ORIGINAL ARTICLE

MRI of axillary brachial plexus blocks

A randomised controlled study

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BACKGROUND Axillary plexus blocks are usually guided by ultrasound, but alternative methods may be used when ultrasound equipment is lacking. For a nonultrasound-guided axillary block, the need for three injections has been questioned.

OBJECTIVES Could differences in block success between single, double and triple deposits methods be explained by differences in local anaesthetic distribution as observed by MRI?

DESIGN A blinded and randomised controlled study.

SETTING Conducted at Oslo University Hospital, Rikshospitalet, Norway from 2009 to 2011.

PATIENTS Forty-five ASA 1 to 2 patients scheduled for surgery were randomised to three equally sized groups. All patients completed the study.

INTERVENTIONS Patients in the single-deposit group had an injection through a catheter parallel to the median nerve. In the double-deposit group the patients received a transarterial block. In the triple-deposit group the injections of the two other groups were combined. Upon completion of local anaesthetic injection the patients were scanned by MRI, before clinical block assessment. The distribution of local

anaesthetic was scored by its closeness to terminal nerves and cords of the brachial plexus, as seen by MRI. The clinical effect was scored by the degree of sensory block in terminal nerve innervation areas.

MAIN OUTCOME MEASURES Sensory block effect and MRI distribution pattern.

RESULTS The triple-deposit method had a higher success rate (100%) than the single-deposit method (67%) and the double-deposit method (67%) in blocking all cutaneous nerves distal to the elbow ($P=0.04$). The patients in the triple-deposit group most often had the best MRI scores. For any nerve or cord, at least one of the single-deposit or double-deposit groups had a similarly high MRI score as the triple-deposit group.

CONCLUSION Distal to the elbow, the triple-deposit method had the highest sensory block success rate. This could be explained to some extent by analysis of the magnetic resonance images.

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Introduction

Axillary brachial plexus block can be performed by single or multiple injections of local anaesthetics, guided by anatomical landmarks, nerve stimulator or ultrasound.^{1–3} Although sonographic guidance is increasingly used, the transarterial technique may be an alternative when ultrasound equipment is not available, during emergency situations or in field conditions. The nerve stimulator

is still a standard application to locate peripheral nerves, either alone or in conjunction with ultrasound, and to reduce the risk of an intraneural needle tip position.

The first author of our study has developed a nonultrasound-guided axillary block method with three deposits.⁴ Although our experience with this method has been

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favourable,^{4,5} we have been challenged by the question of whether all the injections are necessary.

In the present study, our goal was to study whether differences in block success between single, double and triple-injection axillary block methods could be explained by differences in the local anaesthetic distribution as observed by MRI.

Materials and methods

The study was conducted at Oslo University Hospital, Rikshospitalet, in the period from 26 January 2009 to 4 February 2011. It was performed in accordance with the Helsinki II declaration and approved by the Regional Ethics Committee (REK Sør-Øst, Pb 1130 Blindern,

N 0318 Oslo, ref. Nr S-04115, June 8th, 2004, Prof. Nitter-Hauge). Forty-five patients scheduled for day surgery of the hand or forearm were recruited and gave written informed consent to participate in the study (Fig. 1). Inclusion criteria were ASA physical status 1 to 2, age 18 to 75 years and weight 50 to 95 kg. Exclusion criteria were neurological disease, prior adverse reaction to local anaesthetic or contraindication to MRI examination. The patients were randomised into three groups each of 15 patients, using random digits (The Rand Corporation, USA, www.rand.org). Group allocation was sealed in envelopes that were opened just before the axillary block. The three groups were defined by the number of axillary local anaesthetic injections, namely single, double and triple-deposit groups.

Fig. 1

Flow diagram of the study.

Block procedures

Premedication consisted of midazolam 3.5 mg and paracetamol 1 to 1.5 g per os. Monitoring included electrocardiogram, noninvasive blood pressure and pulse oximeter. A total of 100 µg fentanyl intravenously (i.v.) was given before the skin infiltration with 1 ml lidocaine 10 mg ml⁻¹.

