

Functional Anatomy of the Brachial Plexus Sheaths

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The brachial plexus sheath was examined in cadavers by using a combination of anatomic dissection, histologic preparations, and x-rays made after injection of x-ray contrast media, and in surgical patients by using computed tomography (CT) dye studies. The connective tissue forming the sheath was organized more densely proximally near its origin and became loosely organized distally as it ended by joining the medial intermuscular septum of the arm. The connective tissue forming the sheath extends inward, forming septa between components of the plexus. Thus, the sheath is a multicompartmented structure, formed by the thin connective tissue sheath surrounding the plexus and by the septa which extend inward from the sheath. A fascial compartment is created for each nerve, and this compartment serves to define the anatomic limits of that nerve. These compartments have potential clinical importance and implication in the techniques for brachial plexus block. They serve functionally to limit the circumferential spread of injected solutions of local anesthetics. These studies also indicate that injected anesthetic solutions spread easily in a longitudinal manner up and down the nerve and remain compartmentalized. The data presented here provide a rational explanation for the not uncommon occurrence of a profound block of rapid onset in one nerve, yet partial or absent block in other nerves, following any of the techniques of brachial plexus anesthesia. (Key words: Anatomy: brachial plexus. Anesthetic techniques: Regional, axillary, brachial plexus. Nerve: block.)

IN RECENT YEARS, there has been a great deal of attention directed toward single-injection nerve block techniques for the brachial, cervical, and lumbar plexuses.¹⁻⁷ The anatomic basis for these procedures is one that conceives of the nerves and vessels to be enclosed by a tubular sheath into which local anesthetic solution is injected. This sheath serves to confine the injected drug so that structures contained within the sheath are surrounded by local anesthetic solution. The design is simple and its description has been an encouragement to the practice of regional anesthesia, but there are perplexing discrepancies in clinical application.⁷ For instance, in performing axillary nerve block of the brachial plexus, one is concerned with anesthesia of the ulnar, radial, median, and musculocutaneous nerves. Why is anesthesia rapid in onset and complete in some nerves, delayed in onset or incomplete in others, and sometimes totally absent in still others? Such results

would not be expected if a single tubular sheath enclosed these nerves in a common compartment and the injected drug completely surrounded all of the nerves contained therein. We have reexamined the anatomy of the brachial plexus sheath using a combination of anatomic dissection in the cadaver, x-rays made after injection of x-ray contrast media, histologic examination of the connective tissue sheath, and computed tomography (CT) dye studies in surgical patients. Preliminary presentations of some of these data have been made.^{8,9}

Methods and Materials

CADAVER STUDIES

Brachial plexuses were examined in three bodies donated to Mayo Foundation for the purpose of medical science. The age at death was 48-67 years. Only bodies that, by medical history and physical examination, were free of pathology involving the proximal upper extremity, axilla, and brachial plexus were used for study. The studies were commenced 6-10 h following death.

In each body, the skin of the axilla and arm, and subsequently the subcutaneous tissue, were removed by careful dissection so that the neurovascular bundle was identified. Care was taken to not disrupt the connective tissue surrounding the nerves and vessels. The median, radial, and ulnar nerves were identified within the undissected fascia surrounding the neurovascular bundle.

With the arm abducted 90°, an 18-gauge blunt-tipped hypodermic needle connected to a plastic tubing was inserted into the neurovascular bundle at an angle of 75° with the humerus. The point of insertion was 1 cm proximal to the lateral edge of the insertion of the pectoralis major muscle. The needle tip was placed in contact with the median nerve in one body, the ulnar nerve in one, and the radial in the remaining body. Radioopaque dye (15, 30, and 50 ml) was injected into the neurovascular bundle along each nerve. Serial anterior-to-posterior x-rays were made within 2 min of completing injection of each volume of dye.

