Does circumferential spread of local anaesthetic improve the success of peripheral nerve block?

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Editor’s key points
- The relation between circumferential or non-circumferential local anaesthetic (LA) spread and peripheral nerve block success is unclear.
- Multiplanar ultrasound imaging was used to compare median nerve block success with or without circumferential LA spread in healthy volunteers.
- Block success was similar with or without circumferential LA spread in this model.

Background. The relation between the pattern of local anaesthetic (LA) spread and the quality of peripheral nerve block is unclear.

Methods. Twenty-one volunteers were randomized to receive a median nerve block with intended circumferential or intended non-circumferential spread of LA. Different predetermined volumes and needle placement techniques were used to produce the different patterns of LA spread. Volumetric, multiplanar 3D ultrasound imaging was performed to evaluate the pattern and extent of LA spread. Sensory block was assessed at predetermined intervals.

Results. Complete circumferential spread of LA was achieved in only 67% of cases in the intended circumferential study group and in 33% of cases in the intended non-circumferential group. Block success was similar (90%) and independent of whether circumferential or non-circumferential spread of the LA was achieved. All block failures (n=4) occurred in the intended non-circumferential group with low volumes of LA. The onset of sensory block (independent of group allocation) was faster with circumferential spread of LA [median (IQR) onset time, 15 (8; 20) min] compared with non-circumferential spread of LA [median (IQR) onset time, 20 (15; 30) min]. More LA was used for circumferential blocks [median (IQR) volume of LA 2.8 (1.3; 3.6) ml] vs 1.3 (1.1; 2.4) ml.

Conclusions. Even under optimal conditions, it was not possible to achieve circumferential spread of LA in all intended cases. The success of median nerve block seems to be independent of the pattern of LA spread.

Clinical trial registration. DRKS 00003826.

Keywords: anaesthetic techniques, regional; equipment, ultrasound machines; regional anaesthesia

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Peripheral nerve blocks are frequently used for anaesthesia or analgesia during the perioperative period. Despite the widespread use of ultrasound-guided peripheral nerve block, it is not known if circumferential spread of local anaesthetic (LA) around the nerve is essential for block success. Current evidence suggests that partial encirclement of a nerve with LA is adequate for block success. The lack of data correlating the distribution of LA with block dynamics might be due to the inability of 2D ultrasound imaging to comprehensively delineate the extent of LA spread since it only allows visualization in one plane (transverse or sagittal). Three-dimensional (3D) ultrasound imaging allows one to simultaneously visualize a volume of interest (e.g. a nerve) in the transverse (x-axis), sagittal (y-axis), and coronal (z-axis) plane. Published data on the use of 3D ultrasound for peripheral nerve block are limited, but preliminary reports indicate that it can be used to preview anatomy, assist in performing peripheral nerve blocks, facilitate placement of a peripheral nerve catheter, and visualize the spread of the LA in multiple orthogonal planes. The latter might be useful to correlate the pattern of LA spread with block success. The aim of this study was to determine, using multiplanar 3D ultrasound imaging after nerve block, if the pattern of LA spread (circumferential or non-circumferential) affects nerve block success.
Methods

The study was approved by the research ethics committee of the Medical University of Vienna (EK 1313/1012) and by the Austrian Agency for Health and Food Safety (EudraCT 2012-001847-31). The trial was also registered with the German Clinical Trials Registry (registration number DRKS 00003826).

