment syndrome can also result from external causes such as casts, constrictive dressings or 'antishock' lower extremity garments. Compartment syndrome has also been reported in patients subjected to prolonged lithotomy position in obstetric and urological reconstructive operations. The basic physiological mechanism is excessive intracompartmental pressure, which causes microcirculatory failure of perfusion of the tissues in the compartment. As the pressure increases, it eventually exceeds the arteriolar pressure, causing a rapid failure of the local capillary anastamoses, and blood flow to the tissues ceases. Excessive pressure also inhibits venous return, further blocking flow within the compartment.

Tissue damage depends on the duration of the compartment syndrome. Muscle tissue can usually survive 4 h of ischemia, but more than 8 h of ischemia causes irreversible damage. Peripheral nerves will continue to conduct normally for up to 1 h of complete ischemia and will survive without injury when subjected to 4 h of ischemia but will be irreversibly damaged after 8 h.

The characteristic symptom of compartment syndrome is progressive, unrelenting pain out of proportion to the underlying condition. These patients frequently report severe increases of pain with a fairly rapid onset. This is mainly a clinical diagnosis, especially in patients at risk. The leg is firm and often shiny. The earliest and most reliable physical sign is severe exacerbation of tenderness of the affected compartment by manual compression or passive stretching of the muscles within the compartment. A gentle squeeze of the calf or passive flexion of the toe or ankle is excruciatingly painful.

Because compartment syndrome is due to a microcirculatory

failure, the peripheral pulses are usually intact. Anesthesiologists, who incorrectly believe that the presence of arterial pulses rules out compartment syndrome, do often not realize this extremely important fact. This is in direct contrast to an acute arterial thrombosis. The misconception that the legs of patients with compartment syndrome are pulseless needs to be corrected. The pulses are often bounding and only very late in a compartment syndrome, when pressures are dramatically elevated, does the affected extremity become pulseless. Due to increased perfusion to the subcutaneous tissues surrounding the compartment, the leg is often pink and shiny, in contrast to a mottled, pallorous extremity seen in cases of arterial thrombosis. Early in a compartment syndrome, the peripheral nerves function normally. It is not until the compartment syndrome has advanced that patients complain of tingling and numbness. Finally, in advanced cases, the limb becomes paralytic.

In an alert patient with a firm painful leg that becomes more painful with gentle passive stretching, the diagnosis should be made immediately and emergency fasciotomy should be performed. In less obvious cases, compartment pressure can be measured. Once the diagnosis of compartment syndrome is established, the affected compartment should be decompressed immediately.

The most common compartment syndromes are those in leg and forearm. Because the crucial window of opportunity to save the limb by decompression is within 4 to 8 h and because most peripheral nerve blocks will last 4 to 8 hours, regional anesthesia or peripheral nerve block must be avoided in these patients, since it will mask the most important and often the only symptom of compartment syndrome - namely, pain. After fixation of fractures, the pain usually subsides and gets progressively less. Any exacerbation of pain after fractures have been fixed should be regarded with great caution.[44]

FAILED OR INCOMPLETE BLOCKS

Arguably, the most common 'complication' with nerve blocks is failed blocks or incomplete blocks. Possibly the most common reason for failure is not poor technique but blocking the wrong nerve or not blocking all the nerves for the planned surgery. This might seem very basic, but to do the appropriate block or blocks for the surgery is probably the most overlooked or neglected issue in regional anesthesia. Common examples are:

