Distribution of Local Anesthetic in Axillary Brachial Plexus Block

A Clinical and Magnetic Resonance Imaging Study


Background: There is an unsettled discussion about whether the distribution of local anesthetic is free or inhibited when performing brachial plexus blocks. This is the first study to use magnetic resonance imaging (MRI) to help answer this question.

Methods: Thirteen patients received axillary block by a catheter–nerve stimulator technique. After locating the median nerve, a total dose of 50 ml local anesthetic was injected into the examining in local divided doses of 1, 4, 15, and 30 ml. Results of sensory and motor testing were compared with the spread of local anesthetic as seen by MRI scans taken after each dose. The distribution of local anesthetic was described with reference to a 20-mm diameter circle around the artery.

Results: Thirty minutes after the last dose, only two patients demonstrated analgesia or anesthesia in the areas of the radial, median, and ulnar nerves. At that time, eight of the patients had incomplete spread of local anesthetic around the artery, as seen by MRI. Their blocks were significantly poorer than those of the five patients with complete filling of the circle, although incomplete blocks were also present in the latter group.

Conclusion: This study demonstrated that MRI is useful in examining local anesthetic distribution in axillary blocks because it can show the correlation between MRI distribution pattern and clinical effect. The cross-sectional spread of fluid around the brachial–axillary artery was often incomplete–inhibited, and the clinical effect often inadequate.

BRACHIAL plexus blocks may often give patchy and delayed anesthesia in one or more nerves. Among the many proposed explanations are inadequate volume of injected local anesthetic, inadequate concentration of the anesthetic, or unintentional movement of the needle or the patient. In 1927, Labat4 proposed that the answer could be found in an appreciation of “minute anatomy.” He stated that a solution injected on one side of a fascia normally does not reach the other side of that fascia. Thompson and Rorie5 made similar observations using computed tomography of patients with axillary blocks and histologic examination of the brachial plexus from cadavers. They concluded that fascial compartments exist for each nerve of the plexus and that these fascial barriers serve to limit circumferential (cross-sectional) spread of injected local anesthetic solutions. Consequently, they recommended injecting into multiple sites.6 Partridge et al.7 also studied cadavers but questioned the functional importance of these fascial compartments based on the spread of injected methylene blue dye. This view is similar to that of Winnie et al.,8 who described a perivascular concept for brachial plexus blocks. They claimed that only a single needle insertion is necessary because the injected solution locates the various nerves to be blocked.9 The controversy regarding whether the spread of local anesthetic is free or inhibited has still not been settled.9 Therefore, the aim of the current study was to contribute to the solution of this question. We hoped to gain new information about the distribution of local anesthetic by taking repeat magnetic resonance images after injections of local anesthetic and then correlating these images with the sensory and motor status of the upper extremity.

Materials and Methods

After obtaining approval of the protocol from the regional ethical committee (Regional Komité for Medisinsk Forskningsetikk, Helseregion II, Oslo, Norway), 14 adult patients scheduled for elective hand or forearm surgery gave written, informed consent to participate in the study. The same investigator performed all blocks. An 18-gauge cannula (Contiplex® A/D; B. Braun, Melsungen, Germany) with an outside short catheter (length, 45–55 mm) was inserted approximately 4 cm distal to the lateral border of the pectoralis major muscle and immediately superior to the brachial artery, while the patients ab ducted the arm approximately 90° (fig. 1A). The cannula–catheter was directed toward the axilla and parallel...
to the artery with an initial needle angle to the skin of 30–40°. After “fascial click,” the cannula–catheter was advanced (aided by a nerve stimulator) with a flat angle to the skin. The catheter was taped in median nerve–stimulating position. Subsequently, the cannula was withdrawn and a flexible extension tube was connected to the catheter for later injections of local anesthetic. Continuous suction (using a syringe) was applied to the cannula to detect inadvertent intravascular position of its tip. Muscle twitches distinctive for median nerve stimulation were sought with a maximum current of 0.5 mA and an impulse width of 0.1 ms. The catheter was fixed in this nerve-stimulating position, the cannula was withdrawn, and the catheter was connected to a flexible extension tube for later injection of local anesthetic. The extension tube had a dead space of 0.5 ml and was prefilled with local anesthetic solution.