Volunteer recruitment

Twenty-one volunteers (aged 18–45 yr) who gave written informed consent were recruited for this prospective, randomized, double-blind, controlled trial (Fig. 1). Three weeks before the start of the investigation, each volunteer underwent a health screening examination, which included a general physical examination, arterial pressure, and heart rate measurements, blood tests (red and white blood cell counts, coagulation profile), and a 12-lead ECG. Volunteers were excluded if they refused to participate, had any anatomical abnormality in the forearm, gave history of allergy to mepivacaine or amide LA drugs, reported using non-steroidal anti-inflammatory drugs during the preceding 2 weeks, had recently (in the previous 4 weeks) participated in a clinical trial, or had coagulopathy or ECG abnormalities. The volunteers also had an ultrasound examination of the median nerve in the forearm of the non-dominant upper limb using a Supersonic Aixplorer ultrasound system (Supersonic Imagine™, Aix-en-Provence, France) and a SuperLinear™ Volumetric ultrasound transducer (SLV 16–5 MHz, integrated mechanical transducer). The median nerve was identified as a round to oval, hyperechoic, or honey-comb like structure between the flexor digitorum superficialis and the flexor digitorum profundus muscles of the forearm (Fig. 2A). The ultrasound image was optimized and the site for the subsequent median nerve block was determined using the following criteria: (i) the

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**Fig 1** Consort E-flowchart.
outlines of the median nerve relative to the surrounding tissue were clearly delineated and (ii) there was no blood vessel close to the median nerve. Thereafter, the distance (in mm) from the base of the ipsilateral middle finger to the forearm where the optimal ultrasound image of the median nerve was obtained was measured. The cross-sectional area of the median nerve was also measured using the internal calliper and measurement tools of the ultrasound system (Fig. 2A).

Crossover study design

A crossover study design was used in which every volunteer had both the study interventions (interventional group 1 and interventional group 2) as per their randomization. So volunteers who were randomized to receive a median nerve block with intended circumferential spread of LA for their first intervention had the median nerve block with intended non-circumferential spread of LA for their second intervention and vice-versa. In order to prevent the effects of the first injection carrying over to the period of the second intervention, the latter was performed 3 days (wash-out period) after the first injection. Also a short-acting LA (mepivacaine 1%) was used for the block, and a sensory assessment was performed in the dermatomal distribution of the median nerve in the hand to ensure that there was no residual block before the second intervention.

Randomization

Patients were randomized to one of the two study groups by drawing sequentially numbered, coded, sealed, and opaque envelopes with a computer-generated allocation number. The sealed envelopes for the randomization were prepared by a research assistant who took no further part in the study. An in-plane needle insertion technique was used for the median nerve block (Fig. 2A) for both study groups.

Study group 1 (icLA): median nerve block with intended circumferential spread of LA around the median nerve in the transverse sonogram (2D ultrasound, Fig. 2C). Circumferential spread was defined as a halo of LA around the median nerve.

Study group 2 (incLA): median nerve block with intended non-circumferential spread of LA in the transverse sonogram (2D ultrasound, Fig. 2D). Non-circumferential spread was defined as localized spread of LA on one aspect of the median nerve.

Blinding

The study drug (mepivacaine) was prepared under strict aseptic precautions by a research nurse outside the area where the nerve blocks were performed. The volunteers were also unaware of the group allocation or the volume of
mepivacaine used for the median nerve block. The ultrasound-guided median nerve blocks were performed by the same two anaesthetists. The anaesthetist (outcome assessor) who performed the sensory assessment after the block was also blind to the group allocation or the volume of mepivacaine used for the median nerve block. Two study physicians who were otherwise not involved with the study evaluated the multiplanar 3D ultrasound images and analysed the data recorded.

**Ultrasound-guided median nerve block**

On the day of the study when the volunteers arrived at the clinical research ward, routine monitoring (ECG, arterial oxygen saturation, \( S_{O_2} \), and non-invasive arterial pressure) was established and monitored until complete resolution of the block. An i.v. cannula was sited at the antecubital fossa of the dominant arm, but no i.v. fluid was administered. The site for the median nerve block was determined during the health screening visit as described above. All median nerve blocks were performed under strict aseptic precautions and real-time ultrasound guidance using a SonoSite Edge\textsuperscript{TM} ultrasound system (SonoSite Inc., Bothell, WA, USA) with a high-frequency linear array transducer (HF50x, 15–6 MHz). Two-dimensional ultrasound imaging was used during the nerve block to replicate the clinical practice of ultrasound-guided nerve block and for better ergonomics, since 2D ultrasound transducers are easier to handle than the more bulky integrated mechanical 3D transducers. Moreover, the slow screen refresh rate with currently available 3D ultrasound technology does not allow for accurate assessment of the spread of the injected LA in real time.\textsuperscript{5} Thus, performance of the nerve block using 2D ultrasound guidance and post-block assessment of the spread of LA using 3D ultrasound imaging as was done in this study reflects the technical reality.