Following completion of these injections, the neurovascular bundle was removed, with the surrounding connective tissue intact, from the roots of origin of the plexus proximally to its entry into the medial intermuscular septum distally. Cross sectional cuts at 2-cm intervals were made through the entire bundle in order to macroscopically examine the connective tissue surrounding the bundle as well as that between individual components of the bundle. Samples of these tissues were

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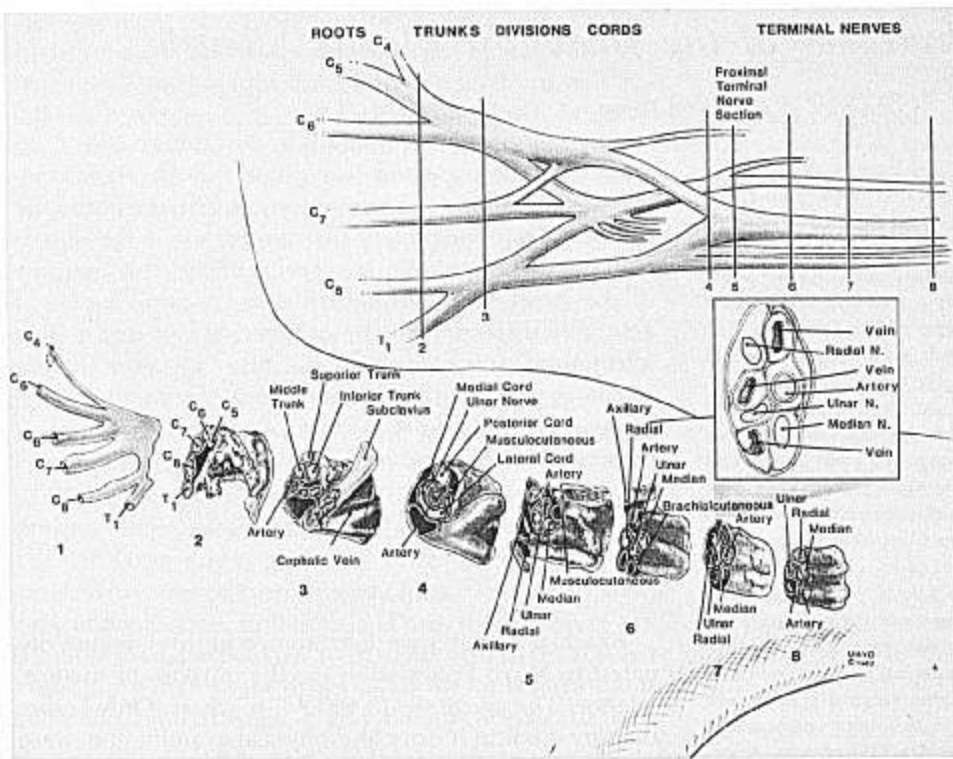


FIG. 1. A brachial plexus with surrounding fascial sheath intact removed from the left side of a body has been transected at 2-cm intervals. The lines across the plexus drawn in the upper right indicate the level of each cut. The sketch of the torso indicates the approximate relationship of the plexus to the neck, shoulder, and upper extremity. Septa of the same approximate thickness as the fascial sheath extend inward from the sheath to form compartments for the individual nerves. The insert shows the fascial compartments containing the nerves and the relationship of each to the axillary artery at the location used by the axillary approach to a brachial plexus block (transection 8).

taken for histologic study. A sample of deep cervical fascia from near the origin of the brachial plexus also was removed for histologic study. All histologic preparations were stained with hematoxylin and eosin.

TOMOGRAPHY STUDIES

Further studies were done on 10 volunteers or surgical patients scheduled for hand operations at Virginia Mason Hospital. Informed consent was obtained in accordance with institutional policies on human experimentation. Computer tomography scans were obtained after axillary brachial plexus nerve block done with the arm positioned perpendicular to the body and the elbow flexed. Upon completion of the block, both arms were extended overhead in order to allow passage of the patient's body through the scanner's aperture. Only in this manner could the arm be viewed to obtain sequential films that would demonstrate the spread of injected solution. The solution injected consisted of long-acting local anesthetic drug (bupivacaine 0.5%) premixed with iohalamate (Conray 60®) in a 5:1 ratio. The injected dye diluted with local anesthetic allowed correlation of anatomy, as viewed by tomograms, with nerve function, as tested by sensory and motor function tests. The total volume of injected solution varied from 10–50 ml. Three different techniques of axillary block were used: perivascular infiltration without seeking paresthesias (four patients), injection only after obtaining paresthesias (four patients), and, a transaxillary artery injection (two patients).

