The first brachial plexus block is said to have been performed by William Halsted in 1884 [32], soon after Koller [13] had demonstrated the local anaesthetic properties of cocaine. He injected the drug under direct vision, after exposing the plexus using infiltration anaesthesia. The first percutaneous blocks were performed independently in 1911 by Hirschel [11] and Kulenkampff [14], using the axillary and supraclavicular routes, respectively. Interscalene block was described by Etienne [8] in 1925.

**ANATOMY**

**Position**

The brachial plexus lies initially in the myofascial plane between scalenus anterior and medius. The fascia surrounding these muscles continues along the plexus as a fibrous sheath, enveloping the nerves and the subclavian vessels to form the neurovascular bundle. The plexus crosses the first rib posterior to the subclavian artery, to pass into the axilla and surround the axillary artery. The neurovascular bundle then passes down the arm between the coracobrachialis, biceps and triceps muscles.

**Composition**

The plexus is formed from the anterior rami of C5–8 and T1 (fig. 1), with variable contributions from C4 and T1. The five roots unite to form three trunks at the lateral border of the scalene muscles. The roots from C5/6 form the upper trunk, C7 the middle and C8/T1 the lower trunk, all of which pass around the subclavian artery to enter the axilla between the axillary artery and the pectoralis major muscle. Interscalene block is performed by infiltrating the subclavicular tissue in the space between the scalenuses and the clavicle.

**KEY WORDS**

Anaesthetic techniques, regional: axillary brachial plexus.
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which lie in the same tissue plane as the subclavian artery. The upper and middle trunks lie above the artery and the lower behind it. Each trunk divides into anterior and posterior divisions which cross the first rib posterior to the clavicle, and unite to form the cords. The cords are named according to their relationship to the second part of the axillary artery. The posterior cord is formed from the three posterior divisions, the lateral from the two upper anterior divisions and the medial from the lower anterior division.

Branches issue from the roots, trunks and cords of the brachial plexus. The major branches of the roots are the C5 contribution to the phrenic nerve and the nerves to the serratus anterior, rhomboid, scalene and levator scapulae muscles. The trunks give rise to the suprascapular nerve and the nerve to subclavius. The musculocutaneous and lateral pectoral nerves and the lateral head of the median nerve arise from the lateral cord. The posterior cord has five branches: the radial, axillary, thoracodorsal and upper and lower subscapular nerves. The medial cord gives rise to the median pectoral, ulnar, medial cutaneous nerves of forearm and arm, and the medial contribution to the median nerve.

The sympathetic innervation of the arm is derived from T1–5, the T1–2 contribution joining the branchial plexus via the stellate ganglion, whilst fibres from T3–5 run with the arterial tree.

Relations

Initially the brachial plexus lies between the scalene muscles and traverses the posterior triangle of the neck (fig. 2). Anteriorly it is covered by the skin, superficial fascia, platysma, deep fascia and the scalenus anterior. It is crossed by the suprascapular nerves, nerve to subclavius, inferior belly of omohyoid, external jugular vein and transverse cervical artery. The posterior relations are scalenus medius and the long thoracic nerve. Inferiorly lie the first rib and the first digitation of serratus anterior with the subclavian artery anteriorly and the scalenus medius behind. The dome of the pleura, covered by Sibson’s fascia, lies inferomedial to the plexus just before it crosses the first rib.

In the axilla, the lateral and posterior cords are lateral to the first part of the axillary artery, whilst the medial cord is behind it. The cords surround the second part of the artery and derive their names from their positions relative to it: medial, posterior and lateral. With the exception of the medial root of the median nerve, the branches of the cords maintain this relationship to the third part of the axillary artery, and these positions reflect their distribution in the limb.

TECHNIQUES OF BRACHIAL PLEXUS BLOCK

Although many techniques of brachial plexus block have been described, there are essentially four sites of approach: interscalene, suprascavicular, infraclavicular and axillary.

