

Functional Anatomy of the Brachial Plexus Sheath: Implications for Anesthesia

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Anatomical study of the brachial plexus of 18 cadavers was undertaken to confirm the presence and significance of "septa" dividing the brachial plexus or axillary sheath. Dissection demonstrated that the sheath consists of multiple layers of thin connective tissue surrounding the various elements of the neurovascular bundle. These septa are incomplete, however, forming small bubble-like pockets when solution is injected. Single injections of methylene blue and Latex solutions into the axillary sheath resulted in immediate dye staining of median, radial, and ulnar nerves, despite the presence of septa. These data demonstrate that there are connections between compartments within the sheath and, therefore, do not support the need for multiple injections when performing an axillary block. (Key words: Anatomy: brachial plexus. Anesthetic techniques: axillary; regional.)

BLOCKADE OF THE BRACHIAL plexus with local anesthesia depends upon the anatomic arrangement of the brachial plexus and its terminal nerves in the axilla and the fascial sheath which surrounds them.¹⁻⁶ Some authors consider the axillary sheath to be a dense tubular structure extending from above the first rib to nearly the antecubital fossa with the axillary artery and vein and median, radial, and ulnar nerves lying loose within its center.^{2,4} Recently, Thompson and Rorie^{7,8} proposed a new concept for the axillary sheath in a study of three cadavers and ten human volunteers in whom they injected radioopaque dye. They describe a thinner sheath than that previously appreciated, in which the nerves and vessels lie separated by discrete fascial septa. They argue that, to produce the highest rate of success, an axillary block should be performed with separate injections into the compartments in which each of the nerves in the axillary sheath lie. The presence of septa in the axillary sheath and their clinical relevance has been challenged both on the basis of previous anatomical studies and the indisputable fact that most at-

tempts at axillary block produce adequate anesthesia for surgery even if single injections are made.^{6,9} We undertook this study to confirm Thompson and Rorie's observations regarding the presence of septa, and to examine the degree to which these form a physical barrier to injection of local anesthetic.

Methods

Anatomical studies were carried out in 18 adult cadavers, aged 28-79 yr at death. Only cadavers free from obvious pathology of the upper extremities, axilla, and neck were studied. In each case, the axillary sheath was dissected on both sides, providing a total of 36 cases. In addition, one stillborn fetus, aged 24 weeks, was examined, and histological sections were made of the axillary sheath. Dissections were done between 4 and 20 h post-mortem. With the two arms extended and the shoulder abducted 90°, the skin was incised along the grooves between the long head of the triceps and the short head of the biceps on each side, and carefully dissected back to reveal the axillary sheaths without puncturing them. In each case, the axillary sheath was then dissected to identify the artery, vein, and median, radial, and ulnar nerves, and to attempt to delineate the septa within the sheath. In five cases, percutaneous insertion of a 22-gauge "b-bevel" needle was made on the basis of external anatomical landmarks^{4,10-12} and palpation of cords against the humerus. The needle was inserted until a distinctive "pop" was felt, and the location of the needle tip with respect to the axillary sheath was then determined by careful dissection.

In 20 cases, after opening the skin but prior to dissection of the sheath, a 22-gauge "b-bevel" needle was introduced into the sheath under direct visualization, approximately 50 mm from the apex of the axilla, and 20 ml of methylene blue were injected. The sheath was then immediately dissected to determine the degree of methylene blue staining of each of the nerves within the sheath.