In all patients, the position of the median nerve was primarily identified by percutaneous nerve mapping (Stimuplex Pen; B. Braun, Melsungen, Germany) and marked with a skin pen. A short catheter with an internal cannula (Contiplex; 18-gauge, 1.3 × 45 mm, B. Braun) was inserted 1 to 2 cm distal to the lateral border of the pectoralis major muscle. It was advanced parallel to the median nerve and anterior (superior) to the brachial-axillary artery by nerve stimulation guidance (Stimuplex DIG/HNS11; B. Braun).⁴ Using an impulse width of 0.1 ms, a threshold range of 0.2 to 0.8 mA was accepted. The local anaesthetic dose for every patient in all groups was 40 ml of a 50:50 mixture of lidocaine 20 mg ml⁻¹ and bupivacaine 5 mg ml⁻¹ with 5.0 µg ml⁻¹ adrenaline, giving a total dose of 400 mg lidocaine, 100 mg bupivacaine and 100 µg adrenaline. It was injected at approximately at 0.5 ml s⁻¹.

In the single-deposit group, the total volume of local anaesthetic was given through the catheter. In the double-deposit group, a divided transarterial block⁶ was performed with the injection of 30 ml lateral (deep) to, and 10 ml medial (superficial) to the artery, using a standard hypodermic needle (25G, 0.50 × 25 mm, Sterican; B. Braun). It was inserted approximately 1 cm posterior (inferior) to the catheter insertion site. In the triple-deposit group, the block techniques of the single-deposit and double-deposit groups were combined. Here, 20 ml was initially injected deep to, and 10 ml superficial to the artery, followed by 10 ml through the catheter. Pressure was not applied to the neurovascular bundle distal to the injection sites.

Prior to magnetic resonance (MR)-scanning, injections through the short catheter were only given to patients in

the single-deposit and triple-deposit groups. However, the catheter could be utilised for prolongation of per- and postoperative analgesia in any group. In addition, the catheter ensured that the block assessor was blinded to the block that had been performed.

Regarding adverse events, we recorded paraesthesia and heart rate/blood pressure changes of more than 20% from baseline. Patients with paraesthesia were contacted at home for a follow-up interview.

MRI

MRI scanning (Achieva 3T, Philips Healthcare, The Netherlands) was performed immediately after completion of the block procedures, using the protocol of a pilot study.⁷ Two radiologists, blinded for the block method and its clinical effect, independently evaluated the T2-weighted, fat suppressed MRI images. If their assessments differed, consensus was obtained by joint evaluation of the images. The neurovascular bundle and local anaesthetic deposits were examined in short axis view (cross-sectional, Figs. 2 and 3) and the long axis (coronal, Fig. 4). In coronal images, the proximal and distal local anaesthetic distributions were measured using maximal intensity projections with reference to an imaginary line, perpendicular from the most cranial point of the humeral head to the neurovascular bundle. In addition, as a measure of free/inhibited local anaesthetic distribution, the number of separate fluid compartments was counted.¹

In cross-sectional images, we recorded whether the lateral, posterior and medial cords and the five main terminal nerves (the axillary, musculocutaneous, radial, median and ulnar) could be recognised.⁷ Furthermore, the proximity of local anaesthetic to the cords and terminal nerves was described by the following scores: 0, no contact between local anaesthetic and the nerve; 1, local anaesthetic partly contacts the nerve; and 2, local anaesthetic surrounds the nerve. Finally, a circle with a radius of 10 mm was drawn around the centre of the midaxis of the

Fig. 2

Single-deposit group, catheter injection; double-deposit group, transarterial injections; triple-deposit group, transarterial and catheter injections. MRI of local anaesthetic (LA) in the right axilla, cross-sectional view. Typical LA distribution for three axillary block methods, from patients with successful sensory block. T2-weighted MRI images with fat suppression. The LA appears white. In the triple-deposit group, the artery (black circular area) is more centrally located in the LA area. In the double-deposit case, two LA compartments are recognised.

