Comparison of percutaneous electrical nerve stimulation and ultrasound imaging for nerve localization†

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Key points
- Percutaneous nerve stimulation is a recently introduced technique to facilitate peripheral nerve block.
- We evaluated the ability of this technique to localize nerves of the brachial plexus as verified by ultrasound imaging in 20 volunteers.
- There was only a 10% concordance between the most superficial nerves identified by percutaneous stimulation and ultrasound imaging.

Background. Percutaneous nerve stimulation (PNS) is a non-invasive technique to localize superficial nerves before performing peripheral nerve blocks, but its precision has never been evaluated by high-resolution ultrasound. This study compared stimulating points at the skin with the position of nerve structures determined by ultrasound. Correlations between distances and percutaneous stimulation thresholds were determined.

Methods. PNS was performed in 20 healthy volunteers systematically with a stimulating pen at the neck after attaching a transparent film with 49 (7 × 7) perforations. Stimulation thresholds were measured and impedance was controlled. Thereafter, an independent observer measured the depth (D) of the most superficial nerve structure with ultrasound. Distances between stimulating points and the most superficial nerve structure (S) were measured. Correlations between associated stimulating thresholds and distances D and S were calculated.

Results. The stimulating point with the lowest current was identical to the point closest to the nerve in only 10% of measurements. Median S was 12.6 (3.4–32.0) mm and D 7.6 (0.3–28.6) mm. Distances did not correlate with percutaneous stimulation thresholds.

Conclusion. PNS with a stimulating pen is not a reliable technique for nerve localization in the brachial plexus as verified by high-resolution ultrasound.

Keywords: anaesthetic techniques; regional; brachial plexus, measurement techniques; ultrasound nerve; somatic, physiology; neurophysiology, regional blockade

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Electrical nerve stimulation has been the gold standard for nerve localization during peripheral nerve block before high-resolution ultrasound became available. In contrast to invasive nerve stimulation using a needle, a non-invasive technique has been described to localize superficial nerves percutaneously† at considerably lower costs than high-resolution ultrasonography.6–10

A commercial device to percutaneously identify nerves (Stimuplex® Pen, B. Medical Inc., Bethlehem, PA, USA) has been reported to identify the brachial plexus.11 In theory, the function is based on the relationship between current thresholds and electrode-to-nerve distance.12 Since electrical impedance in biological tissues varies,13 14 this relationship is not always linear.15

The primary aim of the present study was to assess the value of percutaneous nerve stimulation (PNS) for superficial nerve localization compared with ultrasound. We investigated whether points on the skin with the lowest current corresponded to locations where the nerve is most superficial to the skin. The secondary aim was to define the correlation between minimal current for PNS and the nerve to skin distance measured with ultrasound.

Methods

In this prospective observational study, 20 volunteers underwent PNS and subsequently ultrasound examination of the neck. After Institutional Medical Ethical Committee approval, written informed consent was obtained from all subjects. Inclusion criteria were age above 18 yr and ASA classification I or II. Exclusion criteria were infection at the site of investigation, known allergy to adhesive transparent film or ultrasound gel,16 implanted cardiac pacemaker or defibrillator, neurological deficit of the arm, known peripheral neuropathy, pregnancy, or lactation.

PNS study

Subjects were positioned supine with the head turned maximally to the left. A perforated transparent film (Tegaderm®, 3M, Maplewood, MN, USA) was attached to the skin on the
right side of the neck parallel to the clavicle to cover the skin at the interscalene groove. The transparent film was prepared with 49 perforations (3 mm diameter) in a square pattern (seven rows of seven perforations) with 7 mm between the centres of the perforations (i.e. 4 mm distance between the edges) and red coloured for easy recognition of the perforations (Fig. 1a). A neutral electrode (3M Red Dot; 3M) was connected to the positive lead of a nerve stimulator (Stimuplex® HSN12, B. Braun, Melsungen, Germany) and placed on the opposite shoulder.

The stimulating pen was applied at each perforation while pressing the metal ball of the pen into the skin without lateral displacement (Fig. 1b). In order to lower skin conductance, gel was applied to the tip of the pen. A rectangular constant current stimulus with a pulse width of 1 ms and a frequency of 2 Hz was generated by the nerve stimulator. The electrical current (0–5 mA) was increased gradually until muscle twitches were elicited. Paraesthesias and local twitches of muscles (mostly platysma) directly at the stimulating pen were not regarded as positive stimulation. Stimulation of the trapezius muscle and diaphragm was regarded as inadequate motor responses. Minimal threshold (mA) and resistance (kΩ) for evoked motor response and type of activated muscle (group) were noted for each stimulated point.