Finally, in two cases, liquid Latex solution was injected and the entire sheath was removed from the clavicle to the end of the sheath at the intramuscular septum, above the antecubital fossa. To prepare the solution, Latex powder was dissolved in acetone. A 22-gauge "b-bevel" needle was inserted into the sheath and held fixed in place. Approximately 40 ml of acetone were slowly injected into the sheath, followed by 30 ml of the Latex solution. Contact of the solution with water in the tissue resulted in

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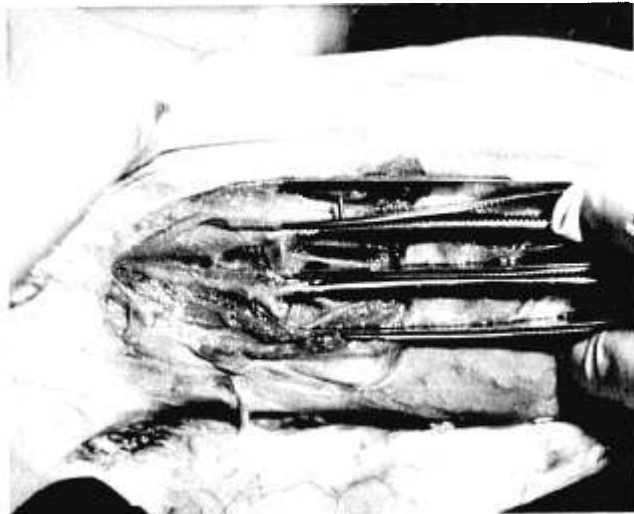


FIG. 1. Dissection of adult cadaver to demonstrate septa within the axillary sheath. The sheath has been exposed and a blunt probe has been passed along the lengths of the median, radial, and ulnar nerves (top to bottom) to free the connective tissue from the nerves. Forceps have been inserted along the course of each nerve to demonstrate the compartments running along their length.

immediate precipitation and hardening of the Latex. Ligatures were placed at the proximal and distal ends of the sheath, and the sheath was dissected free of the arm. The specimen was then fixed overnight in 10% formalin. Sections were made through the entire sheath at approximately 1-cm intervals to determine the paths of the vessels and nerves within it.

In the stillborn fetus, the axillary sheath was dissected *en block* and fixed in Bouin's solution, then embedded in paraffin and sectioned for histological examination after hematoxylin and eosin staining.

Results

When carefully dissected, the axillary sheath does not appear as a tough fibrous cord, as previously depicted,^{1,5} and neither is it hollow.⁹ Rather, it is made up of numerous thin layers of velamentous fascia with no free space between layers. It is possible, however, to dissect between layers or to inject fluid to separate them. By passing a probe along the length of the nerves of the sheath, the separate compartments can be seen as described by Thompson and Rorie^{7,8} (fig. 1). These compartments, extending the length of the nerves in the axillary sheath, are always present. The degree of adherence to the nerves is somewhat variable, but, in the cadavers we studied, the connective tissue was usually adherent to the nerves, leaving no space between them prior to dissection or injection of dye solution.

Injection of methylene blue solution or saline into the axillary sheath demonstrated that it is not a uniform tube

or collection of tubes. Multiple layers of interconnecting fibrous tissue form numerous compartments and channels within the axillary sheath. Slow steady injection resulted in gradual inflation of multiple small grapelike pockets within the sheath (fig. 2A). In only three cases did the sheath seem to inflate smoothly and uniformly. Inflation of the pockets generally occurred in a distal to proximal fashion, but, occasionally, a pocket would suddenly fill well behind the proximal flow of the methylene blue. From this pattern of inflation, the sheath is clearly made up of interconnecting septa, forming multiple distinct pockets.