Fig. 3

MRI of the right axilla, cross-sectional view. T2-weighted MRI image with fat suppression from a patient with a successful sensory block after a single local anaesthetic (LA) injection, through a short catheter positioned parallel to the median nerve. The local anaesthetic appears white. The musculocutaneous nerve (Mcn) is clearly seen before entering the coracobrachial muscle and is surrounded by LA.

axillary-brachial artery.⁸ One of the radiologists recorded whether the five main terminal nerves were inside or outside of the described circle, evaluating all cross-sectional levels.

Block testing

The closed-bore MRI scanner did not allow clinical block assessment during imaging. As soon as the patients were accessible after scanning, a sensory-motor status was obtained. The assessors were anaesthetists who were blinded to the block method and MR images.

Sensory testing also included, in addition to the five main terminal nerves, the medial antebrachial cutaneous,

medial brachial cutaneous and intercostobrachial nerve. We used a cold test, repeatedly touching the skin with ice cubes at predefined points in the sensory areas of the nerves applying the following scale: 0, normal; 1, hypoalgesia, patient felt coldness but less than on the contralateral side; 2, analgesia, patient felt touch but not coldness; and 3, anaesthesia, no feeling at all.⁹ Muscle power was recorded for the five main terminal nerves using the following scale: 0, normal; 1, slightly reduced power; 2, moderately reduced power; and 3, strongly reduced power (paralysis).⁸ A block was defined as successful when all five nerves distal to the elbow (musculocutaneous, radial, median, ulnar and medial antebrachial cutaneous nerve) had sensory test scores

Fig. 4

Single-deposit group, catheter injection; double-deposit group, transarterial injections; triple-deposit group, transarterial and catheter injections. MRI of right shoulder and axilla with local anaesthetic (LA), coronal (frontal) view. Typical LA distribution for three axillary block methods with successful sensory block. Maximum intensity projections of coronal T2-weighted MR images with fat suppression. The LA appears white. It extends more proximally in the single- and triple-deposit groups than in the double-deposit group ($P=0.001$), although the distal distribution is almost equal in all groups. The catheter with an extension tube is seen as a white string.

of 2 or 3.⁹ Similarly, a cutaneous nerve territory was defined as successfully blocked when its sensory score was 2 or 3.

If a territory distal to the elbow had a sensory score of 0 or 1, the patient received a supplementary peripheral nerve block at the elbow, by nerve stimulation guidance or infiltration technique.

Correlation between MRI score and sensory score

An innervation area may become anaesthetised because local anaesthetic has reached the terminal nerve, the cord from where the terminal nerve originates or has an effect at both nerve levels. To correlate MRI and sensory scores, a summarised MRI score was derived by adding the MRI score at terminal nerve level to the MRI score of the related cord. These scores were weighted equally with a maximal score of 2 at each nerve level, giving a maximal summarised score of 4. There was, however, an exception when scoring for the median nerve territory. As the median nerve has a root from both the lateral and medial cord, the maximal score for each of these cords was 1.

Statistics

Due to limited access to the MRI facility, we based the study on only 15 patients in each of the three groups. With an experienced block difference of almost 30% between single and triple injection⁴ and a 5% significance level for one-sided tests, a statistical power of 74% was calculated. Data were described by mean, standard deviation and counts. The groups were compared with one-way analysis of variance (ANOVA) or the Pearson Chi-square test for continuous or categorical variables as appropriate. Correlating MRI scores with the sensory scores from correspondingly innervated areas, we used cross tabulation and the gamma test, considering all patients as one group. Gamma values may be characterised as follows: 0, no; ± 0.01 to 0.09, weak; ± 0.1 to 0.29, moderate; ± 0.3 to 0.99, strong; ± 1 , perfect, strongest possible association/correlation (SPSS etutor by Dee Britton. Available at <http://commons.esc.edu/spss/>). The assessments of the two radiologists in scoring the

local anaesthetic distribution were compared by cross tabulation and the Kappa test. Kappa values may be characterised as follows: less than 0.40, poor; 0.4 to 0.75, fair/good; more than 0.75, excellent.¹⁰ *P* values below 0.05 were considered statistically significant. For statistical analysis we used SPSS version 20 (IBM Corporation, Armonk, New York, USA) or the online calculators <http://www.openepi.com> (including the Fisher's exact test) and <http://vassarstats.net> (including the Kappa test). For the power calculations, the online <http://www.dssresearch.com> was used.

