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Electrophysiologic Effect of Injectates on Peripheral Nerve Stimulation

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Background and Objectives: A small volume of local anesthetic or normal saline abolishes the muscle twitch induced by a 1ow current (0.5 mA) during electrolocation. This study examines the hypothesis that the mechanism of this phenomenon is primarily the electrophysiologic effect of the injectate on the electrical current density at the needle tip.

Methods: Five pigs were studied. An insulated Tuohy needle was inserted in each pig toward the left and right brachial plexuses and the left and right femoral nerves. The needle was advanced until corresponding motor responses were observed at each site, using a current of 0.5 mA. The effect of injecting 1 mL each of normal saline and 5% dextrose in water (NS and D5W) on muscle twitch was investigated at all 20 needle insertion sites. Changes in the conductive area induced by the injectates were also demonstrated using gel electrophoresis.

Results: In all cases, the muscle twitches were abolished immediately after the injection of NS and recovered instantaneously after a subsequent injection of D5W. The electrical resistance between the needle and the ground electrodes decreased instantly after the NS injection. The resistance not only recovered but also increased after the injection of D5W. In the gel electrophoresis experiment, the results demonstrated that the expanded conductive area induced by the saline column surrounding the insulated needle was similar to that observed with the uninsulated needle.

Conclusion: The injection of a conducting solution (i.e., NS) rendered the current that was previously sufficient to elicit a motor response (0.5 mA) ineffective. The most likely reason for this change is that the conductive area surrounding the stimulating needle expanded after the injection and dispersion of the conducting solution (i.e., NS), thereby reducing the current density at the target nerve. This effect can be reversed by injecting a nonconducting solution (i.e., D5W) via the stimulating needle. *Reg Anesth Pain Med 2004;29:189-193.*

Key Words: Electrophysiologic effect, Injectates, D5W, Peripheral nerve stimulation.

The use of electrical stimulation to enhance the accuracy of needle placement in close proximity to a nerve has been widely employed for more than 3 decades. The observation that a small volume of local anesthetic or normal saline (NS) abolishes a motor response induced by a weak current (0.5 mA) has been reported and is commonly referred to as the "Raj test."[1-3] It has been suggested that the mechanism of this phenomenon is the physical displacement of the nerve by the injectate.[1-3] This explanation has been generally accepted and cited by most anesthesiologists, and it is cited in most textbooks. However, we hypothesize that the mechanism is primarily the electrophysiologic effect of the injectate on the electrical current density at the needle tip. In this study, we examined this hypothesis using both in vitro and in vivo (animal model) experiments. First, we used gel electrophoresis to demonstrate changes in the conductive area surrounding insulated needles caused by conducting and nonconducting injectates. Second, we examined the electrophysiologic effects induced by these injectates in a porcine model.

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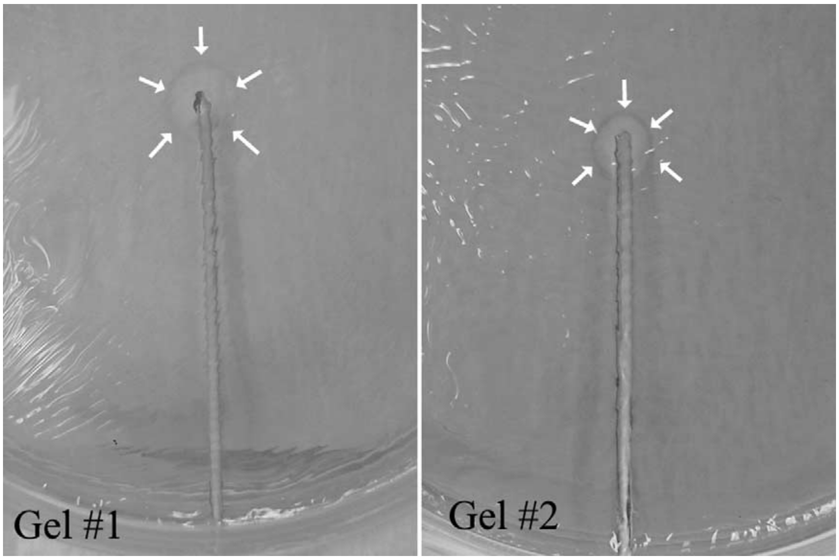


Fig 1. Gel electrophoresis with insulated needles. Arrows show the margin of the clear zone (gel #1: an insulated needle without any injectate present; gel #2: an insulated needle with D5W injectate).