Results

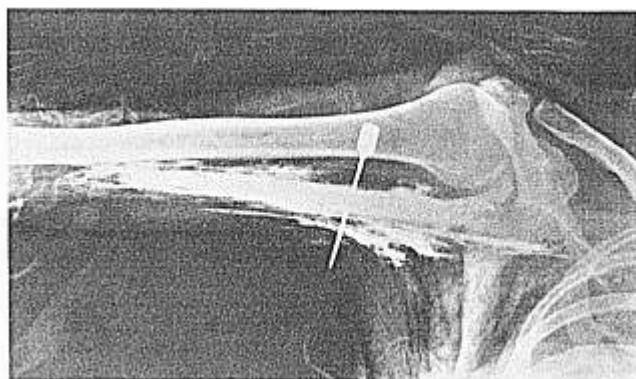
Results

CADAVER STUDIES

Seven cross-sectional cuts at 2-cm intervals across the neurovascular bundles made possible a sequential examination of the relationship of the connective tissue components (fig. 1). Histologic preparations showed that the neurovascular bundle is most dense proximally as it leaves the deep cervical fascia (data not shown). Distally, it becomes organized more loosely. At each level, the connective tissue surrounding the neurovascular bundle was found to extend inward forming distinct septa between components of the bundle (fig. 1). These septa were similar in thickness and density to the surrounding fascia. The septa are a consistent feature throughout the entire length of the plexus as can be seen in the cross section cuts of figure 1.

The septa, together with the surrounding sheath, serve as a barrier to define the limits of spread of injected solutions (fig. 2). Following the injection of x-ray contrast media into the fascial compartment containing the median nerve, the solution spreads up and down that single nerve compartment. After an increased volume was injected (30 ml in fig. 2), it spread to a level proximal to the head of the humerus.

FIG. 2. Anterior-to-posterior x-ray made of a cadaver 2 min after injecting 30 ml x-ray contrast media (diatrizoate meglumine) into the fascial compartment containing the median nerve. The hypodermic needle marks only the site of injection of the media. The media accumulates at the site of injection and spreads proximally in the compartment reaching a level above the head of the humerus (distal cord).



TOMOGRAPHY STUDIES

The overview of figure 3 gives perspective to the arm position and to the multiple levels at which computed tomograms were obtained. A composite of these views as seen in figure 4 demonstrates characteristics of the spread of injected solution. In this patient, there were two distinct compartments visible at the level of injection (*view C*). These solutions come together and totally surround the upper axillary artery (*view D*). Above the head of the humerus there is an extension of solution that spreads further proximally and medially toward the roots of origin of the plexus (*views E and F*). The head of the humerus did not appear to obstruct proximal spread of solution in any patient.

Additional evidence in support of a multiple com-

partmented sheath is seen in figures 5 and 6. In figure 5, anesthetic solution was injected after eliciting paresthesias on both sides of the artery (superior and inferior) and after passing the needle through the artery (posterior). The solution stays confined within three distinct compartments (*view B*). Figure 6 shows four views from three patients; all show spread of solution along the brachial plexus to a level at the head of the humerus or proximal to it. In each view, there are single or multiple fingerlike extensions of solution spreading medially. Another perspective on the nonunicompartamental nature of the neurovascular bundle is seen in figure 7. Although the axillary artery was surrounded totally by anesthetic solution in these two patients, the blocks were incomplete in the distribution of radial and musculocutaneous nerves.