Subsequently, the patients entered the magnetic resonance imaging (MRI) scanner. Its open design allowed the patients to be supine with the arm abducted 90°. The local anesthetic was injected in divided doses (1, 4, 15, and 30 ml) at a speed of approximately 0.5 ml/s and with 10 min between each dose. The total volume was always 50 ml, usually as 1% lidocaine with 5 μg/ml epinephrine. In case of longer operations, allowance was made for replacing some of the lidocaine with 0.5% bupivacaine. No contrast agent was added. To limit distal spread, digital compression was applied at the insertion site during and for 1 min after the injection of the second, third, and fourth dose.

A sequence of MRI scanning and block assessment (sensory and motor testing) was performed after each local anesthetic injection. Scanning and clinical testing were also repeated 10, 20, and 30 min after the last dose and at a variable time after the end of surgery.

Giving the total dose of local anesthetic in divided doses, with MRI performed between each dose, was expected to yield a better dynamic impression of the local anesthetic distribution than after a single large bolus dose. In particular, the position of the 1-ml dose in the cross-sectional MRI plane would indicate if the catheter tip had an appropriate position in this plane, close to the brachial–axillary artery.

Imaging was performed with an open 0.5 T GE Signa SP scanner (GE Medical, Milwaukee, WI). Twenty-two sagittal images, covering the lateral part of the clavicle as well as the proximal part of the abducted arm, were acquired with a T2-weighted fast-spin echo sequence (repetition time, 7,700 ms; effective echo time, 95 ms; slice thickness, 4 mm; slice interval, 4 mm; matrix, 128 × 256; field of view, 32 × 24 cm). The images were evaluated by the radiology team, who were blinded to the clinical effect.

The local anesthetic distribution was studied in sagittal MRI slices, giving cross-sectional views of the neurovascular bundle with the brachial plexus. A circle was drawn in the images with a diameter of 20 mm and center in the midaxis of the brachial–axillary artery (fig. 1B). The circle was divided into four quadrants. With reference to the 90° abducted arm, the quadrants were named according to the terminology of Thompson and

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**Fig. 1.** (A) Illustration of the point of needle insertion. The patient is in a supine position with the right arm abducted 90° and maximally rotated externally, exposing the medial surface of the arm. The cannula with an outside catheter was inserted immediately superior to the brachial artery, approximately 4 cm distal to the lateral border of the pectoralis major muscle. It was directed toward the axilla, parallel to the artery. The initial cannula angle to the skin was 30–40°. After fascial click, the cannula–catheter was advanced (aided by a nerve stimulator) with a flat angle to the skin. The catheter was taped in median nerve–stimulating position. Subsequently, the cannula was withdrawn and a flexible extension tube was connected to the catheter for later injections of local anesthetic. (B) Schematic cross-sectional drawing from the right arm illustrating the quadrant system around the brachial artery and the common position of the four terminal nerves. The musculocutaneous nerve is usually found in the deep superior quadrant (Q1), the median nerve in the superficial superior quadrant (Q2), the ulnar nerve in the superficial inferior quadrant (Q3), and the radial nerve in the deep inferior quadrant (Q4). The terms deep and superficial refer to the medial surface of the arm.
Brown: the deep superior quadrant (Q1), the superficial superior quadrant (Q2), the superficial inferior quadrant (Q3), and the deep inferior quadrant (Q4), at both the brachial and axillary artery levels. For each quadrant, we recorded whether the fluid filled the quadrant inside the circle (not considering the area of the artery and muscle tissue) completely (score 2) or partially (score 1), or whether fluid was not present (score 0). Two groups of patients were defined according to the cross-sectional distribution of local anesthetic 30 min after the last dose. Patients in the complete-spread group had all quadrants filled, determined by counting quadrants in the same slice or filled quadrants from all anatomic levels imaged (fig. 2). Patients in the incomplete-spread group lacked complete filling of one or more quadrants, even when all slices were considered (figs. 3 and 4). Longitudinally, the most proximal and most distal slices containing local anesthetic fluid were determined. The distance between these images was the longitudinal extension of the fluid.