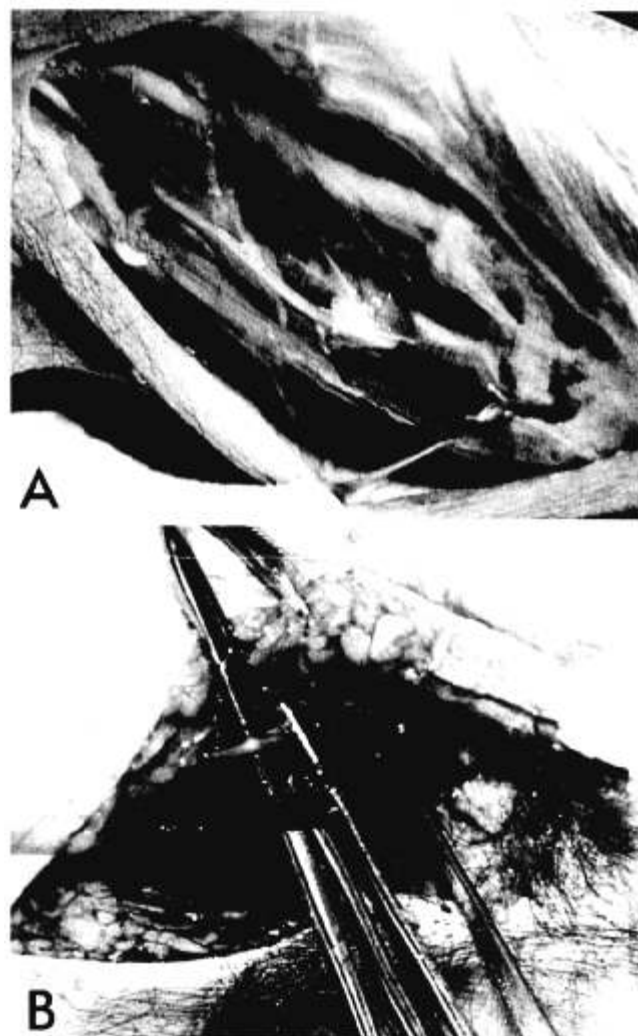
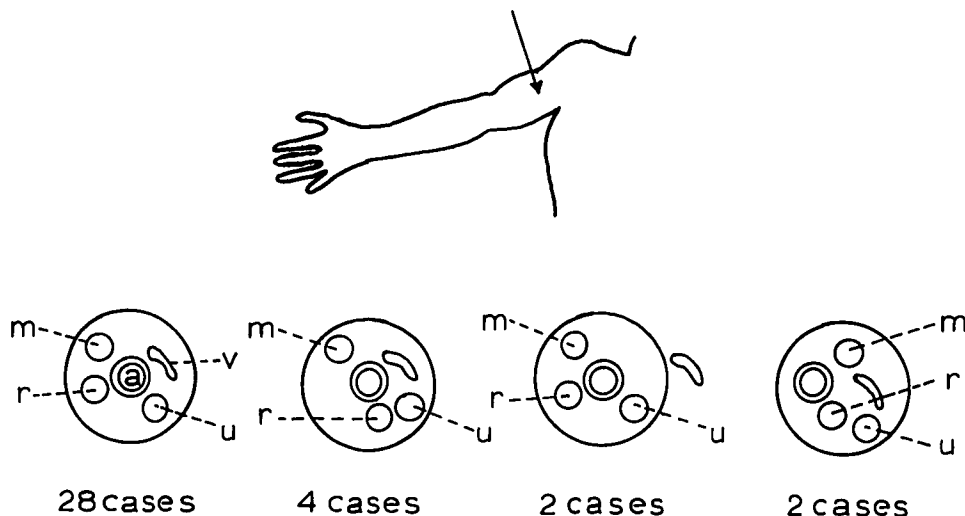


FIG. 2. Injection of methylene blue into the axillary sheath. A. A single injection of 20 ml dilute methylene blue solution has been made into the sheath as described in the text. Numerous small compartments of fluid are seen and the velamentous nature of the layers of the axillary sheath is apparent. B. Following injection of methylene blue, the sheath has been carefully dissected to reveal dye staining of the median, radial, and ulnar nerves (top to bottom) within it. Note that, while stained, the median nerve is a lighter color than the radial and ulnar nerves. Darkest staining in this case was of the ulnar nerve, nearest the site of injection.