Interscalene

The current popularity of this block is a result of the work of Winnie [31]. The patient is placed supine with the arm to the side and the head turned slightly away. The sternoclavicular and scalene muscles are identified. The former may be accentuated by making the patient lift the head, and the latter by a maximal inspiration. Level with the 6th cervical vertebra (in line with the cricoid cartilage), and at the lateral border of the clavicular head of sternoclavicular, the index finger is rolled laterally across the belly of scalenus anterior until the interscalene groove is identified. The needle is inserted into the groove in a direction that is perpendicular to the skin in all planes and advanced until appropriate paresthesiae or response to electrical stimulation are obtained.
Supraclavicular

There are numerous techniques and modifications of this approach, and the one used is largely a matter of individual preference. The brachial plexus is in its most compact state in this region—the three trunks lie very close together—so that complete block should be more likely.

The patient adopts a position similar to that described above. The procedure may be facilitated by asking him to reach for his knee or by placing a small sandbag between his scapulae. Both manoeuvres have the effect of lowering the shoulder. The point of needle insertion is approximately 1 cm above the midclavicular point, just lateral to the subclavian artery and the outer border of scalenus anterior. This point should be near a line projected from the initial course of the external jugular vein (which can be made more prominent by blowing out the cheeks). The needle is directed downwards, inwards and backwards so that it is pointing towards the spine of the 6th thoracic vertebra. As the needle is advanced, the plexus should be located by either paraesthesiae or electrical stimulation. If contact with the upper face of the first rib is made without having located the plexus, the needle is moved in an anteroposterior direction until it is found.

Another popular method of supraclavicular block is the subclavian perivascular technique, described by Winnie [33]. For this block the patient adopts a position similar to that described above. The subclavian artery is palpated at the base of the interscalene groove, the pulsation being more readily appreciated if the patient lies completely flat without a pillow. The needle is inserted just above the palpating finger and directed caudally until paraesthesiae or response to electrical stimulation are obtained. A click may be felt as the needle enters the sheath.

Infraclavicular

Raj and his colleagues described this, least used, approach to the brachial plexus in 1973 [20]. With the patient in the supine position, the needle is inserted and directed laterally at 45° to the skin in the coronal plane, 2-3 cm below the midclavicular point. It is usual practice to use a nerve stimulator with this technique. Initially, the pectoral muscles are stimulated, but this response ceases as the tip advances. As the plexus is approached, appropriate contractions are elicited and the voltage should be decreased until movement just persists. The needle is advanced again until maximal movement is observed.

Axillary

The patient lies supine with the arm in the coronal plane and abducted to about 80° with the humerus externally rotated and the elbow flexed. Further abduction should be avoided as it impedes arterial palpation [12] and proximal [19] and circumferential spread of local anaesthetic [26]. The axillary artery is palpated at its most medial point, the needle is inserted over it and directed towards the perceived course of the neurovascular bundle. A click is often felt as the tip enters the sheath; other signs of correct needle placement include paraesthesiae, response to electrical stimulation, transmitted pulsation from the artery or puncture thereof. It is usual practice to advance the needle or catheter some distance centrally, to try and ensure that the injection is made above the point where the musculocutaneous nerve leaves the sheath.

COMPLICATIONS

Each block described may produce complications. Puncture of a vessel with subsequent haematoma formation (which may compress the neurovascular bundle) and intravascular injection are, of course, possible with any approach, so careful aspiration tests should always precede injection. Other potential complications with all the approaches are systemic toxicity caused by local anaesthetic drug overdose, neural damage caused by intraneural injection, needle or current trauma or accidental injection of a neurolytic substance.

It has been suggested that the elicitation of paraesthesiae increases the incidence of postanaesthetic neuropathy compared with other techniques. Selander and colleagues [24] described 10 cases of neuropathy attributed to anaesthesia. Eight of these cases were found in a paraesthesia group (290 cases—2.8%), whilst only two were found in a transarterial group (243 patients—0.8%). However, this difference was not statistically significant and interpretation of the findings is complicated further by the types of solution used. All subjects in the paraesthesia group (n = 290) received mepivacaine with adrenaline, but only 116 of the 243 patients in the transarterial group received that solution. The others received mepivacaine without vasoconstrictor. All the patients who developed post-
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anaesthetic neuropathy received mepivacaine with adrenaline. The blocks in the study were performed using a 14° (i.e. long) bevel needle.

