Opening Injection Pressure Consistently Detects Needle–Nerve Contact during Ultrasound-guided Interscalene Brachial Plexus Block

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ABSTRACT

Background: Needle trauma may cause neuropathy after nerve blockade. Even without injection, nerve injury can result from forceful needle–nerve contact (NNC). High opening injection pressures (OIPs) have been associated with intrafascicular needle tip placement and nerve damage; however, the relationship between OIP and NNC is unclear. The authors conducted a prospective, observational study to define this relationship.

Methods: Sixteen patients scheduled for shoulder surgery under interscalene block were enrolled if they had clear ultrasound images of the brachial plexus roots. A 22-gauge stimulating needle was inserted within 1 mm of the root, and 1-ml D5W injected at 10 ml/min by using an automated pump. OIP was monitored using an in-line pressure manometer and injections aborted if 15 psi or greater. The needle was advanced to displace the nerve slightly (NNC), and the procedure repeated. Occurrence of evoked motor response and paresthesia were recorded.

Results: Fifteen patients had at least one clearly visible root. OIP at 1 mm distance from the nerve was less than 15 psi (mean peak pressure 8.2 ± 2.4 psi) and the 1-ml injection could be completed in all but two cases (3%). In contrast, OIP during NNC was 15 psi or greater (mean peak pressure 20.9 ± 3.7 psi) in 35 of 36 injections. Aborting the injection when OIP reached 15 psi prevented commencement of injection in all cases of NNC except one.

Conclusion: High OIP (≥15 psi) consistently detected NNC, suggesting that injection pressure monitoring may be useful in preventing injection against nerve roots during interscalene block. **(Anesthesiology 2014; 120:1246-53)**

DESPITE the increased use of ultrasound guidance to aid precise needle placement, neurologic complications during peripheral nerve blockade continue to be reported.[1,2] Nerve inflammation and injury are known to occur after forceful needle–nerve contact or intraneural injection.[3–5] Inadvertent needle–nerve contact and/or trauma may result from misinterpretation of the ultrasound image or inability to visualize the needle during the procedure.[6] Consequently, rates of residual paresthesia and/or numbness after ultrasound-guided peripheral nerve blocks have been estimated to be as high as 0.18 to 0.4%.[7,8] More recent reports suggest that the incidence of transient neurologic symptoms can be as high as 2.6 to 16%.[9,10] Therefore, ultrasonography as a sole method of monitoring may not reliably prevent neurologic injury.

Intrafascicular needle placement associated with high opening injection pressure can result in neurologic injury in animal models.[11,12] Steinfeldt *et al.*[5] also demonstrated that forceful needle–nerve contact and displacement results in inflammatory changes, yet, to date, no study has examined the association between needle–nerve contact and opening injection pressure. In this prospective observational study, we hypothesized that the presence of a high (≥15 psi) opening pressure during the performance of interscalene brachial plexus block can reliably detect needle–nerve contact. Secondary outcomes included minimum current required for evoked motor response (EMR), the presence of paresthesias during injection, block success, and the presence of postoperative signs or symptoms of neurologic injury.

What We Already Know about This Topic

- Needle trauma from injection in or close to peripheral nerves may result in neuropathy, although whether monitoring opening injection pressure can detect needle–nerve contact to improve safety is unknown

What This Article Tells Us That Is New

- In 16 patients scheduled for shoulder surgery, injection of solution 1 mm from a brachial plexus root resulted in low (8.2 psi) opening injection pressure, whereas injection of solution with the needle apposed to the root resulted in high (20 psi) opening injection pressure
- These results suggest that high (≥15 psi) opening injection pressure may indicate needle–nerve contact and avoiding injection in this condition might improve patient safety

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Materials and Methods

The study was approved by the Institutional Review Board of St. Luke's-Roosevelt Hospital, New York, New York. Sixteen American Society of Anesthesiologists physical status I or II patients aged 18 to 65 yr scheduled for elective outpatient arthroscopic shoulder surgery under interscalene brachial plexus block were recruited. Patients were excluded if they had a contraindication to interscalene block (*e.g.*, obvious neck deformity), body mass index greater than 35 kg/m^2, inability to communicate postoperative symptoms, preexisting neurological deficits in the operative extremity, allergy to local anesthetics, or a history of opioid dependence.