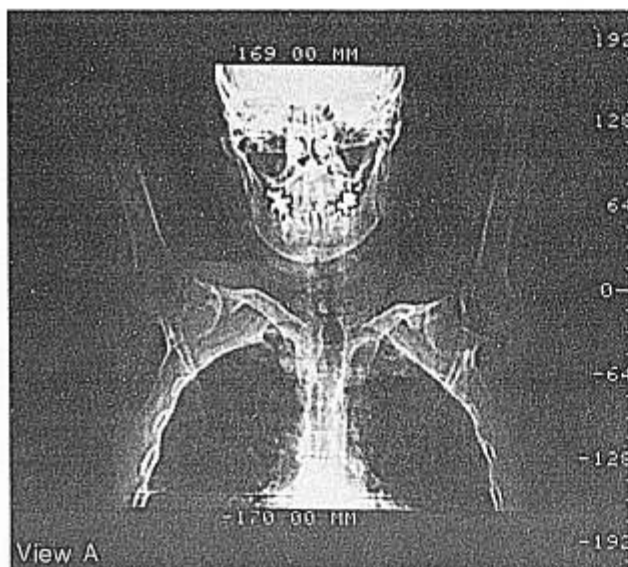


FIG. 3. *View A* is a scout film of a patient inside the CT scanner with arms extended overhead. *View B* illustrates superimposed grid lines where cross-sectional views were obtained from distal arm to proximal, e.g., slice #14 corresponds to *view A* in figure 4 and slice #16 corresponds to *view C* of figure 4

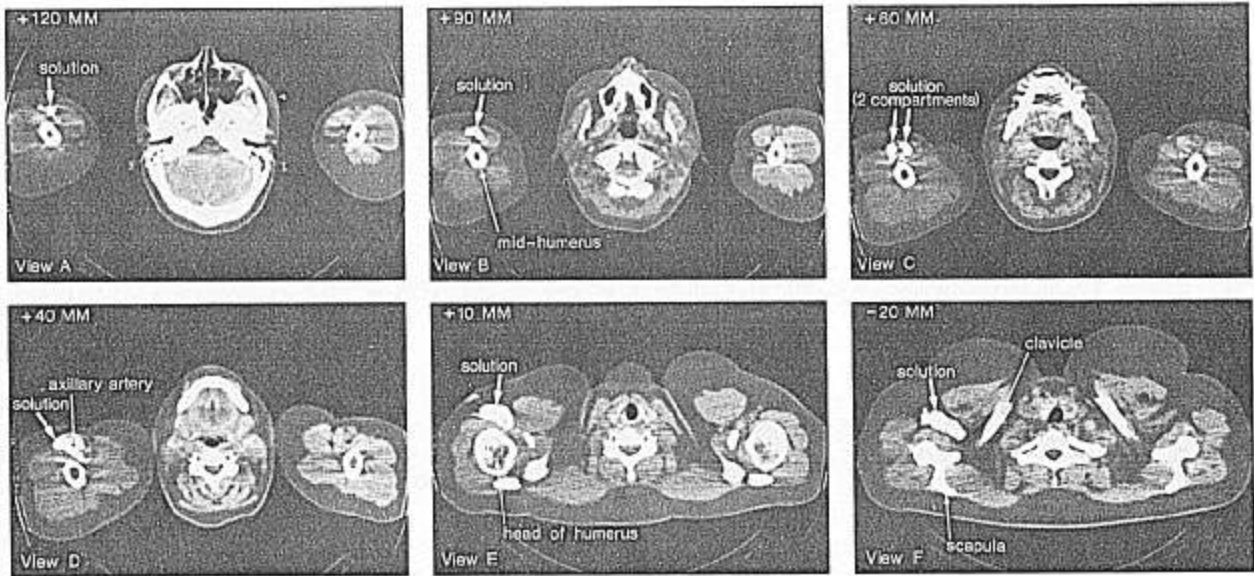


FIG. 4. A composite of tomograms developed from the procedure shown in figure 3. This patient's axillary block was done with a total of 30 ml local anesthetic/iotalamate solution at the level shown in *view C*. At that level, there are two distinct compartments of solution on either side of the axillary artery. The block had been performed by eliciting distinct paresthesias in distribution of ulnar, median, and radial nerves. It was clinically perfect (musculocutaneous nerve also) based on neurologic examination. These views track solution in the right arm over a distance of 14 cm (from 60 mm distal to the site of injection to 80 mm proximal as noted by the grid line levels in the upper left hand corner of each view). The solution totally surrounds the axillary artery in *view D*, proceeds proximally beyond the head of the humerus, and then extends medially toward the lateral edge of the clavicle.