Plevack and colleagues [18] examined retrospectively 716 axillary blocks performed using paraesthetic (477) and transarterial (239) techniques. The found a 2.9% incidence of persistent neuropathy in the paraesthetic group, compared with 0.8% in the transarterial group. Varying local anaesthetic solutions (with and without adrenaline) were used and there is no mention of needle bevel, although the date of the study (1983) suggests a long bevel. Again, interpretation is difficult. In another study Selander and colleagues [23] demonstrated that long-bevelled needles (14°) caused more damage than short-bevelled (45°) when rabbit nerves were pierced deliberately, and they recommended that short bevels should be used in local anaesthetic practice. Unfortunately, there are no studies to date comparing paraesthetic and non-paraesthetic techniques with short-bevelled needles. There also is a tendency now to insert the needle along the course of the axillary sheath, whereas it is likely, although not stated, that the needles were inserted perpendicularly to the nerves in the earlier studies.

Other complications are more specific to the approach used. Pneumothorax is seen most commonly with a supraclavicular approach, but is possible also with infraclavicular and interscalene injection, although with the latter its very occurrence implies incorrect technique or nomenclature. With the interscalene technique there is a risk of phrenic nerve, stellate ganglion and recurrent laryngeal nerve block. Extra- or intradural injection and vertebral artery puncture may occur also [12]. Phrenic nerve, stellate ganglion and recurrent laryngeal nerve block may also follow the supraclavicular technique. Block of these nerves is unlikely with axillary injection.

EXTENT OF BLOCK
The above approaches have usually been considered in terms of their reliability in blocking the various nerves supplying the arm. Interscalene injection reliably anaesthetizes the outer aspect of the arm, but only blocks the ulnar nerve in approximately 50% of cases [12]. The supraclavicular approach is usually thought to provide the most complete block, regularly producing anaesthesia of the whole of the upper arm, with

the exception of the skin over the shoulder [12]. The infraclavicular approach is said to produce a similar distribution of block [19]. Axillary injection produces reliable block of the medial aspect of the arm, forearm and hand, but may fail to anaesthetize the lateral aspect of the limb (that is, the musculocutaneous and radial nerves) in 50% of patients [12].

CHOICE OF METHOD
Because of the ease with which it can be performed and the reliability of block distribution, the supraclavicular approach has become the standard by which the other techniques are judged. As indicated above, the interscalene and axillary approaches do not provide such reliable block distribution, but axillary injection in particular may carry a lower risk of complications, especially for the novice. The infraclavicular approach produces reliable block in experienced hands, but is technically more difficult to perform. The choice between these methods is influenced usually by the familiarity or skill of the individual anaesthetist with a particular technique, the distribution of block required and the perceived risk of complications. However, recent work on axillary injection has suggested that reliable block can be achieved. If this is the case, it would (possibly) become the technique of choice (as predicted by Burnham in 1958 [2]).

FACTORS INFLUENCING AXILLARY BLOCK
One of the main theories advanced for failure of axillary injection to anaesthetize the arm reliably was the existence of septa within the sheath preventing the spread of agent. This theory gained support when Thompson and Rorie [25], using cadavers and computerized axial tomography, demonstrated the existence of septa which appeared to form separate compartments around each nerve. They concluded that these limited circumferential spread of local anaesthetic. Thompson suggested [22] that the key to successful block was multiple, small volume injections.

Against this view is the fact that a single axillary injection not infrequently produces complete block of the upper limb. Vester-Andersen and colleagues [26] carried out further cadaver studies and were unable to demonstrate the presence of any septa. However, they did find that, as the arm was abducted, the stretched neurovascular bundle
progressively approached the lateral wall of the axilla. This appeared to have the effect of limiting circumferential spread, especially to the radial, musculocutaneous and axillary nerves. They concluded that this physical restriction of spread of injected solution (blue stained aqueous gelatine in their study) was responsible for the phenomenon of incomplete block, and suggested that injection with the arm by the side would help promote spread (this would, of course, necessitate a catheter technique).

A further examination of the axillary sheath was undertaken by Partridge and colleagues in 1987 [17]. In cadavers, they demonstrated the presence of extensive velamentous septa forming compartments around the contents of the sheath. However, these septa were found to be incomplete and not a barrier to spread. Indeed, single injections of methylene blue into the axillary sheath resulted in immediate staining of the median, radial and ulnar nerves. Unfortunately, they provided no information on the musculocutaneous and axillary nerves, but concluded that there was no need for multiple injections into the axillary sheath. They also noted the failure of Vester-Andersen and colleagues [26] to demonstrate the existence of septa, and they postulated that the reason for this was the similar consistency of the velamentous septa and the gelatin that the latter investigators had used.