After giving informed consent, patients were brought to the preoperative regional anesthesia suite. All patients were scanned with a linear ultrasound probe (8 to 15 MHz, Flex Focus 400; BK Medical, Peabody, MA) to assess whether at least one root with a diameter 5 mm or greater could be clearly identified. Standard American Society of Anesthesiologists monitors and supplemental oxygen were applied, and patients were sedated with 0.05 μg/kg midazolam and fentanyl 0.5 to 1 μg/kg. Patients were positioned supine with the head turned to the contralateral side. After skin was disinfected with 10% povidone-iodine, a linear transducer covered with a sterile sleeve (Safersonic, Ybbs, Austria) was placed over the interscalene groove to obtain a transverse view of the anterior and middle scalene muscles. The C5, C6, and C7 brachial plexus roots were identified by tracing their course from each respective transverse process 1 to 2 cm distally within the interscalene space. Small adjustments were made to obtain the best possible image of the roots before needle insertion. All injections were performed at the root level, before the formation of brachial plexus trunks.

Pressure Recordings

Pressure-time data were obtained using an electronic manometer (PendoTECH, Princeton, NJ) coupled to a computer *via* an analog-to-digital conversion board (PressureMAT; PendoTECH). The manometer was connected to the needle using nondistensible high-durometer polyvinyl chloride injection tubing (84-inch long arterial pressure tubing manufactured by Abbott Laboratories, North Chicago, IL). In addition, a mechanical pressure manometer (BSmart; Concert Medical, Norwell, MA) was connected in sequence between the syringe and the electronic manometer. These devices have been tested in sequence in a previous study and have been found to correlate well.[13]

After skin anesthesia, a 5-cm 22-gauge insulated block needle (Stimuplex®A; B Braun Medical, Bethlehem, PA) was inserted in-plane from the lateral aspect of the transducer and directed medially. The current used to stimulate the nerve was set at 0.5 mA (2 Hz, 0.1 ms) (Tracer II®; LifeTech Inc., Stafford, TX) and adjusted to determine the minimal current required for EMR. For each visible root, the needle tip was positioned with the bevel always oriented downward for the following conditions:

1. Needle tip advanced to 1 mm from the nerve ("precontact") (fig. 1A)
2. Needle tip against the nerve with the minimum pressure required to displace and/or indent the nerve slightly, as previously described.[14–16] ("needle–nerve contact") (fig. 1B)
3. Needle tip withdrawn 1 mm from the nerve ("disengagement") (fig. 1A).

Care was taken to apply only that pressure required to document the slightest nerve displacement and/or indentation. Several studies have used precisely this type of deliberate needle–nerve contact and reported no neurologic complications.[14–16] In contrast, this type of gentle displacement differs markedly from forced needle–nerve contact, such as the type described in the study by Steinfeldt *et al.*,[5] as well as from intentional intraneural needle placement and/or injection, all of which may be associated with injury.[1,17]

Two observers monitored the ultrasound image and agreed on the needle–nerve relationships. Needle-tip passage through the epimysium of the middle scalene muscle and/or prevertebral fascia and into the interscalene space was confirmed both by the observation of this fascial layer snapping

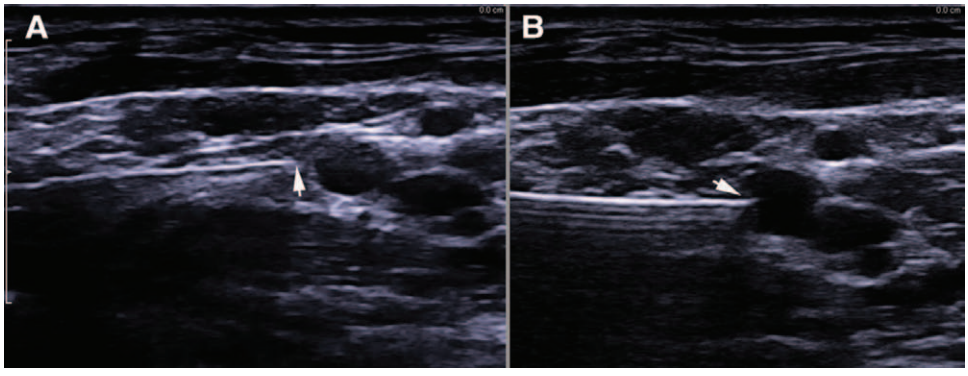

Fig. 1. Ultrasound image of needle in relation to C5 nerve root (*A*) 1 mm away from nerve and (*B*) gently displacing nerve root. *Arrowhead* indicates needle tip.