1. Performing a continuous cervical paravertebral block for shoulder surgery on the C8 or T1 level accepting a triceps muscle motor response. With the initial relatively large bolus, the C5 and C6 roots are reached, but the secondary block with a relatively low infusion volume of say 5 ml/h, does not reach the C5 nerve root and the block is classified as failed.
2. Cervical paravertebral block for elbow and wrist surgery accepting pectoralis major motor response and therefore a C5 root stimulation. This leads to a good initial block, but the next day when the low infusion volume is used, the patient has a numb shoulder and painful elbow and wrist because the C7, C8 and T1 roots are not reached.
3. Pain in the axilla or T1 area following shoulder arthroplasty and continuous interscalene block. The initial block is done on the C5 root or superior trunk and the initial bolus may reach the C8 and T1 roots or inferior trunk. The continuous infusion after the initial block is worn off does not reach the C8 or T1 roots or inferior trunk, and the patient has pain in the T1 and C8 dermatome area.
4. Continuous or single injection interscalene block performed for elbow, wrist and hand surgery is another example of a block with a potential to fail. The interscalene block reaches the C5, C6 roots or upper and middle trunk but not the inferior trunk or lower cervical roots, and therefore the medial part of the lower arm is not blocked.
5. Continuous infraclavicular block on the posterior cord is done for elbow and wrist surgery. If a large initial bolus is used, it usually reaches all three of the cords and therefore the initial block is good. On infusion of a lower volume the next day, the patient suffers extreme pain because the middle and lateral cords are not reached. This block is then deemed to have failed.
6. A number of reasons can cause the axillary block to fail. Typically, the musculocutaneous nerve is blocked and all the other nerves are missed. Alternatively, all the other nerves are blocked and the musculocutaneous is missed. This leads to incomplete block. It is therefore essential when doing an axillary block to ensure that all seven of the nerves are blocked. Two of these nerves are sensory nerves and difficult to identify in the axilla, while the musculocutaneous is a motor nerve in the upper arm and a sensory nerve in the lower arm. These are nerves that are often overlooked, which can lead to a failed block. As can be seen from the above, it is essential to understand the neurotomal, osteotomal and dermatomal supply of each nerve and to do appropriate blocks and to understand Hilton's Law. If a nerve block is in any case not going to have any beneficial effect, we only have the risks and no benefits and in such cases, it is better not to do a block at all.

As said earlier in this article, one of the most crucial requirements for effective regional anesthesia is to have the correct indications and valid reasons for nerve blocks.

There are many examples of major nerve blocks done when pain is likely to be insignificant, such as interscalene or cervical paravertebral blocks for subacromial decompression, femoral nerve blocks for diagnostic knee arthroscopy, etc. Experience has taught us that in most instances of complications leading to medicolegal action, the patient usually did not need the block in the first place. There are examples of major

continuous infraclavicular blocks done for carpal tunnel release[45] and major lumbar plexus or psoas compartment blocks for surgery below the knee where a simple saphenous nerve block would have been efficacious.[46] Patients will tolerate a large number of complications if the indications for the block were good in the first place and the block was done solely for the benefit of the patient. If a block, however, is done for any reason other than real benefit to the patient, complications often cause legal problems.

Duration of nerve blocks

As continuous infraclavicular block for carpal tunnel syndrome is inappropriate, so is single injection interscalene block, for example, probably inappropriate for rotator cuff surgery. Although the patient wakes up from the anesthesia without any pain, he or she usually wakes up in the middle of the night with excruciating unmanageable pain. A continuous nerve block would clearly be a better choice for very painful shoulder operations such as rotator cuff surgery or total shoulder arthroplasty. Also, a single injection infraclavicular block for total elbow or total wrist arthroplasty would be inappropriate as would continuous infraclavicular block be for wrist ganglion excision, for example. The one block that would cover all three major joints of the upper limb at the low infusion rate of the days after surgery would be a continuous cervical paravertebral block done at the correct root level. For example, C5 and C6 level with pectoralis major muscle response would be ideal for shoulder surgery, whereas a triceps response (C7/8) would be ideal for wrist and elbow surgery. It is therefore important to match the duration of the block with the expected duration and severity of the surgical pain.

High yield blocks

A high yield block is one that gives the highest success rate and the lowest complication rate. It is therefore important to have a serious and hard look at individual practices and honestly try to calculate expected success and complication rates. This would eliminate blocks that are unnecessary. High yield blocks could be identified and should make out the bulk of practitioners' routine practice. Only in exceptional circumstances, should 'low yield' blocks be performed.

Generally speaking, there are seven single injection blocks and four continuous nerve blocks in addition to lumbar and thoracic epidural blocks, spinal anesthesia and thoracic paravertebral blocks for thoracic or other major unilateral trunk surgery. The single injection blocks should include interscalene, cervical paravertebral block; infraclavicular or supraclavicular, femoral block; subgluteal block; popliteal block; and ankle block. Only four continuous blocks are absolutely necessary for orthopedic surgery. These are continuous cervical paravertebral block, continuous femoral block, continuous subgluteal block and continuous popliteal block. The other blocks could be done under exceptional circumstances.