Methods

Gel Electrophoresis

Using electrophoresis similar to that described by Bashein et al.,[4] 4 7.5% polyacrylamide gels (1 cm) containing 0.75% bromophenol blue dye were made in 6 cm × 6 cm rectangular regions on 4 separate plastic plates. Three sides of each gel were enclosed by a stainless steel wire connected to the positive lead (anode) of a direct-current power supply. Initially, a 5-cm well was made in each gel with a 17-guage Tuohy needle perpendicular to the fourth side of the rectangle. Subsequently, 18-guage needles were placed into the wells of each gel as follows: gel #1, an insulated needle without any injectate present; gel #2, an insulated needle with 5% dextrose (D5W) injectate; gel #3, an insulated needle with normal saline injectate; and gel #4, an uninsulated needle without any injectate present. To avoid disturbing the gel when the injectates were added (gels #2 and #3), the well was first filled with the injectate followed by 1 mL of injectate carefully injected via the needle, so that the excess injectate tracked back along the shaft of the needle. The needle was then connected to the negative (cathode) pole of the power supply. Each gel ran for 10 min at a constant current of 25 mA. A clear zone was formed when the dye migrated away from the needle, depicting an electrically conductive area.

Porcine Model

Upon receiving approval from the Animal Care Committee in our institution, we anesthetized 5 pigs (each weighing approximately 20 kg) using ketamine and isoflurane, and the animals were allowed to breathe spontaneously. Insulated Tuohy needles (Pajunk, Dyna Medical Corp, London, Ontario, Canada) with small, single, bare metal tips were inserted towards the left and right brachial plexi and the femoral nerve regions in the upper and lower extremities in each pig. A total of 20 needle insertion sites were tested in 5 pigs. A Tuohy needle was connected to the negative lead of a nerve stimulator. Before the study, this nerve stimulator was checked for accuracy. The ground electrode was placed on the surface of the abdominal wall. At each insertion site, the stimulator was set at a current of 1 mA, a pulse width of 0.1 ms, and a frequency of 1 Hz. The current amplitude was gradually decreased to 0.5 mA while the needle was advanced towards the target nerve until corresponding motor responses (radial nerve: wrist extension and femoral nerve: leg extension) were observed at each insertion site. The electrical resistance was calculated by recording the voltage drop between the negative and positive electrodes (Ohm's law) and displayed using a Tektronix TDS 2012 Digital oscilloscope (Tektronix Inc., Beaverton, OR) (Fig 1). While the needle was firmly held in place, the effect of injecting 1 mL of both NS and D5W was observed on the motor response at each insertion site.

Statistical analysis was performed using nonparametric ANOVA and Newman-Keuls multiple comparisons to evaluate the resistance at baseline (dry), after NS and D5W injections. A *P*-value less than .05 was considered statistically significant.

Results

Gel Electrophoresis

The photographs of the clear zones are shown in Figs 1 and 2. In Fig 1, the small clear zones in both gel #1 (insulated needle without injectate) and gel

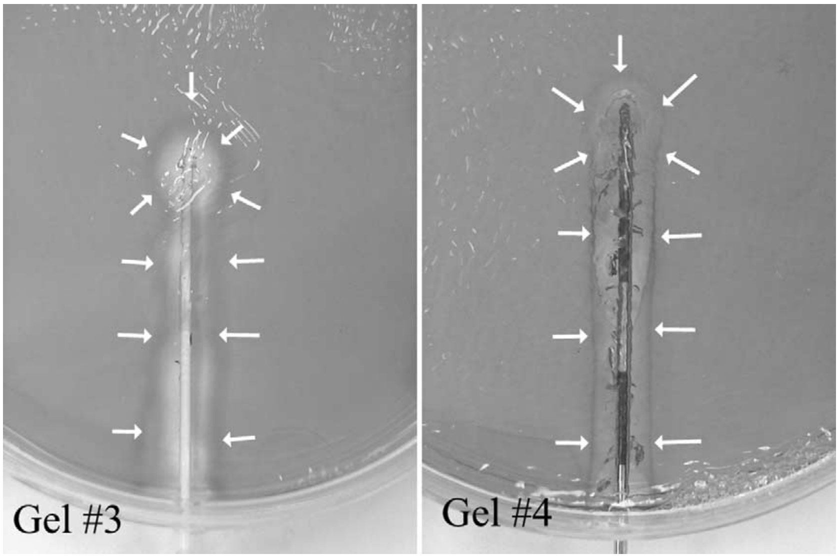


Fig 2. Gel electrophoresis with insulated and uninsulated needles. Arrows show the margin of the clear zone (gel #3: an insulated needle with NS injectate; gel #4: an uninsulated needle without any injectate present).