A 22 G, 50 mm, short-bevel, facet tip needle (Polymedic; Carrières sur Seine, France) was used for the block and was inserted using an in-plane technique (Fig. 2a). The LA was injected after inadvertent intravascular placement of the needle tip was excluded by gently aspirating through the extension tubing attached to the block needle.

Patients randomized to Group icLA received a median nerve block (in-plane technique) with circumferential spread of mepivacaine (1%) around the median nerve in the transverse sonogram (Fig. 2c) using a maximum 5 ml volume of LA. In order to achieve circumferential spread of LA, repositioning of the needle tip to different parts of the median nerve (multiple locations), through the same skin puncture site, was permitted. Once circumferential spread was achieved, the total volume of mepivacaine (ml) used was recorded. Patients randomized to Group icnLA received a median nerve block (in-plane technique) with non-circumferential spread of LA using a previously described \( ED_{25} \) volume of mepivacaine (\( \approx 0.11 \text{ ml of LA per mm}^2 \text{ of nerve area} \)),\textsuperscript{6} which was deposited at a single site (single location) between the flexor digitorum superficialis muscle and the median nerve (Fig. 2c).

**Multiplanar 3D ultrasound imaging**

A 3D ultrasound scan was performed before and immediately (within 20 s) after the median nerve block (Figs 3 and 4) using the Supersonic Aixplorer ultrasound system and a Super-Linear\textsuperscript{TM} 3D volumetric transducer (SLV 16–5 MHz). Liberal amounts of ultrasound gel were applied to the skin over the area to be scanned for acoustic coupling. The 2D ultrasound image was optimized before the 3D ultrasound data set was acquired because the quality of the 3D volume or images is dependent on the quality of the 2D images. Also care was taken to avoid exerting undue pressure over the area scanned. Optimized 2D ultrasound images in the transverse and sagittal axes were recorded on to the hard disc of the ultrasound system. The volume box and volume angle, which determines the angle of sweep for the 3D scan, was adjusted to encompass the area of interest and a 3D volumetric ultrasound scan of the median nerve was then performed with the transverse scan plane as the data acquisition plane. Three data sets were acquired from each volunteer and stored in DICOM (Digital Imaging and Communications in Medicine) format in the hard disc of the ultrasound system for retrospective rendering, display, and evaluation.

**Outcomes measures**

**Sensory assessment**

The loss of sensation to pinprick in the area of the hand innervated by the median nerve ipsilateral to the block, compared with the contralateral side, was assessed using pinprick testing (100, normal sensation, to 0, no sensation) at regular intervals (before, 2, 4, 6, 8, 10, 15, 20, 30, and 60 min) after the block and then every 30 min until complete recovery of sensation. During sensory assessment, the tip of the needle used (22 G short bevelled) was applied to the skin with a force that was adequate to indent the skin but not enough to puncture it. This produced a consistent painful sensation when applied to areas with intact sensation.

Seven areas were marked for assessment of sensory block: over the thenar eminence, palmar aspect of the tips of the thumb, index and middle fingers, radial aspect of the ring finger, and the dorsal aspects of the middle and index fingers. We did not assess motor block because a relatively low concentration of mepivacaine (1%) was used for the median nerve block. Sensory onset time was defined as the time it took for all the areas innervated by the median nerve to have a pinprick test <10. The median nerve block was considered successful if the sensory onset time was ≤60 min. The total duration of sensory block was defined as the time it took from completion of the median nerve block to complete regression of the sensory block (pinprick testing \( =100 \)).