Results

All 45 patients completed the study. The groups were equal with regard to demographic and anaesthetic data (Table 1), except for block performance time ($P = 0.001$ between groups 1 and 2 and 1 and 3). Sensory-motor testing was performed at a mean of 54.5 ± 8.4 min after completion of the local anaesthetic injection (Table 1), delayed because of prior MR-scanning.

Clinical effects

The number of patients with successful blocks (having analgesia or anaesthesia for all five nerves distal to the elbow) was 10 in the single-deposit, 10 in the double-deposit and all 15 patients in the triple-deposit group. This difference (33%) between groups was statistically significant ($P = 0.04$, Fisher's exact test). When considering the terminal nerves separately (Table 2), there was no sensory block difference between the groups. The ulnar nerve was the only terminal nerve with a successful sensory block in all patients of all groups.

To obtain anaesthesia or analgesia for all nerve territories distal to the elbow, five supplementary peripheral nerve blocks (among five patients) were made in the single-deposit group and 11 supplementary blocks (among five patients) in the double-deposit group. For these blocks, we used the same local anaesthetic mixture as described above, using an average of 8.1 ml for each nerve. All surgeries took place distal to the elbow and all the blocks were adequate for surgery (Table 1).

Table 1 Demographic and anaesthetic data

	Single-deposit group (n = 15)	Double-deposit group (n = 15)	Triple-deposit group (n = 15)
Age (years)	49.1 $\pm$ 17.8	42.3 $\pm$ 17	44.3 $\pm$ 15.9
BMI (kg m ⁻²)	25.3 $\pm$ 3.7	25.2 $\pm$ 3.4	24.7 $\pm$ 2.5
Sex (female/male)	4/11	4/11	4/11
ASA (1 or 2)	14/1	12/3	14/1
Block performance time (min)	10.5 $\pm$ 2.5	15.6 $\pm$ 4.4	13.7 $\pm$ 3.2
Minimal median nerve stimulation (mA)	0.49 $\pm$ 0.14	–	0.46 $\pm$ 0.15
Block assessment time (min)	57.3 $\pm$ 9.9	53.8 $\pm$ 8.2	52.3 $\pm$ 7.2
Types of surgery Hs/Hb/Fsb	10/4/1	8/6/1	4/8/3

Continuous data are shown as mean $\pm$ standard deviation. Categorical data are presented as counts. Single-deposit group, catheter injection; double-deposit group, transarterial injections; triple-deposit group, transarterial and catheter injections. Block assessment time = the interval (min) from finishing the local anaesthetic (LA) injection to the block assessment. In patients of the double-deposit group, a catheter was inserted (although not used for LA injection), as in the two other groups. This explains the similar block performance time in the double and triple-deposit groups. Types of surgery: Fsb, forearm soft tissue or bone; Hb, hand bone; Hs, soft tissue.