#2 (insulated needle containing D5W) illustrate only a small conductive area. In contrast, the expanded clear zone surrounding the tip and shaft of the uninsulated needle in gel #3 and the tip and shaft of the insulated needle containing NS in gel #4, demonstrate a substantial increase in the conductive area.

Porcine Model

In all cases, the motor responses were abolished immediately after the injection of NS and recovered instantaneously after a subsequent injection of D5W. In each case, the electrical resistance between the needle and the ground electrodes also immediately decreased after NS injection and subsequently increased after an injection of D5W (Table 1, Fig 3). Using ANOVA with Newman-Keuls multiple comparisons, the resistance at baseline, after NS and D5W injection, were all significantly different ($P < .01$).

Discussion

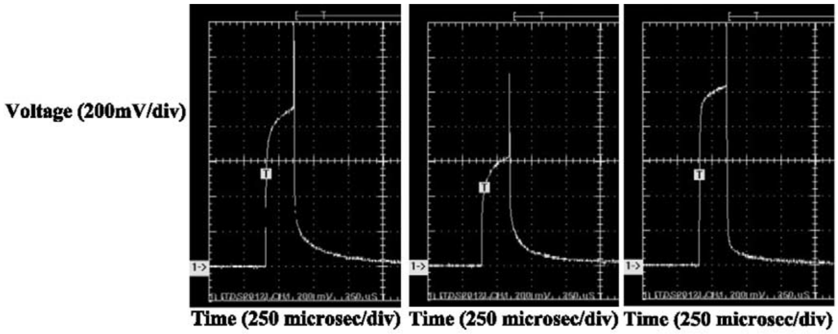
Despite years of clinical use of nerve stimulation in regional anesthesia, the electrophysiologic effect of injectates on nerve conduction remains unanswered. This is the first study to examine the electrophysiologic effects of injectates on the electrical current density at the needle tip.

Electrical current density is dependent on the total conductive area and total current flow from a stimulating needle. The smaller the conductive area for current flow at the needle tip, the higher the current density at the tip and the lower the threshold current for motor response when the nerve is stimulated. We hypothesize that the minimum current (0.5 mA) required to confirm accurate needle placement close to a nerve is altered after the injection of electrically conducting solutions such as local anesthetics or NS. An injection of these electrically conducting solutions towards a target nerve decreases the current density at the needle tip while the total current remains constant. The total conductive surface area will be expanded by the injected conducting medium and, as a result, will no longer have enough current density to stimulate the desired nerve. If this hypothesis is correct, the situation should be reversed when a nonconducting solution is injected. In this study, D5W was selected

Table 1. Electrical Resistance Between the Needle and the Ground Electrodes

	Saline		D5W	
Dry Baseline (Ohm)*	Ohm	Baseline (%)*	Ohm	Baseline (%)*
1,800	1,200	66.67	2,000	111.11
1,500	1,200	80.00	2,100	140.00
1,600	1,400	87.50	1,700	106.25
2,000	1,400	70.00	2,100	105.00
3,500	2,500	71.43	5,000	142.86
4,400	4,000	90.91	4,400	100.00
3,000	2,500	83.33	3,000	100.00
4,500	4,000	88.89	5,000	111.11
4,000	3,600	90.00	4,500	112.50
4,200	3,600	85.71	4,400	104.76
7,600	5,000	65.79	10,000	131.58
7,000	6,000	85.71	7,000	100.00
3,500	2,500	71.43	3,500	100.00
3,400	2,000	58.82	3,500	102.94
3,000	2,400	80.00	4,000	133.33
6,000	5,600	93.33	6,500	108.33
4,500	3,500	77.78	5,500	122.22
5,000	4,000	80.00	6,000	120.00
3,600	3,000	83.33	3,500	97.22
5,000	4,800	96.00	6,200	124.00

*Indicates each group is different from all others at $P < .01$ by Newman-Keuls multiple comparisons test.



	BASELINE	SALINE	D5W
Voltage (mV)	900	600	1000
Current (mA)	0.5	0.5	0.5
Resistance * (ohm)	1800	1200	2000

*** By Ohm's law : Resistance = Voltage / Current**

Fig 3. Example of a baseline voltage and voltage changes after injection of NS and D5W.

as the nonconducting solution because its osmolality is similar to that of NS.