**Three-dimensional ultrasound image processing and evaluation**

The stored 3D data sets were rendered retrospectively using the 3D rendering software (Supersonic Imagine\textsuperscript{TM}) installed in the ultrasound system (in-cart rendering) and displayed in the quad screen format as a multiplanar display (Figs 3 and 4). In the multiplanar display, image 1 (a) was the transverse image, image 2 (a) was the sagittal image, image 3 (c) was the coronal image, and image 4 (c) was the slice plane or...
3D view. The point where these three orthogonal scan planes intersected was represented by a ‘reference marker’, which is seen in all the ultrasound images, and is a reference point that depicts the same anatomical location in all three scan planes. In order to evaluate the extent of spread of LA, multiplanar ultrasound images were rendered with the reference marker placed over the centre of the median nerve in the transverse sonogram (primary acquisition plane). LA spread around the median nerve was quantified in the transverse image by dividing the area surrounding the median nerve into 12 equal sectors of 30° and recording how many of these sectors were covered by LA. LA spread above, under, and on either side (radial and ulnar side) of the median nerve was evaluated in the sagittal and coronal images, respectively, and recorded as a ‘yes’ or ‘no’, and the longitudinal extent of spread was also measured in millimetres using the internal calliper of the ultrasound system.

Clinical and ultrasound quantification of sensory block

In order to compare the median nerve block produced by circumferential or a non-circumferential spread of LA, a 12-point scale (block quality score) was designed. Block success was scored as 4 points and failure as 0 point. Sensory onset time was scored as follows: 0–6 min, 4 points; 8–10 min, 3 points; 15–30 min, 2 points; and 60 min, 1 point. Duration of sensory block was scored as follows: ≥180 min, 4 points; 150 min, 3 points; 120 min, 2 points; and ≤90 min, 1 point. In addition, the number of sectors (0–12) covered by the LA in the transverse multiplanar display was recorded.

Follow-up

One week after study day 2, all volunteers were examined in the clinic by a physician for clinical signs of the median nerve injury, local inflammation, or infection at the skin puncture site.
Statistical analysis

Power calculation and data analysis

Prospective power analysis was performed using the success rate after median nerve block as the primary outcome variable. We expected the success rate in Group 1 to be 100% and that in Group 2 was not known. We assumed that a 30% failure rate with the need for a rescue block was considered clinically relevant. Therefore, 21 subjects per group would provide 80% power to demonstrate a 30% difference in failure rate with an $\alpha$ of 0.05.

The volume of LA, the number of sectors covered by the LA, and the longitudinal spread of LA in Groups icLA and incLA were compared using the Wilcoxon matched-pair test. Difference in block success between study groups was tested by the two-sided $\chi^2$ test. Subsequently, all data recorded were grouped as the median nerve blocks with or without circumferential spread of LA and compared for block success (McNemar test), sensory onset time, duration of sensory block, and block quality score (Mann–Whitney U-test). The Pearson correlation test was also used to determine the relationship between the number of sectors covered by LA and sensory onset time, duration of sensory block, and block quality score. Data are represented as mean (SD) or median (IQR) as appropriate. A $P$-value of $\leq 0.05$ was considered statistically significant. Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 19.0 (IBM Inc., Armonk, NY, USA).

Results

Forty-two median nerve blocks were successfully performed on 21 volunteers; there were no dropouts (Fig. 1). Patient
characteristic data of the volunteers are presented in Table 1. There were no complications directly related to the median nerve block or the LA injection. Data on the volume of LA used for the median nerve block, number of sectors (surrounding the median nerve) covered by LA, number of volunteers in whom circumferential spread of LA was achieved, and LA spread (presence and distance) relative to the median nerve (above, under, radial, and on the ulnar side) as assessed in the multiplanar 3D ultrasound images, in the two study groups (icLA and incLA) are presented in Table 2.