Table 2 Successful sensory and motor block of terminal nerves by clinical test

Nerves	Single-deposit group (n = 15)		Double-deposit group (n = 15)		Triple-deposit group (n = 15)		P _s	P _m
	Sensory	Motor	Sensory	Motor	Sensory	Motor		
Ax	6	4	7	1	9	2	0.59	0.69
Mcن	11	13	11	7	15	13	0.32	0.11
Rad	14	9	12	14	15	13	0.39	0.05
Med	15	14	13	15	15	14	0.28	0.59
Uln	15	14	15	15	15	15	0.84	0.36
Mca	15		13		15		0.33	

The numbers indicate the counts of patients with successful sensory and motor blocks. Sensory, successful sensory block of a terminal nerve, that is analgesia or anaesthesia. Motor, successful motor block of a terminal nerve, that is paralysis. Single-deposit group, catheter injection; double-deposit group, transarterial injections; triple-deposit group, transarterial and catheter injections. Nerves: Ax, axillary; Mcن, musculocutaneous; Rad, radial; Med, median; Uln, ulnar; Mca, Medial cutaneous antebrachial nerve. P_s, P value when considering all sensory block scores; P_m, P value when considering all motor block scores.

MRI findings

The local anaesthetic fluid was always clearly visualised in the T2-weighted images, both in cross-sectional and coronal images (Figs. 2, 4).

Cross-sectional images

Among the 135 cords and 225 terminal nerves of the 45 patients, all the cords and 218 (97%) of the terminal nerves were recognised (Fig. 3). This required consensus assessment for only four cords and three terminal nerves. All but two of the terminal nerves (99%) were located inside the described 20 mm diameter periarterial circle. There was a trend for the axillary-brachial artery to be more centrally located within the local anaesthetic area in the triple-deposit group than in the two other groups (Fig. 2). According to the consensus between the radiologists, 204 (93%) of the terminal nerves were surrounded by local anaesthetic (MRI-score 2, Table 3). This occurred for all of the superficially located median and ulnar nerves. Only partly contacted by local anaesthetic were 12 terminal nerves (5.5%), although four nerves were not reached by local anaesthetic. For three axillary and two musculocutaneous nerves, no MRI-score was recorded (Table 3). A significant difference between the groups was found for the radial nerve (Table 3). It was completely surrounded by local anaesthetic in all patients in the

double-deposit and triple-deposit groups, although this occurred only in 11 patients in the single-deposit group.

Of the 135 cords, 90 (67%) were surrounded by local anaesthetic, 35 (26%) were partly contacted by local anaesthetic and the remaining 10 cords (7%) were not reached by local anaesthetic (Table 3). The lateral and posterior cords in the single-deposit and triple-deposit group were more often surrounded by local anaesthetic than in the double-deposit group.

Coronal images

Referring to the most proximal point of the humeral head, the proximal distribution in the single, double and triple-deposit groups measured (mean $\pm$ SD) 4.5 ± 2.0 , 1.8 ± 1.5 and 3.6 ± 2.0 cm, respectively ($P = 0.001$). In contrast, the distal distribution was longer and of almost identical length in each of the groups 14.5 ± 2.6 , 14.2 ± 2.2 and 14.5 ± 2.3 cm ($P = 0.9$) respectively, (Fig. 4).

The local anaesthetic deposit was recognised as one-fluid compartment in 14 of 15 patients (93%) in the single-deposit group and in 12 of 15 patients (80%) in both the double and triple-deposit groups. There were two fluid compartments in all the remaining patients.

Table 3 Scoring of local anaesthetic distribution as observed by MRI

Nerves	Single-deposit group (n = 15) MRI score			Double-deposit group (n = 15) MRI score			Triple-deposit group (n = 15) MRI score			Missing scores	P all scores
	0	1	2	0	1	2	0	1	2		
Ax	1	3	9	0	1	13	2	0	13	3	0.17
Mcن	0	1	14	0	3	11	1	0	13	2	0.2
Rad	0	4	11	0	0	15	0	0	15	0	0.012
Med	0	0	15	0	0	15	0	0	15	0	nc
Uln	0	0	15	0	0	15	0	0	15	0	nc
Lat. C	0	3	12	4	5	6	0	2	13	0	0.016
Post. C	0	4	11	3	6	6	0	2	13	0	0.031
Med. C	0	4	11	3	3	9	0	6	9	0	0.12

The numbers indicate the counts of patients with MRI score 0 to 1 to 2 in the three groups. Score 0, no local anaesthetic (LA) in contact with the nerve. Score 1, LA partly contacts the nerve. Score 2, LA surrounds the nerve. Missing scores, Number of patients without MRI score. P value all scores: the P values are based on the scores of all patients for each nerve and cord. nc, not calculable P value. This was the case for both the median and ulnar nerve, both of them having MRI-score 2 in all patients of all groups. Nerves: Ax, axillary; Mcن, musculocutaneous; Rad, radial; Med, median; Uln, ulnar; Lat C, lateral cord; Post C, posterior cord; Med C, medial cord.