FIG. 3. Variable anatomy of the axillary sheath. Displayed are drawings of the most common arrangements of components of the neurovascular bundle in 36 dissections from 18 cadavers. Cross-sections were taken at the point labeled with an arrow. Approximate positions of the median (m), radial (r), and ulnar (u) nerves are shown relative to the axillary artery (a) and vein (v).



In the 20 methylene blue injections, the medial, ulnar, and radial nerves were immediately tinged with dye in each case, despite injections being made at a single point. An attempt was made to vary the location of the injections within the sheath, making some shallow and some deeper. Depth of the needle within the sheath had no major effect on overall distribution of dye within the sheath. While all three nerves were dyed in each case, they were not always colored equally. Injection of dye superficially in the sheath did not always heavily dye the median nerve. Figure 2B shows the results from one such injection. In it, the median nerve has taken up less dye than the radial and ulnar nerves, but is clearly tinged with the methylene blue.

Location of individual components of the neurovascular bundle within the sheath is quite variable. In general, the positions of the nerves with respect to the axillary artery correspond to those described previously,^{1,2} but a number of variations were seen in 36 dissections from the 18 cadavers (fig. 3). Most commonly (28 cases out of 36), the median nerve lay posterior to and above the axillary artery, the radial nerve lay directly posterior to the artery, below the midline, and the ulnar nerve lay slightly below and anterior to the artery. In four cases, however, the radial nerve lay anterior to the artery and adjacent to the ulnar nerve. In two other cases, all three nerves lay anterior to the axillary artery, and, in an additional two cases, the axillary vein lay outside the axillary sheath altogether. In each individual where an anatomical variant was seen, the contralateral arm had the more common "normal" anatomy.

Representative sections through one of the Latex injected axillary sheaths are shown in figure 4. Injection was made at approximately the point shown by the arrow in the figure. Some muscle tissue remains adherent to the axillary sheath in the sections. Tracings from the sections are also shown with areas embedded with Latex shaded in gray. It is clear that injection in a single location coats

all three nerves of the axillary sheath. In addition, the multiple layers of the septa can be seen clearly in the photographs of the sections as thin wavy lines coated with Latex. As noted for figure 2, in this instance, the median, radial, and ulnar nerves are all located anterior to the axillary artery. This is the case even though only 30 cc of Latex were deposited and no large collection lies posterior to the nerves, making it unlikely that the relative position of the nerves and arteries is an artifact of injection.

In each of the five attempts to place a needle in the axillary sheath, a clear "pop" was felt approximately 0.5–1.0 cm below the skin surface. Upon dissection, however, the "b-bevel" needle clearly had not penetrated the axillary sheath in a single case, although it was always found to overly it. In each instance, the needle had penetrated the skin and the subcutaneous fascia, and was lodged in the layer of fat anterior to the axillary sheath. When the sheath was actually penetrated under direct visualization, no "pop" was felt. Instead, the needle passed smoothly and easily through the thin layers of the sheath, and resistance was only felt on encountering the nerves or vessels within it.

Examination of sections through the axillary sheath demonstrated the same arrangement of connective tissue seen in gross examination of the adult cadavers. Multiple thin layers separated and surrounded the components of the sheath. Some layers of connective tissue wrapped around the nerves and vessels, and others extended to the edge of the sheath and continued around the bundle as a whole.

Discussion

In light of our studies, we envisage the axillary sheath in the following way. Multiple thin layers of connective tissue surround the neurovascular bundle, but, as previously noted,^{7,8} this external covering is not a solid sheath.