**Ultrasound examination**

After PNS, the brachial plexus (at the level of the neck) was examined using ultrasound by a second independent observer blinded to the results of the stimulating pen examination. The plexus was first identified with a 13–6 MHz linear ultrasound probe (HFL 38 x and Turbo M, Sonosite Inc., Bothell, WA, USA). Thereafter, the probe was applied to each of the seven rows at the transparent film in a standardized manner. In order not to compress tissues, the probe was placed perpendicular to the skin with the least possible pressure (Fig. 1c). At each row, ultrasound images were saved for off-line analysis. The most superficial nerve structure was identified on the ultrasound image, and vital structures like arteries or veins between the skin and the most superficial nerve structure were determined.

**Calculations and data analysis**

Perforations were represented on the ultrasound images by means of projecting a maze. The perforations where motor responses could be provoked were identified on the ultrasound image.

The following distances were measured (Fig. 2): (i) shortest distance between the centre of the stimulating pen and the most superficial border of the nerve structure (S); (ii) depth of the most superficial nerve structure (D) (shortest distance between skin and the most superficial border of the nerve structure). Distances S and D were correlated separately with the associated percutaneous current thresholds at the perforations where a motor response could be provoked. These correlations were recalculated to control for measured skin conductance.

**Statistics**

Data are presented as median (range). Correlations were analysed without assuming normal distribution of data, thus non-parametrically. Spearman’s rank-sum-correlation test was used and subsequently controlled for the measured
Percutaneous nerve stimulation vs ultrasound

skin conductance. $P$-values $<0.05$ were considered statistically significant.

**Results**

Twenty subjects participated in this study. Patient characteristic data are presented in Table 1.

Of the total 980 points (20 subjects $\times$ 49 stimulation points) tested with PNS, an adequate muscle twitch of the arm was obtained at 181 points (deltoid muscle at 74 points, biceps muscle at five points, triceps muscle at three points, supination or/and flexion of the forearm at 57 points, and movements of the hand or/and fingers at 50 points). At eight points, stimulations of more than one muscle group were observed. Responses defined as inadequate were observed at 297 points (trapezius muscle at 273 points and diaphragm contractions at 24 points). No responses were observed at 483 points. Local platysma contractions were elicited at 138 points and they were combined with other responses at 119 points. A median of 5 (0–41) motor responses were elicited per subject. In four subjects, no motor response could be provoked. In three subjects, isolated or combined diaphragm contractions were observed during stimulation.

At those points inducing an adequate motor response, the median minimal electrical current was 3.25 (1.0–5.0) mA. Median resistance was 8.5 (2.1–21.1) $\Omega$ at all stimulated points.

After visualizing the brachial plexus with ultrasound at each row containing seven perforations each, we determined the responses at the closest related perforations to the site at the skin most superficial to the nerve structure. One hundred and forty ultrasound images (20 subjects $\times$ 7 images) were examined. The stimulating point with the lowest current was identical to the point closest to the most superficial nerve structure in only 10% of measurements.

Median distances $S$ and $D$ from the points with the lowest current to the plexus (as visualized with ultrasound) were 12.6 (3.4–32.0) and 7.6 (0.3–28.6) mm, respectively.

Typical examples of three different subjects comparing the distance $S$ (stimulating point at the skin to the most superficial nerve structure) and the minimal current (mA) eliciting an adequate motor response are shown in Figure 3.

![Fig 2 Schematic picture of ultrasound scan and transparent film with the perforations (red dotted line) for the stimulating points. ASM, anterior scalene muscle; MSM, medial scalene muscle. D (blue line) is the depth of root C5, which is the most superficial nerve structure. S (yellow line) is the shortest distance between the stimulating point in the perforated film and root C5.](image)

**Table 1** Patient characteristics of the volunteers ($n=20$) presented as median (range)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Median (Range)</th>
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<tbody>
<tr>
<td>Gender (male/female)</td>
<td>12/8</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>34.5 (29–65)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.78 (1.62–1.91)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>75.0 (58–105)</td>
</tr>
<tr>
<td>Body mass index (kg m$^{-2}$)</td>
<td>24.4 (20.3–28.8)</td>
</tr>
<tr>
<td>Handedness (right/left)</td>
<td>17/3</td>
</tr>
</tbody>
</table>

![Fig 3 Three representative examples of correlation between the shortest distance $S$ from the points with a motor response and the plexus (x-axis) and the minimal stimulation current at this point (y-axis). No motor responses were detected in subject 9.](image)
No positive correlation could be demonstrated between the minimal current at the positive response points and distance S (Fig. 4) or D (Fig. 5).