Discussion

These findings from gross anatomic dissection, histologic preparations, dye injections, and computed tomography are mutually supportive of a new anatomic perspective of the sheath of the brachial plexus. The sheath is a multicompartmented structure, formed by a thin connective tissue sheath surrounding the plexus

and by septa extending inward from the sheath. A fascial compartment thus is created for each nerve, and this compartment serves to define the anatomic limits of that nerve. The compartments serve functionally to limit the circumferential spread of injected solutions. In a longitudinal view, the septa confine solution to distinct channels that can be traced from axilla to the supraclavicular origins of the nerve roots.

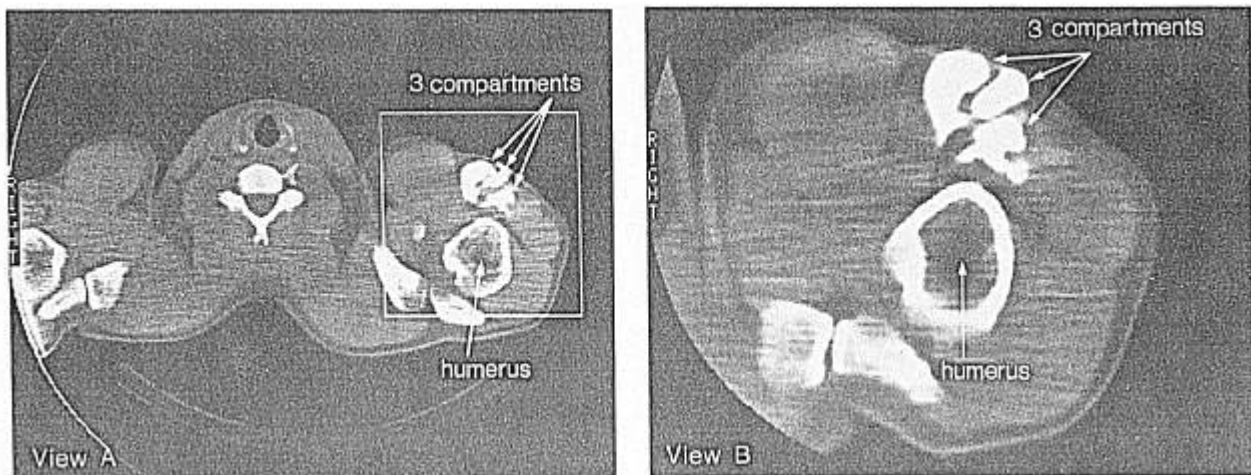


FIG. 5. *View B* is a magnification of the area isolated in *view A*. This patient's block was done by injecting 30 ml solution, 10 ml upon obtaining a median nerve paresthesia; 10 ml for a radial nerve paresthesia; and 10 ml after passing a 25-gauge needle through the axillary artery. The solution stays confined within three distinct compartments. The block was clinically effective.