Volunteers in Group icLA received a larger volume of LA than in Group incLA ($P<0.01$, Table 2). More sectors (around the median nerve) were covered by LA in Group icLA compared with Group incLA ($P<0.01$). The desired pattern of LA spread, that is, complete circumferential or non-circumferential spread, was achieved in only 67% (14/21) of volunteers in both study groups. There was a significant difference ($P<0.05$) in block success between Group icLA (100%) and Group incLA (81%). Complete circumferential spread of the LA was achieved in a greater ($P<0.01$) number of volunteers in Group icLA (67%) compared with that in Group incLA (33%). There were also more volunteers in Group icLA compared with Group incLA who exhibited spread of LA under the median nerve ($P<0.01$). There were no significant intergroup differences in the number of volunteers with LA spread above, on the radial or ulnar sides of the nerve, or the distance through which the LA had spread along the nerve.

When the data recorded were pooled together and analysed, there were equal numbers of blocks (21/42, 50%) that could be classified as having achieved circumferential or non-circumferential spread of LA. Clinical outcomes after the median nerve block (independent of group allocation) with circumferential or non-circumferential spread of LA are presented in Table 3. Subgroup analysis showed that volunteers who exhibited circumferential spread of LA received a larger volume of LA ($P<0.05$) and also had a faster onset of sensory block ($P<0.01$) than volunteers with non-circumferential spread of LA. Otherwise, there were no differences in overall success rate (90%), block failure ($n=2$), duration of nerve block, or block quality score between volunteers with circumferential or non-circumferential spread of LA. There was also no correlation between the number of sectors covered by LA and duration of nerve block ($r=0.02$) or block quality score ($r=0.18$), but there was a weak negative correlation with sensory onset time ($r=-0.32$).

The clinical examination performed 1 week after the study was unremarkable.

### Discussion

This is the first study to evaluate if the pattern of LA spread, assessed using post-block multiplanar 3D ultrasound imaging, affects the quality of sensory block during peripheral nerve block. In this volunteer study, we used multiplanar 3D ultrasound imaging to determine if the pattern of LA spread (circumferential or non-circumferential) affects the success rate of

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**Table 1** Patient characteristic data of volunteers studied. Data are presented as mean (SD)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>180 (8)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76 (9)</td>
</tr>
<tr>
<td>BMI (kg m$^{-2}$)</td>
<td>23 (3)</td>
</tr>
<tr>
<td>Mean nerve area (mm$^2$)</td>
<td>11 (2)</td>
</tr>
</tbody>
</table>

**Table 2** Volume of LA and distribution of the LA solution, as assessed using multiplanar 3D ultrasound imaging, after median nerve block. Data are presented as median (IQR) or as percentage