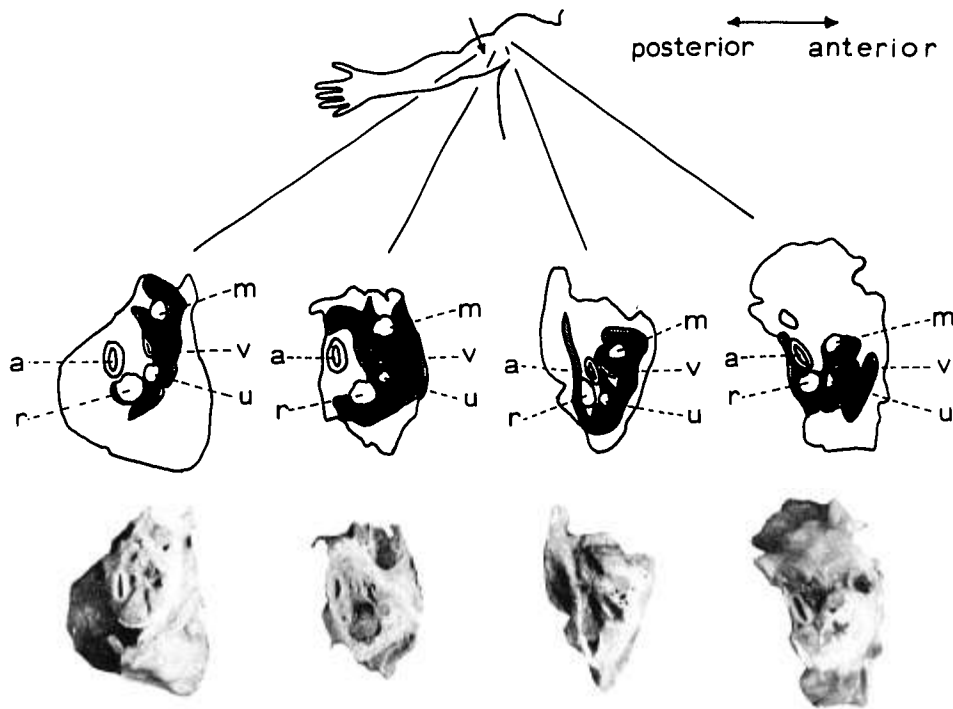


FIG. 4. Representative cross-sections of the axillary sheath after single injection with latex solution. Photographs of sections through the sheath of one patient are shown together with tracings. The sheath is surrounded by remnant muscle tissue in some sections. Virtually the entire sheath has been filled with the latex (shaded areas); the axillary artery (a), axillary vein (v), median nerve (m), radial nerve (r), and ulnar nerve (u) are labeled. Injection was made approximately at the point delineated by the arrow.

Within the sheath, the septa described by Thompson and Rorie^{7,8} do exist, and are, in fact, far more extensive and complicated than previously described. Multiple thin layers of fibrous tissue separate components of the neurovascular bundle within the axillary sheath, and the tissue is frequently adherent to the nerves and vessels. In life, there may normally be no spaces between components of the neurovascular bundle. Injection of solution between layers of the interconnecting septa results in separation and filling of discrete, interconnecting, grapelike bubbles. Vester-Andersen *et al.*⁹ injected a colored gelatin solution into the axillary sheath of 20 cadavers using a catheter technique. They did not observe septa upon dissection, but this may be due to the velamentous nature of the septa and the similar consistency of gelatin. Injection of a liquid makes the septa more obvious.

Presence of septa has implications for brachial plexus anesthesia. Thompson and Rorie^{7,8} recommend a technique of three injections, and they published computed tomographic images of discrete pockets of contrast following use of the three injection technique. As noted by Vester-Andersen *et al.*,⁹ the computed tomographic images do not allow localization of the nerves within areas of contrast. In addition, Thompson and Rorie did not report whether similar pictures might not have been seen with single injections. The high success rate of single injection techniques in producing surgical anesthesia suggests that this would occur, and, certainly, our methylene blue and Latex injections support this notion.