Using ultrasound, the dorsal scapular artery was identified superficial to the brachial plexus in the supraclavicular region in three subjects. A positive motor response was elicited in two subjects at this location.

**Discussion**

A low percentage of the points localized with the stimulating pen at the skin of the interscalene and supraclavicular area corresponded to the points where the plexus was most superficial to the skin according to ultrasound visualization. Most of the points localized with the stimulating pen and ultrasound differed, which were on average 1.3 cm apart. Distances between the stimulating pen and the most superficial nerve structure (distance S) or the depth (distance D) of the nerve structure did not correlate with the stimulating current thresholds. Occasionally, the dorsal scapular artery was located between the skin and a nerve structure, whereas a motor response was provoked by the stimulating pen directly above the artery.

PNS with a stimulating pen is used as a new non-invasive method to localize the optimal point on the skin for needle insertion during peripheral nerve block. Touching the skin with a stimulating pen at the anatomical landmarks of the neck can help to locate the brachial plexus. Unfortunately, published data to evaluate its value are sparse. There is just one feasibility pilot study which has only been published in abstract form. Studies comparing this tool with ultrasound are lacking.

Capdevila and colleagues used percutaneous electrode guidance with a needle tip for prelocating the median, radial, and ulnar nerves and measured the required depth for a nerve block after needle insertion. All three nerves could be stimulated percutaneously in 86% of the subjects. The graphics suggested a positive relationship between the depth of the needle and the percutaneous stimulating current required to provoke a motor response. Differences in the results to our study can be explained by the use of a stimulating needle for measuring depth of the nerve. Tissue can be dislocated while penetrating with an atraumatic needle. Thus, measuring distances between the skin and nerve with a stimulating needle is less reliable. Another reason for the differences in correlation to this study could be differences in electrical tissue characteristics in the neck and the axilla. In the present study, we used ultrasound to measure and calculate the distances from the stimulating pen to the most superficial nerve structure.

The principle of PNS is based on the relationship between the intensity of the electrical current delivered and the distance between the stimulating pen and the stimulated nerve. The current is believed to vary with the inverse of the square of the distance. Thus, a much larger stimulating current will be required as the pen moves away from the nerve according to Coulomb’s law: \( E = \frac{K Q r^{-2}}{2} \), where \( E \) is the current intensity at a distance \( r \) from the electrical source, \( K \) is a constant dependent on the electrical properties of the medium through which the current is transmitted, and \( Q \) is the minimal stimulating current of the electrical source.

The problem with this model is that the electrical properties of different human tissues vary considerably in specific electrical resistance (i.e. blood 150 \( \Omega \) cm, skeletal muscle transverse 675 \( \Omega \) cm, fat tissue about 2 k\( \Omega \) cm, and dry skin above 100 k\( \Omega \) cm). Therefore, the relationship of conductivity and distance in inhomogeneous tissues is not linear.

More recent data comparing minimal stimulation current and distance between the needle tip and the nerve using high-resolution ultrasound suggest that the correlation distance–current is not consistent. In this study, the stimulation threshold outside and inside the nerve trunk was the same in some subjects. Stimulation thresholds >0.2 mA could not rule out intraneural placement in 64% of the subjects. These data were gathered using hypodermic-insulated needles after penetration of the skin in the proximity of nerve where tissue resistance is supposedly more homogenous.

Another reason for not demonstrating a correlation between the distance and the stimulating thresholds might have been the lack of indentation of the skin with the stimulating pen. Usually, the skin is impressed considerably with the stimulating pen when clinically trying to identify nerves
percutaneously. For methodological reasons, this was not done in our study in order to avoid displacement of anatomical structures when using PNS compared with ultrasound. There is no reason to believe that varying impression of the skin should change the correlation between depth and stimulation current since tissue resistance will still be variable. Tilting of the ultrasound probe could have influenced measured distances at the images, but should be minimized by placing the probe perpendicular to the skin with minimal pressure. Furthermore, anatomical structures like blood vessels could have interrupted the current to the nerve structure. Blood vessels like the dorsal scapular artery running through the plexus were found only at three of 140 ultrasound images. However, above these arteries, a motor response was elicited. This is a potentially hazardous situation when the stimulating pen would have been used as a needle-guiding technique.

In conclusion, we compared ultrasound with PNS for localization of the brachial plexus. A pure stochastic correlation of stimulus intensity and distance to the nerve structure is in striking contrast to the theory of nerve stimulation and may raise important questions regarding the technique and theory of nerve stimulation. Compared with ultrasound, PNS is not a reliable technique for identifying the brachial plexus at the neck. Furthermore, ultrasound can give much more information about anatomical variations that might be missed just using a nerve stimulation technique.

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Conflict of interest
None declared.

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References