<table>
<thead>
<tr>
<th>Intended circumferential spread of LA ($n=21$)</th>
<th>Intended non-circumferential spread of LA ($n=21$)</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of LA (ml)</td>
<td>3.2 (2.6; 4.1)</td>
<td>1.1 (1.0; 1.3)</td>
</tr>
<tr>
<td>Sensory onset time (min)</td>
<td>15 (8; 20)</td>
<td>20 (10; 30)</td>
</tr>
<tr>
<td>Success rate of sensory block (%)</td>
<td>100</td>
<td>81</td>
</tr>
<tr>
<td>Duration of sensory block (min)</td>
<td>120 (120; 150)</td>
<td>120 (90; 120)</td>
</tr>
<tr>
<td>Complete circumferential spread (%)</td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>Number of sectors around nerve covered by LA</td>
<td>12 (11; 12)</td>
<td>10 (7; 12)</td>
</tr>
<tr>
<td>LA spread above nerve (sagittal view, ‘yes’ or ‘no’ in %)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>LA spread under nerve (sagittal view, ‘yes’ or ‘no’ in %)</td>
<td>95</td>
<td>43</td>
</tr>
<tr>
<td>LA spread on the radial side of the nerve (coronal view, ‘yes’ or ‘no’ in %)</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>LA spread on the ulnar side of the nerve (coronal view, ‘yes’ or ‘no’ in %)</td>
<td>95</td>
<td>85</td>
</tr>
<tr>
<td>Distance that the LA spread above the nerve (mm)</td>
<td>30.3 (23.2; 33.0)</td>
<td>29.5 (26.5; 32.1)</td>
</tr>
<tr>
<td>Distance that the LA spread under the nerve (mm)</td>
<td>23.7 (19.7; 27.7)</td>
<td>25.5 (19.9; 30.2)</td>
</tr>
<tr>
<td>Distance that the LA spread on the radial side of the nerve (mm)</td>
<td>28.1 (22.9; 31.8)</td>
<td>27.8 (21.9; 30.1)</td>
</tr>
<tr>
<td>Distance that the LA spread on the ulnar side of the nerve (mm)</td>
<td>24.3 (19.5; 28.2)</td>
<td>25.3 (21.2; 27.5)</td>
</tr>
</tbody>
</table>
sensory block after the median nerve block. Volunteers where a circumferential spread of LA was intended received a larger volume of LA and also a greater number of sectors (around the median nerve) were covered by LA compared with those nerve blocks where a circumferential spread of LA was not intended. Under the conditions of this study, the desired pattern of LA spread was achieved in only 67% (14/21). Even under optimal conditions (young and healthy volunteers, experienced anaesthetist) and with volumes of LA up to 5 ml, it was not possible to achieve a circumferential spread of LA in all intended cases. Nevertheless, all of the blocks with an intended circumferential LA spread were clinically successful. Otherwise, 80% of nerve blocks without intended circumferential spread were clinically successful. Subgroup analysis with the pooled data showed that sensory block was faster in volunteers with circumferential spread of LA, but otherwise the pattern of LA spread did not affect the duration of sensory block or block quality. Our results do not allow us to conclude that the faster sensory onset of sensory block was caused by the pattern of LA spread or the higher volume of LA used. We conclude that circumferential spread is not required for successful median nerve block.

Complete circumferential spread of LA and spread of LA under the median nerve was more common in Group icLA. There are no comparable data in the literature, but multiplanar 3D ultrasound imaging has been used to visualize the spread of LA after radial7 and sciatic10 nerve block. The greater occurrence of circumferential spread and spread of LA under the median nerve in Group icLA was an expected finding and can be explained by the technique of LA injection (multiple needle tip location) used. However, it was interesting that despite every effort (use of a larger volume of LA and repositioning of the needle tip if necessary), complete circumferential spread of LA was only achieved in 67% of volunteers in Group icLA. In the majority of volunteers in whom circumferential spread of LA was not achieved, it was due to a lack of LA spread under the median nerve. The reason for this is not clear but could be due to anatomical barriers (fascial septa, connective tissue layers, etc.) that prevent the spread of LA to the undersurface of the median nerve. Circumferential spread of LA was also detected in 33% of volunteers in Group icnLA, and despite Group icnLA receiving a larger volume of LA, there were no intergroup differences in the number of volunteers with LA spread above, on the radial or ulnar sides of the nerve, or the distance of LA spread along the median nerve. This demonstrates that 2D ultrasound, which was used during the median nerve block, does not provide a true picture of overall spread of LA after peripheral nerve block and 3D ultrasound is superior in this regard, in agreement with Missair and colleagues10 observation of LA spread after popliteal sciatic nerve block. Our results also demonstrate that it is not possible to predict the overall pattern of LA spread based on the technique of LA injection (single or multiple location) or the volume of LA used during a peripheral nerve block.

There were no differences in the overall success rate of sensory block, our primary outcome variable, or correlation between the spread of LA around the median nerve and the duration or quality of sensory block whether the spread of LA was circumferential or non-circumferential. There are no comparable data in the literature, and data comparing the spread of LA with sensory–motor block after peripheral nerve block are also limited. There are reports that circumferential spread of LA improves block success.3 11–13 In contrast, there are data showing that successful peripheral nerve block can be achieved with relatively small volumes of LA3 9,11 independent of the degree of encirclement of the nerve by LA.2 3 It is not possible to generalize the results of these reports2 3 9 11–13 because they were performed on different nerve models, for example, musculocutaneous nerve,3 median nerve,12 ulnar nerve,9 and sciatic nerve.2 11 13 However, based on the results of our study and the cumulative evidence,2 3 9 11–13 we believe that factors other than the pattern of LA spread are responsible for nerve block success. We also speculate that complete encirclement of the nerve is more relevant for block success with larger nerves (e.g. sciatic nerve)2 11 13 while, as demonstrated in this study, smaller volumes (dose) and non-circumferential spread of LA can be adequate for block success with smaller nerves.3 9 Future research to confirm our assertion in clinical practice is warranted.