Comparison of MRI assessments by the two radiologists

The MRI scoring of the two radiologists was different for 53 (39%) of the cords and 46 (20%) of the terminal nerves. The poor agreement was also expressed by the kappa values (in parenthesis) for the lateral cord (0.15), posterior cord (0.17), medial cord (0.18), axillary nerve (0.16), the musculocutaneous nerve (0.13) and the radial nerve (0.35). In contrast, the agreement was excellent for the median (1) and ulnar nerve (1).

Correlation between local anaesthetic distribution (MRI) and sensory block

For the local anaesthetic distribution pattern at the axillary nerve/posterior cord, radial nerve/posterior cord, musculocutaneous nerve/lateral cord and the median nerve/lateral and medial cords, the correlation to the corresponding sensory block was strong. We found the following gamma values: 0.53 ($P=0.01$); 0.50 ($P=0.023$); 0.54 ($P=0.007$); and 0.59 ($P=0.007$). The ulnar nerve/medial cord correlation score was poor: -0.09 , $P=0.83$. This paradoxical result is probably due to almost maximal scores in each of the two scoring systems (MRI versus sensory block), giving minimal variation of the values.

Nevertheless, correlations between MRI and clinical scores were not always straightforward. This was highlighted for the innervation area of the musculocutaneous nerve. Among the eight patients of the single and double-deposit groups with insufficient block in the area of the musculocutaneous nerve, four of them had the maximal MRI score of 2 at both the terminal nerve and the cord level.

The radial nerve represents another example. In the single-deposit group, it had a significantly lower MRI-score than in the two other groups (Table 3), but this was not reflected by a poorer sensory block score (Table 2).

All patients had local anaesthetic contact either at terminal nerve level or at the corresponding cord or both. We did not have a patient with a clinical block and lacking local anaesthetic contact at both of these nerve levels.

Adverse events

Paraesthesia was recorded 10 times in the double-deposit group (seven patients) and twice times in the triple-deposit group (two patients), none of which resulted in neurological sequela. The transarterial needle (25 G cannula) was involved in seven of the nine patients who reported paresthesia. After transarterial injection, two patients in the triple-deposit and one patient in the double-deposit group had mild tachycardia for a few minutes. A third patient in the triple-deposit group had mild tachycardia, a 28% SBP elevation and transient dizziness after injection through the catheter. One patient in both the double and triple-deposit groups had temporary pale skin colour in the hand after

transarterial injection. A venous puncture occurred in only one of the 45 patients who had the Contiplex catheter/cannula inserted. Haematomas were not found in any of the groups.

Discussion

Block success showed a statistically significant difference between the triple-deposit group and the two other groups. The patients in the triple-deposit group most often had the best MRI scores as well. Considering the cords the distribution was best in the single and triple-deposit groups, which had local anaesthetic injections through the catheter. At terminal nerve level, the spread to the radial nerve was best in the double and triple-deposit groups, which had transarterial injections. Hence, for any nerve or cord at least one of the two other groups had a similarly high MRI score as the triple-deposit group. This might be explained by the fact that the triple-deposit block is a combination of the single and double-deposit method.

A general correlation between the local anaesthetic proximity to the cords and terminal nerves (as described by MRI scores) and local anaesthetic effect (as described by sensory block scores) could be demonstrated when combining the data sets of all groups.