Our hypothesis on the expanded conductive area caused by the injection of normal saline was well illustrated by the gel electrophoresis experiment. Figure 1 depicts both the insulated needle without injectate and the insulated needle with D5W and demonstrates that even when D5W is injected, the conductive area (clear zone) remains small and focused at the needle tip, as if it were an insulated needle without injectate. Conversely, in Fig 2, we demonstrated how the clear zone broadened at the tip and along the shaft of both the uninsulated needle and the insulated needles after the normal saline injections. This illustrates a substantially increased conductive area (throughout the saline column surrounding the needle) similar to that observed with an uninsulated needle alone. If the total current remains constant, as in the clinical situation but with an increased conductive area, the current density at the tip of the needle would decrease. This explains why the motor response was abolished after the NS injection. This is analogous to using an uninsulated needle for electrolocation in which more current is required to elicit a motor response than when using an insulated needle.

A reduction in current density by conducting solutions is also well known in other medical fields. In urology, nonconducting solutions of glycine 1.5% in sterile water are used instead of NS for transurethral resection of the prostate to maintain the current density at the tip of the resectoscope.[5] In neurosurgery, it is essential to keep the stimulating site dry during intraoperative facial nerve monitoring. Otherwise, blood and cerebrospinal fluid would reduce current density at the facial nerve, requiring a much higher current to elicit a response in the facial nerve.[6-9]

The results of the animal study further demonstrate this phenomenon. According to Ohm's law (electrical resistance = voltage delivered/current), if the voltage delivered decreases while the current remains constant, the electrical resistance will also decrease. In this experiment, the resistance at baseline and after the injection of NS and D5W were significantly different. After each NS injection, the voltage delivered between the needle and the ground electrode decreased immediately, whereas the current remained constant (using a constant-current nerve stimulator). This effect is best explained by the possibility that the NS injection provided a larger conductive surface area in the surrounding tissues in addition to the needle tip, leading to an overall decrease in the electrical resistance of the stimulation circuit with a constant current. More importantly, this study also illustrated that the increased conductive area and reduced current density induced by the NS injection could be reversed when a nonconducting solution (D5W) was injected. After an injection of D5W (Table 1), the voltage not only recovered but also increased, indicating that the electrical resistance also recovered and increased. From a clinical perspective, muscle twitches are abolished after an injection of NS because the current density at the needle tip is reduced as a result of an increased conductive area and is, therefore, no longer sufficient to evoke a motor response. Similarly, the injection of D5W after NS restores the muscle twitch by decreasing the conductive surface area and increasing the current density at the needle tip. The phenomenon of the Raj test is, therefore, best explained in electrical terms and is unlikely to be the result of physical displacement of the needle tip by the volume of the injectate.

Because the Raj test has been used to confirm needle placement in close proximity to a nerve, the understanding of this phenomenon is very important for accurate needle and stimulating catheter placement.[10] Although the clinical interpretation of the Raj test used for needle placement may not be influenced by the results of this study, our observations should warn that the injection of saline via an insulated needle or a stimulating catheter before nerve stimulation may lead to inaccurate interpretation of motor responses. Such false-negative responses might encourage unnecessary efforts to reposition an insulated needle or a stimulating catheter. In a recent clinical study, motor responses to electrical stimulation were compared when using a needle and a stimulating catheter.[11] In that study, the mean currents required to stimulate the intersternocleidodmastoid, axillary, femoral, and sciatic nerves using an insulated needle were 0.6, 0.5, 0.7, and 0.5 mA, respectively. However, the mean currents required to stimulate these nerves using a stimulating catheter after the injection of NS were much higher (1.5, 1.5, 2, and 3 mA, respectively). Reports in which stimulating catheters were threaded, without the use of saline, have not demonstrated such discrepancies between the threshold currents of the needle and the catheter.[12,13] Thus, these clinical observations add further proof to our hypothesis and support the findings in the current study.

On the basis of this study and the above-mentioned clinical observations, additional studies will be needed to establish a new acceptable current range for motor responses after dilating the perineural spaces with conducting solutions. On the other hand, one may potentially use a nonconducting solution such as D5W instead of NS for dilating perineural spaces to avoid the electrical conducting effect of NS. Obviously, additional studies will also be needed to determine the merit of using nonconducting injectates in peripheral nerve blocks.

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