VOLTAGE FIELDS SURROUNDING NEEDLES USED IN REGIONAL ANAESTHESIA

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SUMMARY
Using a bench model, we have studied the voltage fields surrounding both insulated and uninsulated needles used in regional anaesthesia. The findings were compared with earlier computer predictions which suggested that the fields would be markedly different for the two types of needle. The results confirm that the fields differ markedly and suggest that the use of insulated needles may not necessarily improve the accuracy of nerve location and that uninsulated needles may be more appropriate.

KEY WORDS

Low power peripheral nerve stimulators are now used frequently to aid nerve location during regional anaesthesia [1], but there is still controversy regarding the need for insulation of the needles, particularly with regard to the nature of the voltage field which surrounds the different types of needle. Several workers have attempted to quantify these fields. Montgomery and colleagues [2] used conductive paper to measure the voltage field strength at various points around the shaft and tip of uninsulated needles and concluded that maximum current density occurred at the tip of the needle. This study may be criticized on the lack of experimental detail and on the non-biological nature of the model, particularly as regards the electrical resistance of the paper, which was probably several orders of magnitude greater than that found in human tissues. A computer simulation by Bashein, Haschke and Ready [3] suggested that the voltage fields for insulated and uninsulated needles differed markedly. This model might also be criticized on the grounds that it is non-biological and may have used unrealistic boundary conditions to derive the solutions to the Laplace equations upon which the simulation was based.

The present study was undertaken to determine the form and magnitude of the voltage field surrounding different needles in a physiologically compatible model, and to compare the observed results with the earlier computer simulation.

MATERIALS AND METHODS
A rectangular Perspex tray of dimensions 30 cm x 20 cm x 3 cm was filled to a depth of 5 mm with 4.5% human albumin solution (HAS). A 22-gauge Pole needle (Top, RDG Electro-medical) was used as the insulated test needle and a 22-gauge Whitacre pointed spinal needle (Monoject) as the uninsulated needle.

The needle under test was inserted through the centre of one short side of the tray to project 3 cm into the solution (fig. 1). The earth electrode was positioned at the opposite end of the tray. The whole tray was positioned over a sheet of 1-mm grid graph paper to permit accurate measurement of the position of the test and probing needles. A potential difference of 3.0 V was maintained between the test needle and the earth electrode, the needle being negative with respect to the earth, by a constant voltage source (Koutant LA 100.2).

Voltage measurements were made using an electronic voltmeter with an input impedance in excess of 10 MΩ (Maplin Gold, Maplin Ltd), and an uninsulated seeking electrode of the same material as the needle under test. This needle was inserted vertically to the full depth of the tray to ensure that the maximum voltage at each point was recorded in a consistent manner and so that the model was effectively two-dimensional.

![Figure 1](http://bja.oxfordjournals.org/)

Fig. 1. The bench model. A = Tray containing human albumin solution; B = test needle; C = earth electrode; D = constant voltage source; E = voltmeter; F = probe needle.

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Fig. 2. Isopotential lines surrounding the insulated needle (A) and the uninsulated needle (B).

Fig. 3. Voltage plot as a function of distance from the needle tip in the direction of the needle. A: Insulated needle; B: uninsulated needle.

Two sets of voltage readings were made. In the first, the voltage was measured at fixed points between the tip of the test needle and the earth plate. In the second, the probe needle was positioned to identify points of equal voltage surrounding the needle tip—the isopotential points.

RESULTS
The results for both needle types are presented in figures 2 and 3. Figure 2A shows the isopotential lines surrounding the insulated needle, while figure 2B shows the field for an uninsulated needle. The isopotential lines show that there was an approximately circular voltage field surrounding the insulated needle, while that for the uninsulated needle was markedly non-uniform.

Figure 3 shows the fixed point voltage measurements for both insulated and uninsulated needles. For the insulated needle (fig. 3A), at any given distance from the needle tip the measured voltage was less than the corresponding point for the uninsulated needle (fig. 3B). In addition, the gradient of the slope was greater for the uninsulated needle than for the insulated.

The relationship of voltage gradient to distance from the needle tip, over the first 1 cm from the tip, is shown for both needles in figure 4. Curve a is the...
The voltage across a resting nerve cell membrane is approximately 80 mV, the inside of the nerve being negative with respect to the surrounding medium [4]. If sufficient movement of ions can be produced by the application of a voltage gradient, then the transmembrane potential may be reduced to 55 mV. At this point the membrane becomes freely permeable and a spike potential is generated. The movement of ions occurs in proportion to the magnitude of this voltage gradient. The form and magnitude of the voltage field surrounding the needle used for nerve block is therefore important.