Long acting local anesthetic agents

The introduction of long acting local anesthetic agents has been anticipated for some time and seems attractive. But one must bear in mind that the complications or side effects of these blocks would also be long acting. Blocking the phrenic nerve for 6-8 h would not cause too many problems, but for 3-5 days, however, would be totally unacceptable.

CONCLUSION

There are four basic principles for successful regional anesthesia that will help to avoid pitfalls. These are the correct indications, the correct block for the surgery, the correct technique and the right equipment. Furthermore, places where nerves are in confined spaces should be avoided for doing nerve blocks, and conditions causing existing brachial plexopathy should be recognized and approached with caution. Nerve blocks are contraindicated in patients who may develop compartment syndrome, and nerve blocks should be matched to the surgery and severity and duration of the pain.

REFERENCES

1. Chelly JE. How can we possibly prevent complications related to peripheral nerve blocks? Anesth Analg 2001;93:1080-1
2. Boezaart AP, Franco CD. Thin sharp needles around the dura. Reg Anesth Pain Med 2006;31:388-9.
3. Voermans NC, Crul BJ, de Bondt B, Zwarts MJ, van Engelen BG. Permanent loss of spinal cord function associated with the posterior approach. Anesthe Analg 2006;102:330-1.
4. Boezaart AP. Please do not blame the block. Anesth Analg 2006;103.
5. Lundborg G. Ischemic nerve injury. Scand J Plast Reconstr Surg 1970;4.
6. Lundborg G, Dahlin LB. Anatomy, function and pathophysicology of peripheral nerves and nerve compression. Hand Clin 1996;12:185-93.
7. Lundborg, G, Dahlin LB. The pathophysiology of nerve compression. Hand Clin 1992;8:215-27.
8. Winnie AP. Interscalene brachial plexus block. Anesth Analg 1970;49:455-66.
9. Winnie AP, Ramamurthy S, Durrani Z, Radonjic R. Interscalene cervical plexus block: A single-injection technique. Anesth Analg 1975;54:370-5.
10. Boezaart AP, de Beer JF, du Toit C, van Rooyen K. A new technique of continuous interscalene nerve block. Can J Anaesth 1999;46:275-81.
11. Borgeat A, Dullenkopf A, Ekatodramis G, Nagy L. Evaluation of the lateral modified approach for continuous interscalene block for shoulder surgery. Anesthesiology 2003;99:436-42.
12. Frohm RM, Raw RM, Haider N, Boezaart AP. Epidural spread after continuous cervical paravertebral block. Reg Anesth Pain Med 2006;31:279-81.
13. Franco CD, Gloss FJ, Voronov G, Tyler SG, Stojiljkovic LS. Supraclavicular block in the obese population: An analysis of 2020 blocks. Anesth Analg 2006;102:1252-4.
14. Boardman ND 3rd, Cofield RH. Neurologic complications of shoulder surgery. Clin Orthop 1999;368:44-53.
15. McFarland EG, O'Neill OR, Hsu CY. Complications of shoulder arthroscopy. J Southern Orthop Assoc 1997;6:190-6.
16. Bigliani LU, Flatow EL, Deliz ED. Complications of shoulder arthroscopy. Orthop Rev 1991;20:743-51.
17. Weber SC, Abrams JS, Nottage WM. Complications associated