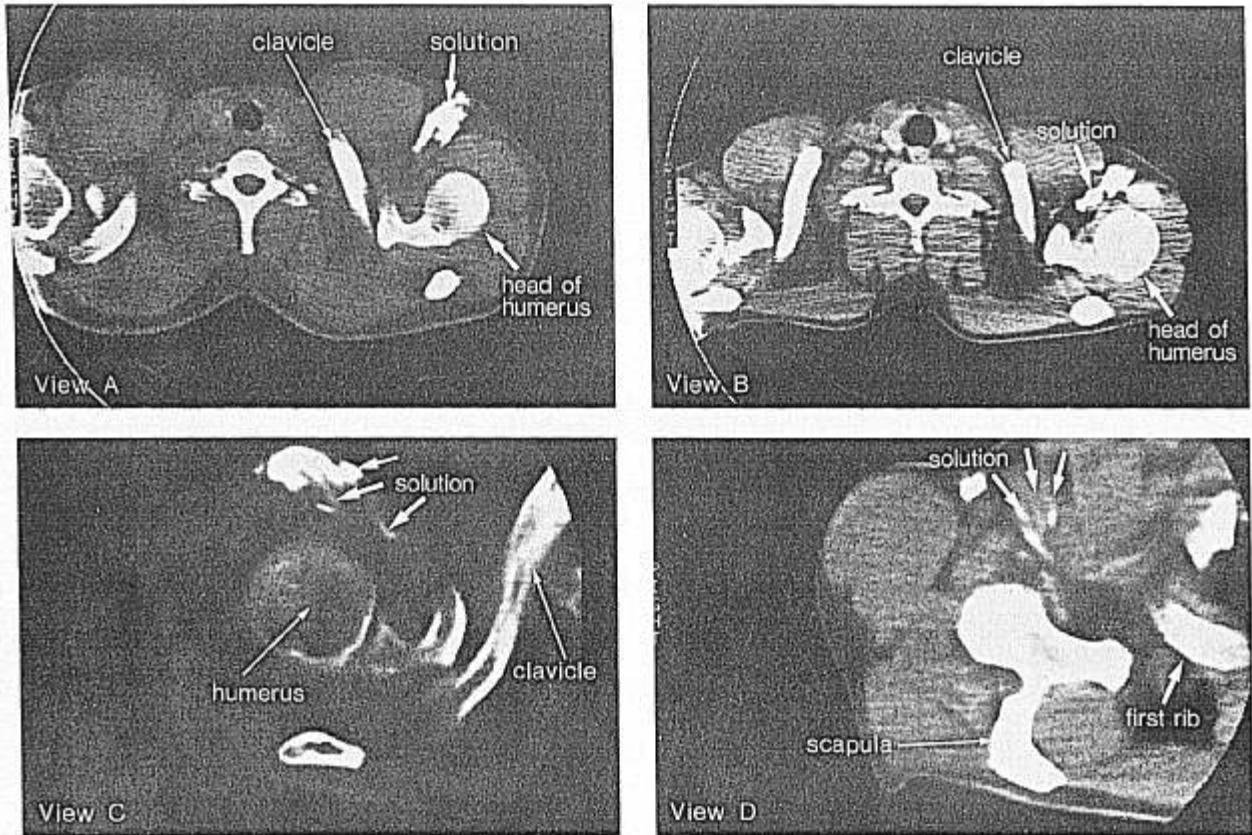


FIG. 6. These four views are from three patients. All portray the proximal spread of solution at, or beyond, the head of the humerus. In each view, there are single or multiple fingerlike extensions of solution as if it were confined to a specific sheath. *View D* is 2 cm proximal to *view C* (the head of the humerus is no longer visible) and the solution is clearly extending medially in separate compartments.

The sheath is derived from deep cervical fascia that is carried distally as the upper extremity develops.^{10,11} The connective tissue forming the sheath and the septa

becomes organized more loosely distally, but it can be traced microscopically and macroscopically from the scalenus anterior and medial muscles in the neck to the