Using an electronic, high-impedence voltmeter it is possible to measure directly the voltage field surrounding a needle. The impedance of the voltmeter is crucial to accurate measurement. If the impedance is low, the meter draws significant current from the model, in essence short-circuiting the voltage field, with consequent distortion of the shape of the field. The problem diminishes as the impedance of the voltmeter increases. For a needle voltage of 3.0 V, the current in the model was 0.9 mA using an insulated needle and 8.6 mA using an uninsulated needle. Therefore the resistance of the model was 3333 Ω and 349 Ω, respectively. (The difference in resistance of the total circuit results from the surface area of the needle in contact with the HAS being smaller in the case of the insulated needle.) Using a high impedance voltmeter of 10 MΩ, the measuring circuit would draw 0.0333 % and 0.0035 % of the total current of the model, respectively.

The two-dimensional nature of the study by Montgomery and colleagues [2] has been criticized. This criticism is unjustified, as the prediction of a three-dimensional field from a two-dimensional analysis is standard practice in the study of voltage fields [5]. Our model was effectively two-dimensional, but the real fields may be assumed to be three dimensional "solid of revolution" of the isopotential plots, except that the potential gradients are steeper close to the needle. In two dimensions, the circumference of isopotential lines (if they are circular) increases in proportion to the radius. When working in three dimensions, the areas of the isopotential surfaces (if they are spherical) increase in proportion to the radius squared. Therefore current density, and hence potential gradient, declines more rapidly with distance in a three-dimensional model. Although a similar argument applies to the non-circular lines or non-spherical surfaces of the uninsulated needles, the mathematical relationship is less clear.

Montgomery's study was criticized also on the basis that the resistance of conductive paper is usually much greater than that of normal tissues, but as no details of their method were given, it is not possible to comment further. For this study, we chose 4.5 % HAS to simulate more closely the clinical situation.

The isopotential lines may be regarded in the same way as contour lines on a map or isobars on a weather map. The maximum voltage gradient is found where the isopotential lines are most dense. From figure 2A, it is clear that there is an almost circular voltage field surrounding the tip of an insulated needle, whereas with the uninsulated needle the lines are most dense in front of the needle (fig. 2B). This supports the theoretical analysis of Bashein, Haschke and Ready [3]. As the nerve is most likely to be stimulated when it lies within a steep voltage gradient, with an uninsulated needle the nerve is most likely to fire when it lies immediately in front of the needle tip. With the insulated needle, the nerve is just as likely to fire when it is adjacent to the needle tip as when it lies in front of it. The nerve would also be stimulated just as readily when it lies behind the needle tip as would occur if the nerve had been transfixed by the needle. The voltage gradient found in front of the uninsulated needle tip (curve c in figure 4) would result in stimulation only when the needle was within approximately 2 mm of the nerve. From figure 4 curve a, it follows that a nerve lying several millimetre to the side of an insulated needle could be fired by the greater voltage gradient found here than would be the case with the uninsulated needle. Such a situation may have occurred in the study by Ford, Pither and Raj [6], who compared insulated and uninsulated needles for sciatic nerve location in the cat, using pulse-synchronous muscle twitch to aid nerve location. With the uninsulated needle it was...
clear that, in the five animals studied, the needle had come within 1 mm of the sciatic nerve in each case, while for the insulated needle three of seven had completely missed the nerve, but had stimulated the nerve. These three cases were excluded from further analysis. Because of this exclusion, while all the cases performed with uninsulated needles were studied, only the best of the insulated needles were included. The principal finding of the study, that insulated needles appeared to result in greater accuracy of nerve location, may be flawed. If the three excluded cases are included in the analysis, the uninsulated needle appears to give the most accurate location of the nerve.

Figure 3A shows that the voltage in front of an insulated needle decreased rapidly over the first 1 cm and then declined only slowly over the next few centimetres. With the uninsulated needle (fig. 3B), the initial voltage decrease was steep, but less than that with the insulated needle, while the decline in voltage over the next few centimetres was noticeably steeper. Assuming that, in clinical practice, the nerve should lie 1–2 mm in front of the tip of the blocking needle, the injection of local anaesthetic solution would displace the nerve from the needle. This would effectively move the nerve down the slope of the voltage gradient, sharply reducing the response of the nerve to stimulation and producing the "fade" effect seen in practice after injection of local anaesthetic solution [7]. The fade is greatest (and may only be seen) if the movement of the nerve is within the steepest part of the curve—that is, the first 5 mm. Fade therefore may be used as a guide for proximity of needle tip to nerve with both needles. While it might appear to be logical to use insulated needles in regional anaesthesia for greater accuracy of nerve location, this conclusion cannot be supported. From the data presented, it would appear that it is necessary to re-examine the role of the less expensive and more widely available uninsulated needle in electrical nerve stimulation in regional anaesthesia.

REFERENCES