with arthroscopic shoulder surgery. Arthroscopy 2002;18:88-95.
18. Selander D, Mansson LG, Karlsson L, Svanvik J. Adrenergic vasoconstriction in peripheral nerves of the rabbit. Anesthesiology 1985;62:6-10.
19. Selander D, Brattsand R, Lundborg G, Nordborg C, Olsson Y. Local anesthetics: Importance of mode of application, concentration and adrenaline for the appearance of nerve lesions. An experimental study of axonal degeneration and barrier damage after intrafascicular injection or topical application of bupivacaine (Marcain). Acta Anaesthesiol Scand 1979;23:127-36.
20. Tsao BE, Wilbourn AJ. Infraclavicular brachial plexus injury following axillary regional block. Muscle Nerve 2004;30:44-8.
21. Boezaart AP, Berry RA, Nell ML, van Dyk AL. A comparison of propofol and Remifentanil for sedation and limitation of movement during peri-retrobulbar block. J Clin Anesth 2001;13:422-6.
22. Bunker TD, Anthony PP. The pathology of frozen shoulder: A Dupuytren-like disease. J Bone Joint Surg Br 1995;77:677-83.
23. Smith SP, Devaraj VS, Bunker TD. The association between frozen shoulder and Dupuytren's disease. J Shoulder Elbow Surg 2001;10:149-51.
24. Noël E, Thomas T, Schaeverbeke T, Thomas P, Bonjean M, Revel M. Frozen shoulder. Joint Bone Spine 2000;67:393-400.
25. Müller LP, Müller LA, Happ J, Kerschbaumer F. Frozen shoulder: A sympathetic dystrophy? Arch Orthop Trauma Surg 2000;120:84-7.
26. Lloyd JA, Lloyd HM. Adhesive capsulitis of the shoulder. Arthrographic diagnosis and treatment. South Med J 1983;76:879-83.
27. Hill JJ, Bogumill H. Manipulation in the treatment of frozen shoulder syndrome. Orthop 1987;11:1255-60.
28. Reeves B. The natural history of frozen shoulder syndrome. Scand J Rheumatol 1975;4:193-6.
29. Boyle-Walker KL, Gabard DL, Bietsch E, Masek-VanArsdale DM, Robinson BL. A profile of patients with adhesive capsulitis. J Hand Ther 1997;10:222-8.
30. Simatas AC, Tsairis P. Adhesive capsulitis of the glenohumeral joint with an unusual neuropathic presentation: A case report. Am J Phys Med Rehabil 1999;78:577-81.
31. Klein AH, France JC, Mutschler A, Fu FH. Measurement of brachial plexus strain in arthroscopy of the shoulder. Arthroscopy 1987;3:45-52.
32. Boezaart AP, Koorn R, Rosenquist RW. Paravertebral approach to the brachial plexus: An anatomic omprovement in technique. Reg Anesth Pain Med 2003;28:241-4.
33. Lemaire A. La perception des douleurs viscerales. Rev Med de Louvain 1926;6:81.
34. Weiss S, Davis O. Significance of afferent impulses from the skin in the mechanism of visceral pain. A J M Sc 1928;176:517.
35. Beekman R, Visser LH. Sonographic detection of diffuse peripheral nerve enlargement in hereditary neuropathy with liability to pressure palsies. J Clin Ultrasound 2002;30:433-6.
36. Pareyson D. Diagnosis of hereditary neuropathies in adult patients. J Neurol 2003;250:148-60.
37. De Visser M, Vermeulen M, Wokke HJH. Neuromusculaire zieke. [Neuromuscular disease]. Maarssen. Elsevier/Bunge: The Netherlands; 1999. p. 174.
38. Keller MP, Chance PF. Inherited neuropathies: From gene to disease. Brian Pathol 1999;9:327-41.
39. Wilbourn AJ. Thoracic outlet syndrome surgery causing severe brachial plexopathy. Muscle Nerve 1988;11:66-84.
40. Roos DB. Historical perspectives and anatomic considerations. Thoracic outlet syndrome. Semin Thorac Cardiovasc Surg 1996;8:183-9.
41. Liu JE, Tahmoush AJ, Roos DB, Schwartzman RJ. Shoulder-arm pain from cervical bands and scalene muscle anomalies. J Neuro Sci 1995;128:175-80.
42. Roos DB. Thoracic outlet syndrome is underdiagnosed. Muscle Nerve 1999;22:126-9.
43. Wilbourn AJ. Thoracic outlet syndrome is overdiagnosed. Muscle Nerve 1999;22:130-7.
44. McKinley T, Boezaart AP. Common fractures, compartment syndrome and crush injuries. *In*: Boezaart AP, editor. Anesthesia and Orthopaedic Surgery. McGraw-Hill: New York; 2005. p. 209-13.
45. Rawal N, Allvin R, Axelsson K, Hallen J, Ekback G, Ohlsson T, *et al*. Patient-controlled regional analgesia (PCRA) at home. Anesthesiology 2002;96:1290-6.
46. Buckenmaier CC, McKnight GM, Winkley JV, Bleckner LL, Shannon C, Klein SM, *et al*. Continuous peripheral nerve block for battlefield anesthesia and evacuation. Reg Anesth Pain Med 2005;30:202-5.

Source of Support: Nil, **Conflict of Interest:** None declared.