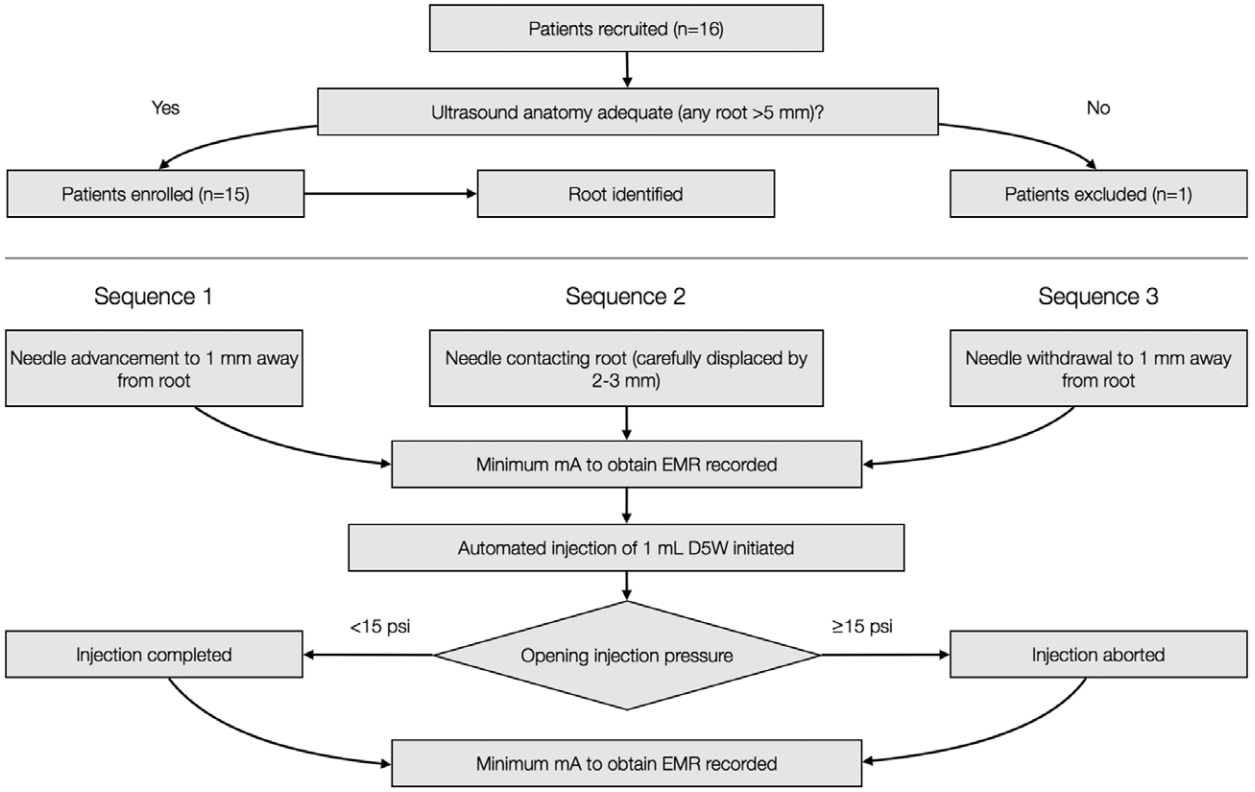

Fig. 2. Flowchart showing sequence of actions taken at each nerve root. EMR = electrical motor response.

back after puncture, as well as the spread of D5W in the correct plane adjacent to the nerve root. Some roots contained more than one fascicle at the level of injection; in these cases, the structure of the root as a whole was confirmed by tracing distally from the transverse process, and the needle positioned to contact the epineurium overlying the most superolateral fascicle. The minimum electrical current (mA) required to elicit an EMR was recorded. One milliliter of D5W was injected using an automated infusion pump (PHD 2000; Harvard Apparatus, Holliston, MA) at 10 ml/min. This injection rate was based on common clinical practice.[18] The minimum electrical current (mA) required to elicit an EMR was again recorded. Of note, an observer blinded to current intensity, EMR, and ultrasonographic image monitored injection pressures and halted the injections of D5W for opening injection pressure 15 psi or greater. Consequently, injections of D5W occurred only when the opening injection pressure was less than 15 psi (fig. 2).