Clinical assessment included sensory and motor function of the axillary, musculocutaneous, radial, median, and ulnar nerves. The sensory testing points were as follows: laterally and in the middle of the proximal half of the arm, over the brachioradial muscle (5 cm distal to the elbow joint), between the first and second metacarpals on the dorsal side, between the second and third metacarpals on the volar side, and on the medial side of the fifth metacarpal. To avoid metal disturbance in the scanner, a pinprick test was performed using a sharpened toothpick, repeatedly touching the skin (0 = normal; 1 = hypalgesia, patient felt sharp touch but less than normal; 2 = analgesia, patient felt touch but not sharp; 3 = anesthesia, patient did not feel touch). Motor tests of the corresponding nerves were abduction of the arm, flexion of the elbow, extension of the fingers–wrist, flexion of the second finger, and abduction of the fingers. The motor power was scored as follows: 0 = normal power, 1 = slightly reduced power, 2 = moderately or strongly reduced power, 3 = no power (paralysis). To avoid change of arm position in the preoperative scanning period, no motor test was performed on the axillary and musculocutaneous nerves until the last preoperative scan had been made. A correlation test was performed based on the status 30 min after the last dose of local anesthetic, comparing the local anesthetic distribution as seen by MRI and its sensory–motor effect. A complete spread of local anesthetic (filling of all quadrants) was expected to result in block of all the main terminal nerves, whereas incomplete spread was expected to be associated with an incomplete block.

Statistical Analysis

Descriptive data are presented as mean, range, and standard deviation. The spread of the fluid in the MRI...
scans was analyzed by studying the maximum spread among all slices and comparing the four quadrants at each time point with the Friedman test, computed with StatView 5.0 (SAS Institute Inc., Cary, NC). The sensory effect in the five nerves of the arm (as well as the motor effect in the three distal nerves) was also compared at each time point with the Friedman test. The clinical effect in the groups with complete and incomplete spread of the fluid 30 min after the last dose was compared with an unpaired Wilcoxon test and computed with JMP 3.1 (SAS Institute Inc.). Results were considered significant at $P < 0.05$.

Results

The patient population included 11 men and 3 women, with an American Society of Anesthesiologists physical status I or II. A technical breakdown of the MRI scanner caused one of the women (no. 10) to be excluded from further analysis. The age, height, and weight of the remaining 13 patients were $51 \pm 13$ yr (range, 30–73 yr), $176 \pm 10$ cm (range, 156–191 cm), and $82 \pm 16$ kg (range, 61–105 kg), respectively. The hand surgery lasted $47 \pm 44$ min (range, 14–155 min). The point of needle insertion was superior to the artery and, on average, was $38$ mm (range, 10–50 mm) distal to the lateral border of the pectoralis major muscle. The catheter tip was calculated to end, on average, $7$ mm proximal to the lateral border of this muscle (range, 25 mm distal to 45 mm proximal to this reference). The nerve stimulator technique was abandoned in two patients (nos. 12 and 13) because of difficulties finding an appropriate motor response. Instead, the “fascial click” technique was applied. In the remaining 11 patients, the median nerve was stimulated in all cases by an average of 0.24 mA (range, 0.15–0.50 mA). Three patients (nos. 4, 9, and 13) had an unintended arterial puncture. There were no signs of catheter dislocation from clinical inspection. Ten patients received the local anesthetic as 50 ml of 1% lidocaine with 5 $\mu$g/ml epinephrine. The remaining three patients (nos. 2, 3, and 4) were given a 50-ml mixture of 200 mg bupivacaine, 100 mg lidocaine, and 50 $\mu$g epinephrine. Only patient no. 1 had a supplementary dose given via the catheter, immediately before start of surgery.

The local anesthetic was distinctly seen on MRI scans and did not obliterate arteries or nerves (figs. 2–4). The fluid demarcation tended to be irregular in outline. In the reference images (before the injection of the 1-ml dose), extravasated blood or hematoma could not be definitely discerned, even in the three patients in whom an arterial puncture occurred. Of the 22 images acquired in each MRI scan, an average of 17 (range, 13–22) were of good enough quality for scoring the fluid in the cross-sectional...
plane. For patient no. 4, images were not obtained 10 min after the last dose (technical reason) and postoperatively (the patient was too sedated).

The initial 1-ml dose of local anesthetic spread over several levels (longitudinally) and usually engaged more than one quadrant (cross-sectionally), both inside (fig. 5) and outside the circle. In one of the patients (no. 9), the 1-ml dose could not be recognized, and in another (no. 1), the lateral border was outside the scanned area. Among the remaining 11 patients, the longitudinal spread of the 1-ml dose inside the circle was, on average, 36 mm (range, 24–64 mm). Except for patient nos. 1 and 8, the 1-ml dose touched the artery in all patients.

