Educational and clinical aspects of peripheral nerve blockade
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Comparison of percutaneous electrical nerve stimulation and ultrasound imaging for nerve localization

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Abstract

Background and Objectives
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.
Comparison of percutaneous electrical nerve stimulation and ultrasound imaging for nerve localization

Abstract

Introduction

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Introduction

Electrical nerve stimulation has been the gold standard for nerve localization during peripheral nerve blockade before high-resolution ultrasound became available. In contrast to invasive nerve stimulation using a needle, a non-invasive technique has been described to localise superficial nerves percutaneously\textsuperscript{1-5} at considerably lower costs than high-resolution ultrasonography.\textsuperscript{6-10}

In 2007 a commercial devise was launched to percutaneously identify nerves to depths up to 3 cm (Stimuplex\textsuperscript{®} Pen, B. Medical Inc. Bethlehem, PA). Identification of the brachial plexus with this stimulating pen was reported to be rapid and non-painful.\textsuperscript{11} In theory, the function is based on the relationship between electrode-to-nerve distance and current thresholds.\textsuperscript{12} Since electrical impedance in biological tissues varies,\textsuperscript{13,14} this relationship is not always linear.\textsuperscript{15} Primary aim of the present study was to assess the value of percutaneous nerve stimulation (PNS) for superficial nerve localisation compared to ultrasound. Therefore, we investigated whether points on the skin with the lowest current corresponded to locations where the nerve is most superficial to the skin. 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 years and American Society of Anesthesiologists (ASA) classification I or II. Additional exclusion criteria were infection at the site of investigation, known allergy to adhesive transparent film or ultrasound gel,\textsuperscript{16} implanted pacemaker or cardio defibrillator (ICD), neurologic deficit of the arm, known peripheral neuropathy, pregnancy or lactation period. Demographic data like gender, age, size and weight, left or right-handed from each volunteer were collected.

Percutaneous nerve stimulation study

The volunteers were positioned supine with the head turned maximally to the left side. A standardized perforated and transparent film (Tegaderm \textsuperscript{®}, 3M,
Maplewood, MN) was attached to the skin on the right side of the neck parallel to the clavicle to cover the skin at the interscalene groove. Beforehand the transparent film was prepared with 49 perforations (3 mm Ø) in a square pattern (7 rows of 7 perforations) of 7 mm distances between the centres of the perforations (i.e. 4 mm distance between the edges of the perforations) and red coloured for easy recognition of the perforations (Fig. 1a). A neutral electrode (3M Red Dot; 3M, Maplewood, MN) 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 intending the metal ball of the pen completely 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. Paresthesias and local twitches of muscles (mostly platysma) directly at the stimulating pen were not regarded as positive stimulation. Stimulation of trapezius muscle and diaphragm were 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

Following PNS, the brachial plexus (at the level of the neck) was examined 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 & Turbo M, Sonosite Inc., Bothell, WA). Thereafter, the probe was applied to each of the 7 rows at the transparent film in a standardized manner. In order not to compress tissues, the probe was attached 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. Any vital structure like arteries or veins between the skin and the most superficial nerve structure was determined.

Calculations and data analysis

All 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.

Following distances were measured (Fig. 2):
Figure 1

a. Perforated transparent film covering the skin at the interscalene groove.
b. The stimulating pen applied to the perforations at the skin.
c. The probe is placed at one of the seven rows for ultrasound examination.
Figure 2  Schematic picture of ultrasound scan and transparent film with the perforations for the stimulating points. ASM, anterior scalene muscle; MSM, medial scalene muscle. D (dotted line) is the depth of root C5, which is the most superficial nerve structure. S (dashed line) is the shortest distance between the stimulating point in the perforated film and root C5.
– Shortest distance between center of stimulating pen and the most superficial border of the nerve structure (S).
– Depth of the most superficial nerve structure (D) (shortest distance between skin and the most superficial border of the nerve structure).
Finally, distances S and D were correlated separately with the associated percutaneous current thresholds at the perforations where a motor response could be provoked. All these correlations were recalculated and controlled for measured skin conductance.