To what extent do the septa form a physical barrier to

anesthetic solutions? Since single injections resulted in immediate dye-staining of all three nerves in the sheath, the septa must be incomplete and allow fluid to pass between layers. Nerve block depends upon the volume of anesthetic reaching the individual nerve bundles within the sheath, so staining by dye does not necessarily ensure equal or adequate block. The volume of anesthetic required to produce anesthesia is small, however. For instance, one drop of 2% Lidocaine placed directly on the sciatic nerve of the rat completely abolishes nerve conduction (unpublished observations). In brachial plexus anesthesia, an order of magnitude more drug is usually employed than is required for anesthesia of individual nerves in order to provide proximal flow of anesthetic.^{6,13} In clinical use of brachial plexus anesthesia, anesthetic may also diffuse through the connective tissue septa. Evidence that this takes place in significant amounts comes from continuous plexus anesthesia techniques using catheters demonstrated to lie outside the axillary sheath altogether.¹⁰ In their study, Ang *et al.* found that onset of anesthesia took up to 45 min, further evidence that the anesthetic needed to diffuse to the site of the nerves.

Lowest success rates are seen for techniques relying on a "pop" as evidence of penetrating the axillary sheath.^{2,3,13} In this study, in no case did the "pop" correspond to actually entering the sheath. Perhaps this is due to changes in tissue consistency postmortem, but adequate anesthesia produced after feeling a "pop" is not evidence of having entered the sheath, since diffusion of anesthetic clearly occurs.⁹

The variable anatomy of the sheath adds to the complexity of predicting the relative locations of nerves in it to obtain multiple paresthesias, but, in any case, our methylene blue studies suggest that this should not be necessary in practice. Note, however, that we made only 20 injections. The incidence of failure using single injection techniques in plexus anesthesia is reported as 2–5% in experienced hands.^{3,4,6,9,15} We cannot exclude the possibility that, in some cases, incomplete blocks, or ones requiring an unusually long time to come on, are due to aberrant anatomy or septa which are truly separating the nerves. Since the nerves are frequently near the edge of the sheath, however, a certain proportion of failed blocks are no doubt due to missing the axillary sheath altogether and, perhaps, injecting into muscle where the anesthetic could be carried away by the vascular supply, even if a paresthesia had previously been elicited. Success of catheter techniques may result from a continuous supply of local anesthetic to the area or to the more proximal positioning of the catheters.^{9,10}

Perhaps some of the variable anatomy we observed is an artifact of our dissection of cadavers. The skin overlying the sheath had been removed and, certainly, the muscle mass surrounding the axillary sheath was firmer than in living patients. Injection of methylene blue or Latex could have shifted contents of the neurovascular bundle, but, given the multiple interconnections between septa, this seems unlikely. In addition, there is no reason to expect that the nerves would be more easily shifted than the artery or vein.

A more worrisome objection is that disposition of methylene blue might be different in cadavers than in living patients. It was for this reason that we did not attempt quantitative studies of the proximal flow of methylene blue as a function of volume injected.^{11,12} Lack of a vascular supply might have prevented dye from being carried away, but little dye could have been removed in the 30 s or so that it took to dissect the nerves within the sheath. Another possibility is that integrity of the septa was compromised in the cadavers, allowing dye to pass from one area to another. We cannot exclude this possibility, but, since all three nerves stained with methylene blue regardless of the time since death, we do not believe that autolysis was a significant problem.

Previous investigators^{4,5,9,10,12,14} have shown that most of the different techniques for plexus anesthesia produce similar success rates. (The fact that so many different techniques are advocated suggests that one is not markedly better than another.) Ultimately, the amount of experi-

ence with a technique is probably the best indicator of the likelihood of a block succeeding. Paresthesias carry a risk of neurological sequelae, however, even if they are elicited accidentally.¹⁵ The risk of neural complications should rise with increased numbers of injections, particularly since, with the onset of anesthesia, nerves might be touched without eliciting a paresthesia. If the compartments surrounding nerves within the brachial plexus sheath did not communicate, then multiple injections would be indicated for brachial plexus anesthesia. The anatomical data presented here demonstrate that there are connections between compartments within the sheath and, therefore, do not support the need for multiple injections when performing axillary blocks.

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