After administration of each of the subsequent three doses, the longitudinal local anesthetic spread increased until the last dose had been given and stayed unchanged for the next 30 min. Thirty minutes after the last dose, the proximal border of the fluid was outside the scanned area in one patient (no. 12). In the remaining 12 patients, the proximal border was, on average, 8 mm proximal to the humeral head (range, 32 mm proximal to 16 mm distal to this reference). The distal border of the fluid was definable only in three patients, either because it was outside the scanned area or because of poor image quality. With this uncertainty, the average measured length of longitudinal spread inside the circle was 92 mm (range, 32–128 mm).

The degree of cross-sectional spread also increased after each dose and remained unchanged during the 30 min after the last dose (fig. 6). Thirty minutes after the last dose, all but one patient (no. 1) had some fluid in all quadrants. Five patients had all quadrants completely filled (complete-spread group), whereas eight lacked complete filling of at least one quadrant (incomplete-spread group) (figs. 2–5). In general, the two superficial quadrants (Q2 and Q3) had a higher degree of fluid filling than the two deep quadrants (Q1 and Q4). The difference between quadrants was significant after the two last doses but did not approach significance 10 min or more after the end of injection (fig. 6). Postoperative scans taken at 155 min (range, 110–226 min) after the last dose still showed considerable volumes of fluid surrounding the artery.

Figure 7 shows that, 30 min after the last dose, a higher degree of analgesia or anesthesia was found for the median and ulnar nerves (92 and 69%, respectively) than for the axillary, musculocutaneous, and radial nerves (0, 38, and 38%). Significant differences between the nerves were present at all times except for after the first two doses (1 and 4 ml). Only one of 13 patients (no. 11, in the complete-spread group) demonstrated surgical anesthesia (analgesia or anesthesia) in the areas of the mus-
culocutaneous, median, ulnar, and radial nerves. Surgery was allowed after supplementary peripheral blocks in five patients (nos. 3, 4, 5, 9, and 13) and general anesthesia in one patient (no. 12, who also had supplementary peripheral blocks).

Comparing MRI distribution and clinical effect, the complete-spread group had a significantly better sensory block than the incomplete-spread group 30 min after the last dose (table 1). Nevertheless, blocks were insufficient in the complete-spread group (fig. 7). The motor block developed similarly to the sensory block. Only when considering the three distal nerves was the motor block significantly better in the complete-spread group than in the incomplete-spread group (table 1). The proximal

![Fig. 5. Magnetic resonance imaging quadrant scores. The diagram describes the magnetic resonance imaging distribution of local anesthetic for each patient (nos. P01-P14) at 10-min intervals (from the first dose until 30 min after the last dose) and at a variable postoperative time. When considering all anatomic levels, the best fluid score of each quadrant (Q1, Q2, Q3, Q4) is recorded. Patient nos. 4, 7, 9, 11, and 14 belong to the complete-spread group of patients (all quadrants filled 30 min after the last dose).]
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spread did not correlate to the sensory or motor effect on any nerve.

Additional information regarding this is available on the Anesthesiology Web site at http://www.anesthesiology.org.

Discussion

The current study was undertaken to help determine whether the distribution of local anesthetic is free or inhibited when using axillary blocks. On patients receiving such blocks, we frequently compared the clinical effect of divided doses of local anesthetic injected into a single site with its spread as seen by MRI.

A cross-sectional view at our approximate average injection site (the lateral border of the pectoralis major muscle) should show the three distal brachial plexus nerves (the radial, median, and ulnar) closely surrounding the artery. The axillary nerve (regularly) and the musculocutaneous nerve (in approximately half the cases) leave the neurovascular bundle more proximally. If the cross-sectional distribution of local anesthetic were free, one would therefore expect the 50-ml local anesthetic deposit to readily block the median, ulnar, and radial nerves (none of them demanding a proximal spread). But of the 13 patients in our study, only two had the median, ulnar, and radial nerves sufficiently blocked for surgery 30 min after the last dose. Only the median nerve, toward which the local anesthetic was primarily intended, showed satisfactory effect. This alone suggests an inhibited cross-sectional spread. The MRI results corroborate this impression. Although the first dose (1 ml) was on target (touching close to the artery), in the majority of the patients the full dose did not completely surround the axillary–brachial artery 30 min after the last dose. These patients showed a significantly poorer clinical effect than the smaller group of patients with local anesthetic completely surrounding the artery.