Statistics
Data are presented as median (range). Correlations were analyzed without assuming normal distribution of data, thus non-parametrically. Spearmans rank-sum-correlation test was used and subsequently controlled for the measured skin conductance. P-values smaller than 0.05 were considered statistically significant.

Demographic data

<table>
<thead>
<tr>
<th>Demographic data</th>
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<tr>
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<tr>
<td>Handedness</td>
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</tbody>
</table>

Table 1 Demographics of the volunteers (n = 20) presented in median (range)
Results

Twenty volunteers participated in this study. Demographic data are presented in table 1.

Of the total 980 points (20 volunteers x 49 stimulation points in the adhesive film) tested with PNS, at 181 points an adequate muscle twitch of the arm was obtained (deltoid muscle at 74 points, biceps muscle at 5 points, triceps muscle at 3 points, supination or/and flexion of forearm at 57 points, movements of hand or/and fingers at 50 points). At 8 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. Per volunteer a median of 5 (0-41) motor responses were elicited. In four subjects no motor response could be provoked at all. 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 mA (1.0-5.0). Median resistance was 8.5 kΩ (2.1-21.1) at all stimulated points.

After visualizing the brachial plexus with ultrasound at each row containing 7 perforations each, we determined the responses at the closest related perforations to the site at the skin most superficial to the nerve structure. 140 ultrasound images (20 volunteers x 7 images) were examined. Only in 10.0% the point at the skin with the lowest current was identical to the point closest to the most superficial nerve structure.

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

Typical examples of three different subjects comparing the distance S (stimulating point at the skin to most superficial nerve structure) and the minimal current (mA) eliciting an adequate motor response are shown in figure 3. 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 3 volunteers. Nevertheless, a positive motor response was elicited in two persons at this location.
Figure 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.
**Figure 4** Shortest distances (S) between the motor response point to the plexus (x-axis) and minimal stimulating currents (y-axis).

**Figure 5** Depth of the most superficial nerve structures (D) (x-axis) and minimal currents (y-axis).
Discussion

Only 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 and was 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 while 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 blockade. Touching the skin with a stimulating pen at the anatomical landmarks of the neck can help to locate the brachial plexus. The Stimuplex® Pen was launched by B. Braun in 2007 as a non-invasive device for locating superficial peripheral nerves. Unfortunately, the 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. Capdevilla et al. used percutaneous electrode guidance with a needle tip for prelocating the median, radial and ulnar nerve and measured the required depth for a nerve block after needle insertion in patients. All three nerves could be stimulated percutaneously in 85.5% of patients. The graphics suggested a positive relationship between the depth of the needle and the minimal 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 may be dislocated while penetrating with an atraumatic needle. Thus, measuring distances between skin and nerve with a stimulating needle is less reliable. Furthermore, the correlation varied over a wide range and unfortunately correlation coefficients and p-values were not mentioned. 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 at the skin 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: \( E = K (Qr^{-2}) \) 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.\(^{12}\) 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).\(^{17,18}\) Therefore, in men the relationship of conductivity and distance in inhomogeneous tissues cannot be linear.

More recent data comparing minimal stimulation current and distance between the needle tip and the nerve in patients using high-resolution ultrasound suggest that the correlation distance-current is not consistent.\(^{19}\) In this study the stimulation threshold outside and inside the nerve trunk was the same in some patients. Stimulation thresholds greater then 0.2 mA could not rule out intraneural placement in 64% of patients. Clearly, these data were gathered by using hypodermic insulated needles after penetration of the skin in the proximity of nerve where the tissue resistance is supposedly more homogenous.

Another reason for not demonstrating any correlation between the distance and the stimulating thresholds might have been 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 percutaneous electrical stimulation compared with ultrasound. Besides, 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. Since we placed the probe perpendicular to the skin with minimal pressure we reduced possible inaccuracies to a minimum.

Furthermore, anatomical structures like blood vessels could have interrupted the current to the nerve structure. Blood vessels like the dorsal scapular artery\(^{20}\) running through the plexus were found only at 3 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.

Finally, we compared ultrasound with PNS for localisation of the brachial

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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 technique and theory of nerve stimulation. In Conclusion, compared to 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.
References