Independent of whether circumferential or non-circumferential spread of LA was achieved, there were two block failures (2/21, ~ 10%) after pooling the data. The two failed blocks with circumferential spread of LA are of particular interest because factors other than distribution of LA might be involved. Choice of LA (type, dose, concentration, and volume), lipid solubility and pKa (ionization constant) of the LA, local pH, intra-epineural diffusion of LA, and individual sensitivity of sodium channels are possible factors for block success.

Volunteers in Group icLA received a larger volume (dose) of LA, compared with that in Group icnLA, to achieve circumferential spread of LA around the median nerve. This might explain

| Table 3 LA spread after the median nerve block for pooled data (irrespective of group allocation). Data are presented as percentage or median (IQR) |
|---------------------------------|-------------------------------|-----------------|
| Volume of LA used (ml)          | 2.8 (1.3; 3.6)                | 1.3 (1.1; 2.4)  |
| Sensory onset time (min)        | 15 (8; 20)                    | 20 (15; 30)     |
| Success rate of sensory block (%)| 90                            | 90              |
| Duration of sensory block (min) | 120 (90; 120)                 | 120 (120; 150)  |
| Block quality score (0–12)     | 10 (8; 11)                    | 9 (9; 10)       |

P-value

<0.05

<0.01

NS

NS
the higher incidence of circumferential spread, greater number of sectors covered by LA, and faster onset of sensory block in Group icLA compared with Group incLA. Nevertheless, it should not detract from the primary objective of this study which was to determine if the pattern of LA spread (circumferential or non-circumferential) affects the success rate of sensory block after the median nerve block.

The results of this study might not translate to other peripheral nerve blocks because only a median nerve block model was used. Moreover, the median nerve blocks were performed in healthy young volunteers who did not undergo a surgical procedure. Therefore, the clinical applicability of the sensory outcomes presented in this report needs validation in future clinical trials investigating a larger variety of single nerve blocks and block of complex nerve structures.

This study used an experimental design and therefore our results must be interpreted after considering its limitations. The extent of LA spread was assessed using 3D ultrasound imaging after block performance, which does not reflect routine clinical practice. Moreover, as described above, the slow screen refresh rates of currently available 3D ultrasound technology do not allow for accurate assessment of the spread of the injected LA in real time. Nevertheless, the 3D ultrasound imaging provided detailed information about the spread of LA for our study design. Secondly, under the conditions of this study, our results might only be valid for small nerves since there are published data suggesting that circumferential spread of LA might produce higher success with larger nerves. Great efforts have been made to implement low volume peripheral nerve block in clinical practice, but the optimal pattern of LA spread during peripheral nerve block is still not known. We also acknowledge that the results of the present study are only applicable for the median nerve and possibly for other nerves of similar size. Nevertheless, the same experimental model could be used to investigate block characteristics of larger nerves.

In conclusion, we have shown that even under optimal conditions, it is not possible to achieve circumferential spread of LA in all intended cases. Circumferential spread of LA was associated with faster onset of sensory block than non-circumferential spread. However, we cannot conclude that faster onset of sensory block was due to circumferential spread of LA or the higher volume of LA used. Otherwise, there was no difference in the overall success rate, or duration or quality of sensory block whether the pattern of LA spread was circumferential or non-circumferential.

**Authors’ contributions**


**Declaration of interest**

D.M. has received unrestricted grants from Pajunk Inc. and Temena International. P.M. has received honoraria from Sonosite International, and is on the editorial boards of the BJA and Paediatric Anaesthesia. P.M. and S.C.K. are on the scientific board of the European Society of Anaesthesiology.

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