The clinical effect of the method used in this study may at first appear surprisingly poor. However, except for the lacking and inconsistent effect on the axillary and musculocutaneous nerves, our results are comparable to those of several recent studies on axillary blocks with injection into a single site.1–5,12 Because the axillary and musculocutaneous nerves leave the neurovascular bundle proximally, we primarily assumed that the poor effect on these nerves was caused by the short proximal spread in our study, e.g., compared with results of Yamamoto et al.12 The short proximal fluid spread observed in our study was a result of the distal catheter tip position and probably the reduced proximal thrust of local anesthetic injection (slow injection rate, local anesthetic not given as a bolus dose). On the other hand, we found no correlation between the proximal spread and the sensory–motor effect of any nerve studied, including the axillary and musculocutaneous nerves. Although Yamamoto et al.12 confirmed that the proximal spread is inhibited by 90° arm abduction during injection with 0° abduction, arm position had no impact on the sensory block of any of the brachial plexus nerves in their study, as also found by Koscielnik-Nielsen et al.13

In the cross-sectional plane, the low current sufficient for stimulating the median nerve indicated that the catheter tips were very close to this nerve initially. Although there was a risk of catheter dislodgment by arm movements on entering the scanner, in most cases the 1-ml dose was found by MRI to contact the brachial-axillary artery. Thus, the catheter tips were, in general, maintained in an appropriate cross-sectional position during the injections.

To our knowledge, the current study is the first to use MRI to investigate local anesthetic distribution by a brachial plexus block technique. We wanted to determine whether the local anesthetic reached or surrounded the brachial plexus nerves. Because, in a preliminary investigation, we found that the terminal nerves were often indistinguishable from small vessels, we had to make this description differently. Given the known proximity of the axillary–brachial artery and the brachial plexus nerves, we expected all or most of the nerves to be found inside a small circle concentrically around the artery. The literature gives few clues for an appropriately sized circle. De Jong14 described the brachial plexus sheath at the axillary level with a diameter of 2–3 cm. A circle with a 30-mm diameter included disproportionately more muscle tissue in our images. We decided to use a circle with a 20-mm diameter because it gave a better MRI fit and agreed with our impression from dissection of human cadavers. With free cross-sectional spread of local anesthetic, the 50-ml dose should fill all quadrants of such a circle in one or more images and give a complete block at least of the three distal nerves. On the contrary, inhibited spread would give incomplete circle filling and incomplete block.

It is noteworthy that patients with complete filling of the circle demonstrated incomplete blocks. This could indicate that our circle was too small to regularly em-
brace all relevant nerves or that some structure inhibited sufficient local anesthetic access to the nerves. When Thompson and Rorie made the same observation in their computed tomography study—that nerves could stay unblocked although the local anesthetic totally surrounded the artery—they considered this a sign of the non-unicompartmental nature of the neurovascular bundle: The fascial compartment surrounding a nerve impeded local anesthetic contact with the nerve. Extending this view, one may speculate that, if a needle or catheter is located on the inside (nerve side) of a fascial compartment, e.g., with ambitious use of a nerve stimulator at minimal amperage, such a position would facilitate the block of that nerve but hamper the local anes-

Fig. 7. Sensory block effect. The diagram shows the sensory block effect of each patient (nos. P01–P14) over time. Nerves tested were the axillary (Ax), musculocutaneous (MC), median (Med), ulnar (Uln), and radial (Rad). Postoperative sensory scores for patient nos. 3, 4, 5, 9, 12, and 13 cannot be related to magnetic resonance imaging scores at this time because these patients received supplementary peripheral blocks (after the last preoperative scan). Patient nos. 4, 7, 9, 11, and 14 belong to the complete-spread group.
thet plastic spread to the other nerves. This could be an explanation for our sometimes surprising finding of anesthesia only in the area of the stimulated median nerve.