It would seem, therefore, that the septa of the axillary sheath are not normally responsible for so-called “patchy” blocks. Of course, anatomical variation cannot be excluded, and it is possible that in some patients more substantial septa exist which are capable of isolating some nerves from the others, especially as they spread apart in the distal part of the sheath (fig. 3). Ang and colleagues [1] found that injection outside the sheath could still produce block, although somewhat more latently. Nevertheless, it is probably a fair assumption that the more remote the site of injection, the greater likelihood of patchy block. Selander [22] stated that one reason for failure of a single axillary injection technique might be inadequate spread because of insufficient volume of agent.

In 1987, Cockings and colleagues [5] described a transarterial technique of axillary plexus block. This involved deliberate penetration of the axillary artery, then advancing the needle until its tip was just outside the vessel again, when 25 ml of 1.5% plain mepivacaine was injected. The needle was then withdrawn into the arterial lumen, and advanced again until just outside the vessel, when a further 25 ml of the agent was injected. During the procedure, firm digital pressure was applied to the artery distal to the injection site, a manoeuvre used frequently to promote proximal spread, and one which has been shown to be more effective than a rubber tourniquet [34]. When injection was complete, firm pressure was maintained over the injection site for at least 7 min. An extremely impressive success rate of 99%, including the radial and musculocutaneous distributions, was reported; this is considerably greater than that of

![Fig. 3. Cross section of the arm high in the axilla (A) and at its mid point (B) to show relationship of the main nerves of the forearm to the axillary/brachial artery. The more medial the injection, the more likely is local anaesthetic solution to reach all the nerves. (Drawn from information in [1] and [17].)](image_url)
any other author or following other techniques. Indeed, their one failure was a complete failure, indicating that injection had occurred outside the sheath. They attributed their success to several factors: the volume and concentration of drug used; deposition of the local anaesthetic deep to the axillary artery (and therefore in the proximity of the radial nerve); and precise landmark identification (knowing they were injecting very close to the artery).

Using the catheter technique described by Selander [21], Vester-Andersen and colleagues [27] injected 1% mepivacaine 40 ml with adrenaline into the axillary sheath. They reported complete block in 63% of patients, the remaining 37% having deficient block in one or more areas. The radial nerve was blocked in 75% and the musculocutaneous in 80%. Many variables were examined in an attempt to find a relationship with incomplete block, including age, weight, height, elicitation of paraesthesiae, and incidental arterial puncture, but no correlation was discovered. They concluded that “the results reject the essential influence of factors to which great importance has previously been attached”. A noteworthy point raised in that paper is the definition of the “successful block”. Unfortunately, most papers describe a successful block as one that is adequate for surgery. The success rate thus depends on the site of surgery, in addition to the extent of block. Therefore, axillary blocks for operations in the distribution of the ulnar and medial nerves will inevitably achieve greater success rates than those performed for surgery in the radial or musculocutaneous distributions. Whilst the description is adequate clinically, it makes scientific interpretation difficult. Investigation of factors influencing block requires thorough examination in all cutaneous areas before conclusions are drawn.

Many “ideal” volumes have been described for axillary block, ranging from 16 to 50 ml [3, 6, 7]. In 1983, Vester-Andersen and colleagues [28] investigated the role of volume in axillary block. Using the same technique as before, they injected 20, 40 or 80 ml of mepivacaine with adrenaline such that the total dose of mepivacaine was 400 mg. Increasing the volume from 20 to 40 ml, and from 40 to 80 ml significantly increased the incidence of analgesia in the distribution of the axillary nerve. There was a significant increase in musculocutaneous block in the 40- and 80-ml groups compared with the 20-ml. Anaesthesia of the radial nerve tended to increase with volume, although not significantly. The study suggested that increasing volume, although tending to extend the analgesic areas, was not in itself the solution to reliable block.