Some secondary findings deserve discussion. In this study not only the cords⁸ but also the main terminal nerves of the brachial plexus could be identified, which had been indicated in our pilot study.⁷ Although earlier only assumed,⁸ the present study confirmed these nerves to be located inside a circle of 20 mm surrounding the brachial-axillary artery.

At the level of the cords, the double-deposit method had a significantly lower MRI score than the two other methods. We assume that this method's injection, perpendicular to the brachial artery, gave a weaker proximal local anaesthetic thrust and spread than the two other methods, by which local anaesthetic was injected through a distal-to-proximal directed catheter. This consideration is strengthened by the significantly longer proximal distribution with the single and triple-deposit than with the double-deposit method.

Remarkably, in some patients, a nerve was not successfully blocked, although it was surrounded by local anaesthetic. Similar observations have been made in previous computed tomography and MRI studies.^{1,8} What may be the particular barrier for local anaesthetic reaching the axons of the nerve? Thompson and Rorie¹ suggested the 'nonunicompartmental' nature of the neurovascular bundle. We have not come closer to the answer, except for the obvious possibility of errors in identification of the nerves or the local anaesthetic's relation to the nerves.

Among a majority of patients in both the double and triple-deposit groups, MRI demonstrated that the local

anaesthetic merged to form a single fluid compartment. This could suggest a free distribution of local anaesthetic. However, in a smaller group, three patients in both the double and triple-deposit groups (six patients), local anaesthetic was identified as two fluid compartments, indicating inhibited local anaesthetic spread. This supports the established recommendation to use multiple injections when performing axillary blocks.¹¹

Moreover, we found that the distal distribution was practically constant among all patients in the coronal images. It ended regularly 14 to 15 cm distal from the top of the caput humeri. We assume that the distal end of the local anaesthetic spread corresponds to the distal end of the tunnel containing the neurovascular bundle.^{6,12,13}

Although the musculocutaneous nerve was not blocked selectively in any of the three groups, it was successfully blocked in all patients of the triple-deposit group. This is interesting with regard to double-deposit ultrasound-guided axillary blocks, for which a separate local anaesthetic injection towards the musculocutaneous nerve has been recommended.^{14–16}

The long performance time in all study groups (Table 1) can be explained by the combination of several block methods that included transcutaneous mapping, transarterial injections and particularly the nerve stimulator guided insertion of the catheter. Although not used for local anaesthetic injection, a catheter was also placed in the double-deposit group.

The five patients in our study who showed local or systemic signs of intravascular injections during transarterial injections underline the importance of using this technique with outmost care.

There are several limitations to our study. Nonultrasound-guided axillary brachial plexus blocks have typically used high doses of local anaesthetic. The mixture, concentration and volume of local anaesthetics in the present study were similar to a series of studies by Sia et al.,^{17–20} except for adrenaline that was not contained in their mixture. Our results are valid only for the mixture of local anaesthetics, volume and concentration used in this study. When nerves are detected individually by ultrasound guidance or electrical nerve stimulations, lower local anaesthetic volumes can be used.²¹

A larger number of patients would probably have characterised the group differences more strongly, for both the sensory-motor block effect and the local anaesthetic distribution patterns. The MR images were obtained at variable intervals before block assessment, with an unknown impact on our results. The discrepancies between the two radiologists in scoring the proximity of local anaesthetic to the nerves were considerable, in spite of their profound experience. Distortion of the anatomy after local anaesthetic injection was mainly responsible for the difficulties in identification of the

cords and terminal nerves, as demonstrated in our pilot study.⁷ In addition, when the rim of local anaesthetic close to a nerve was narrow, it was difficult to distinguish between MRI scores 0, 1 and 2. MRI of local anaesthetic in the axillary region is further a less explored field in radiology, which could have influenced the results.

Conclusion

In this combined clinical and MRI study of three axillary block methods, the sensory block effect distal to the elbow was best for the triple-deposit method. This could to some extent be explained by analysis of the MRI distribution patterns. The transarterial technique, however, has an increased risk of paraesthesia and intravascular local anaesthetic injection.

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