In the 30-min period of local anesthetic injections, there was more fluid in the superficial than in the deep quadrants. This fits with our better clinical effect on median and ulnar nerves (both usually superficially located) than on the radial (usually deeper located). During the 10–30 min after the last dose and postoperatively, no significant difference between superficial and deep fluid filling was seen. This indicates that some cross-sectional spread must have taken place. However, the clinical effect on the radial nerve remained poor, possibly because of delayed distribution. Taken together, these findings suggest that inhibited cross-sectional spread remains the most likely explanation for insufficient clinical effect on the radial nerve.

Limitations of our study include the lack of a stringent protocol in performing the block: the position of the catheter tip varied, in two patients the fascial click was used instead of the nerve stimulator, and three patients received a mixture of two local anesthetics in stead of the standard local anesthetic. However, the duration of all local anesthetics used was long enough to cover the 30-min postinjection scan. Furthermore, there is an uncertainty about how well our circle in the MRI scans embraces all the nerves of interest. Finally, the small number of patients in our study and the known variability of nerve positions around the artery did not allow a more detailed study of the relation between the filling of separate quadrants and clinical effect on the individual nerves.

Our study agrees with the findings and conclusions of Thompson and Rorie. In their computed tomography study, in which injections were made into multiple sites, the local anesthetic tended to stay in isolated pockets. Because our technique did not rely on a contrast medium, we could be certain that the fluid observed with MRI corresponded to the local anesthetic distribution only. In the subsequent cadaver study by Partridge et al., the presence of fascial compartments (septa) was confirmed. Nevertheless, single injections of methylene blue into the perivascular axillary area of the cadavers resulted in immediate coloring of the nerves observed (median, ulnar, and radial), although not always to the same degree. Therefore, connections between the compartments of the neurovascular bundle were postulated as not inhibiting the distribution of local anesthetic, and multiple injections were judged unnecessary for performing axillary blocks. Considering the rapid spreading capacity of methylene blue, we believe that there may be little correlation between the spread of methylene blue in cadavers and local anesthetics in patients. In our study, the results of limited spread determined by MRI agree with limited clinical effect in the same patients.

The remarkable large and irregular area of local anesthetic in our cross-sectional images questions the concept of a sturdy, tubular brachial plexus sheath, confining the fluid injected inside of it. The fate and rate of absorption of the pooled solution is also of great intrigue because much of the anesthetic volume seems to be “unused” or unnecessary in producing the block. Future studies would benefit from MRI scanners that could delineate terminal nerves and their inclusion or exclusion from the pooled anesthetic. The ability to correlate images with clinical effect is essential for further understanding of why different brachial plexus blocks may vary in efficiency.

In conclusion, the current combined clinical and MRI study demonstrated that MRI is useful for the study of local anesthetic distribution in axillary blocks, showing correlation between MRI distribution pattern and clinical effect. The cross-sectional spread of fluid around the brachial-axillary artery was often incomplete–inhibited, and the clinical effect was often inadequate.

The authors thank Kari Ruud (Technician, Department of Anatomy, University of Oslo, Oslo, Norway) for preparing figures 1A and B.

References


Table 1. Comparing Magnetic Resonance Imaging Spread and Clinical Effect

<table>
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<tr>
<th></th>
<th>All Patients (n = 13)</th>
<th>Complete Spread (n = 5)</th>
<th>Incomplete Spread (n = 8)</th>
<th>Wilcoxon Test</th>
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<td>Sensory score (five nerves)</td>
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<td>8.8</td>
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<td>Motor score (five nerves)</td>
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<td>9.4</td>
<td>5.0</td>
<td>ns</td>
</tr>
<tr>
<td>Motor score (three nerves)</td>
<td>4.9</td>
<td>6.8</td>
<td>3.8</td>
<td>P &lt; 0.05</td>
</tr>
</tbody>
</table>

The table shows sensory and motor scores of three groups of patients (all patients, the complete spread group, and the incomplete spread group) with regard to five nerves (axillary, musculocutaneous, median, ulnar, and radial) and three nerves (median, ulnar, and radial). A four-graded scale (0, 1, 2, 3) was used for both the sensory and the motor scores. With five and three nerves tested, the highest possible scores were 15 and 9, respectively. The Wilcoxon test demonstrated that the complete spread group had a significantly better sensory score than the incomplete spread group. The motor blocking effect was significantly better in the complete spread group only when considering the three distal nerves (median, ulnar, and radial).