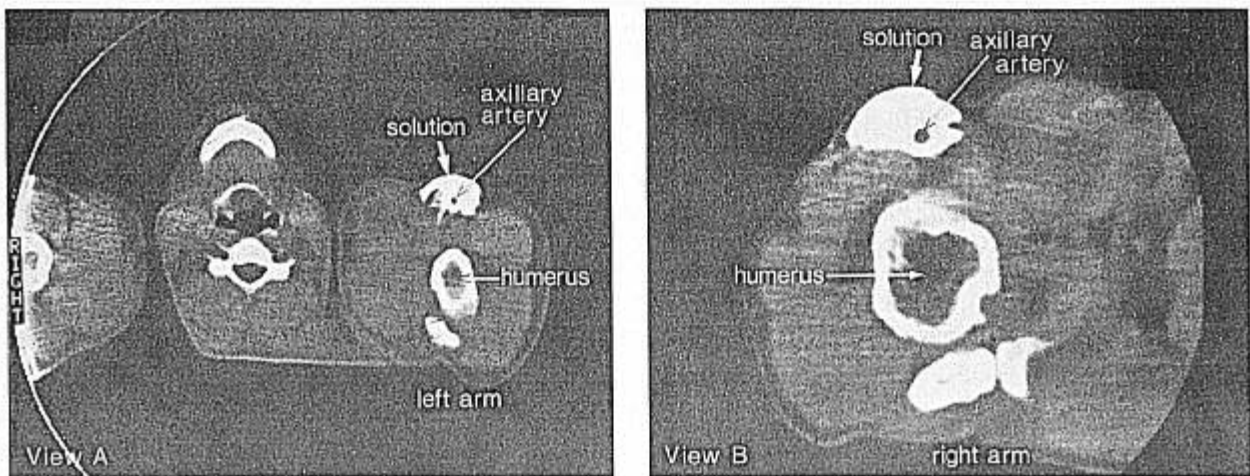


FIG. 7. Views from two patients in which injected solution completely surrounds the axillary artery and yet the blocks were clinically incomplete. For *view A*, a total of 48 ml solution was injected without seeking paresthesias, and the patient had no block of radial and musculocutaneous nerves. The block for *view B* was done by injecting 15 ml solution fan-wise inferior to the artery and 15 ml fan-wise superior to the artery. Again, the block of radial and musculocutaneous nerves was clinically inadequate.

point where the vessels and nerves enter the medial intermuscular septum at the level of the upper humerus. The sheath ends at this point by blending with the anterior and posterior laminae of this septum. Our data do not support previous studies suggesting that the head of a humerus that has been abducted to 90° or more limits the spread of local anesthetic to the proximal parts of the brachial plexus.⁷ However, any controversy over the limits of proximal spread is somewhat superfluous if the multicompartmental model leads to a block technique that emphasizes a multicompartmental injection. In other words, proximal spread is not really the key factor in achieving a successful block. On the other hand, it does appear that some of the compartments found in the axilla actually are connected at a more proximal level. The compartment around the median nerve is continuous with those around the medial and lateral cords, and the compartment around the ulnar nerve is continuous with that of the medial cord. These connecting chambers represent a way by which drug can get from one nerve to another. Thus, the flow of local anesthetic solution upward in the median nerve compartment to the level of the cords of the plexus would bring the anesthetic solution in contact with the origin of the ulnar nerve. By contrast, the upward flow of local anesthetic in the compartment around the ulnar nerve would bring the anesthetic solution in contact with only the contribution given by the medial cord to the median nerve. This, perhaps, explains the baffling clinical observation, occasionally seen, of good anesthesia in only part of the peripheral distribution of the median nerve. There would be no connection between the radial nerve compartment and those of the median and ulnar nerves at the cord level. Thus, if local anesthetic is not injected directly into the radial nerve compartment, an adequate block may be dependent upon the injected solution being great enough in volume to spread proximally to the level of the divisions or higher. Other possibilities include the solution diffusing into the radial nerve compartment through the septum separating it from an adjacent compartment. Thus, there are a variety of mechanisms whereby any given axillary injection may produce an effective block. In those patients in whom successful block follows a so-called single injection technique, the result surely must be due to some combination of proximal spread, diffusion of drug between nerve compartments, or passage of drug through connections between adjacent compartments. By the same token, circumferential spread does not guarantee an adequate block as shown in figure 7. Although the volume injected was sufficient to expand the sheaths and

completely surround the axillary artery, the block was incomplete, as judged by sensory and motor examination.

An important point with reference to these studies is whether the studies of spread of x-ray contrast media in cadavers is representative of the spread that may occur in the living body. All bodies were studied more than 6 h after death. Certainly the surrounding skeletal muscle was becoming rigid and the veins were distended with clotted blood, the collapse of these vessels more difficult and the concomitant facilitated spread of local anesthetic within the sheath. In addition, the removal of skin and superficial fascia from the axilla and arm may have enhanced the localized leakage of drug through the thin sheath, thus reducing upward spread. These factors would serve to underestimate the longitudinal spread of local anesthetic up and down the sheath. Because such spread still was observed, we believe the cadaver studies, taken together with the tomography studies, provide a rational explanation for the not uncommon occurrence of a profound block of rapid onset in some nerves, yet partial or absent block in other nerves, following any of the techniques of brachial plexus anesthesia.

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