In a further study [29], Vester-Andersen and colleagues examined the effect of varying concentration of local anaesthetic on axillary block. They used 40 ml of 0.5%, 1.0% or 1.5% mepivacaine with adrenaline injected with the same catheter technique as previously. There was no significant difference in the degree of sensory block achieved between the groups, although motor block increased with concentration. Another study, examining the effect of varying dose and volume on axillary block was carried out by the same group [30] in 1984. This entailed the administration of 40, 50 or 60 ml of 1% mepivacaine with adrenaline. They found that there were no statistical differences with regard to sensory block between the groups, but noted that the “incomplete” blocks tended to be “less incomplete” with the greater doses.

The above studies of Vester-Andersen and colleagues [26-30] were well controlled and this permitted information from all the studies to be analysed together. They concluded that: increasing volume extends the area of analgesia; increasing concentration enhances motor block; and an increase in dose improves “density” of the sensory block achieved. On the basis of these studies, they suggested that 50 ml of 1% mepivacaine with adrenaline would “provide an acceptably high incidence” of reliable block (50 ml is of course the volume suggested originally by Eather [7], and used by Cockings and colleagues [5]).

Youssef and Desgrand [35] compared two techniques of axillary injection—transarterial (although, unlike Cockings and colleagues [5], they punctured the posterior wall of the vessel only once) and a “conventional” method involving no arterial puncture. Both groups received 1% prilocaine 40 ml. They achieved complete block of the arm in 48% and 59% of patients in the transarterial and conventional groups, respectively. The transarterial method tended to increase axillary and radial nerve block (as would be expected), whilst the conventional technique tended to increase musculocutaneous block. These differences were not statistically significant. They also reported complete failure twice as often in the transarterial group compared with the conventional technique (six compared with three;
ns)—a result the authors described as surprising in view of the definite end-point. They related this failure rate to unfamiliarity, and suggested that regular practice of a particular technique should increase success rate. Whilst this is undoubtedly true, it is worthwhile noting that, in Cocking’s study, the blocks were performed by (presumably inexperienced) trainees.

A modified transarterial approach has been described by Gibbons and Leonard [10]. They withdrew the needle into the lumen and re-punctured the posterior wall of the artery, after every 5-ml injection of local anaesthetic, until the total dose (mean 48 ml) had been administered. No formal assessment of the resulting block was undertaken, but the block was “adequate” for surgery (site unstated) in 96% of patients. However, it is of note that, half-way through the (retrospective) study period they modified the technique to include musculocutaneous nerve block in the forearm. This change was initiated presumably because of repeated failure to block the nerve with the other technique.

Since the introduction of axillary catheters by Selander in 1977 [21], many authors have described modifications of the technique. The catheter provides several advantages over needle techniques. These include less risk of trauma when advanced to a medial injection point, the facility to provide protracted analgesia either by infusion or repeated injection [9, 15], the opportunity to top up an inadequate block before surgery [4, 21], and the ability to make the injection with the arm by the patient’s side. This relaxes the sheath, allowing better circumferential spread [26] and also avoids compression by the humeral head, so promoting better proximal spread [32].

CONCLUSION

The transarterial axillary block technique described by Cockings and colleagues [5] stands supreme in terms of reliability. However, deliberate puncture of a major artery is not without risk, especially if multiple penetrations are used. A recent case report [16] emphasizes that arterial damage is a real, albeit rare, complication of axillary block, even when the artery is not punctured deliberately. In addition, Cockings and colleagues used relatively large volumes of a strong solution; 50 ml of 1.5% mepivacaine (750 mg) is approximately twice the amount most other workers have used (400 mg). Therefore they measured plasma concentrations in 10 patients. The mean maximum concentration was 3.33 μg ml⁻¹, and the greatest individual maximum concentration was 5.21 μg ml⁻¹. The threshold for toxicity with mepivacaine is said to be approximately 6 μg ml⁻¹ and, in a series of 514 patients, they saw only one case of mild systemic toxicity. This would suggest that such a dose of mepivacaine can be used for brachial plexus block, given an appropriate standard of care. Prilocaine also has sufficient safety margin for an equivalent dose to be considered.

The results of comparative transarterial studies suggest that it was not arterial puncture per se that was responsible for the success claimed by Cockings and his colleagues, and it would be interesting, therefore, to see if the use of similar amounts of local anaesthetic by other axillary techniques (such as Selander’s catheter [21]) would produce such reliable block, without significant risk of complication.

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