If paresthesia upon needle–nerve contact was reported, the needle was withdrawn in small increments until no paresthesia was reported. Similarly, an injection was immediately halted if paresthesia was elicited during the course of injection. The primary outcome measure was the occurrence of high opening injection pressure (≥15 psi) when the needle tip was in contact with the nerve root. The cutoff of 15 psi was based on data from research conducted on animals and fresh human cadavers.[11,12,19] Because pressures greater than 20 psi have been associated with intrafascicular injection, we arbitrarily chose a cutoff pressure that was 5 psi lower than the lowest reported value that resulted in neurological injury.[11,12]

On completion of the research protocol, the patients received an interscalene brachial plexus block for their planned procedures. For the block, the needle tip was placed in the interscalene space between the C5 and C6 roots. Under ultrasound visualization, 20 ml of ropivacaine 0.5% was injected at 10 ml/min using the automated infusion pump. Injection pressure was monitored and recorded while the entire 20 ml of local anesthetic was administered, to study injection pressure dynamics during typical clinical practice. Patients were transferred to the operating room for their surgical procedures. Block success was defined as the ability to complete the procedure without the need for general anesthesia (induced by any inhaled agent or propofol at a rate greater than 50 $\mu g\ kg^{-1}\ min^{-1}$).

Research Team Member Roles and Follow-up

Data were collected by four team members:

- *Team member A*: Performed all needle manipulations while blinded to injection pressure. Commanded the start of injection, and communicated when spread of injectate was noted on ultrasound. Needle position and occurrence of spread were confirmed by an additional team member, who was experienced with ultrasound imaging and ultrasound-guided regional anesthesia but did not participate in data collection.

- *Team member B*: Recorded all nonpressure data (minimal threshold current, occurrence of EMR, and/or paresthesia).
- *Team member C*: Operated laptop computer and pressure recording, and syringe pump infusion. Monitored injection pressures (PendoTECH and BSmart) and stopped pump if injection pressure reached 15 psi.
- *Team member D*: Operated nerve stimulator and filed ultrasound data and video clips.

In the postanesthetic care unit, each patient was given a take-home data collection form that included questions about their general recovery and any residual neurological symptoms (*e.g.*, numbness, paresthesia, weakness in the operative limb) (appendix). Telephone interviews were conducted on postoperative days 1 and 7. At 2 weeks, patients were seen by their surgeon, and a specific history and physical examination performed to elicit any residual neurologic signs or symptoms. The results of these evaluations were communicated by telephone to the investigators after the office visit.

Statistical Analysis

Continuous variables are presented as mean ± SD; ordinal and nominal (categorical) variables as n (%). The sample size of 13 was estimated for the two-tailed test of paired differences in injection pressure with type I error (α) 0.05, power (1-β) 0.9, difference (Δ) of 15 psi, and SD of paired differences at 15 psi. The difference in psi was based on pilot study data in which extraneural injection with 10 ml/min injection speed and 22-gauge block needle resulted in opening injection pressures of 10 psi or less, whereas intrafascicular injection pressures into roots of the brachial plexus in human cadavers were greater than 25 psi.[19] The sample size was increased to 16 to ensure a sufficient number of patients with at least one clearly visible brachial plexus root. A two-factor repeated measures ANOVA was used to compare differences in peak opening injection pressure (psi) and the three needle conditions for each of the three brachial plexus roots. The Statistical Package for the Social Sciences (version 20.0; SPSS IBM, Chicago, IL, 2011) was used for all analyses. *P* values less than 0.05 were considered statistically significant.

Results

Of the 16 patients recruited, 1 was excluded due to poor visibility of the brachial plexus roots. The roots of C5, C6, and C7 were clearly identified by ultrasound in 15 (100%), 14 (93%), and 7 (47%) of the 15 patients, respectively. Thus a total of 36 visible roots were available for study. Ten of the 15 patients (67%) enrolled were male. Mean weight and height were 84 kg and 170.5 cm, respectively.

For needle–nerve conditions 1 mm distant from the nerve root (36 precontact and 36 disengagement), opening injection pressure was less than 15 psi and the 1-ml injections were completed in all but two cases (3%) (fig. 3). In contrast, opening injection pressure during needle–nerve contact was 15 psi or greater (mean peak pressure 20.9 ± 3.7 psi) in all but one case (97%). Therefore, stopping the injection when the opening injection pressure reached 15 psi consistently prevented the injection when the needle tip was in contact with the nerve root.

A two-factor repeated measures ANOVA compared psi over roots (C5, C6, C7) and position (precontact, needle–nerve contact, disengagement). No main effect of root or

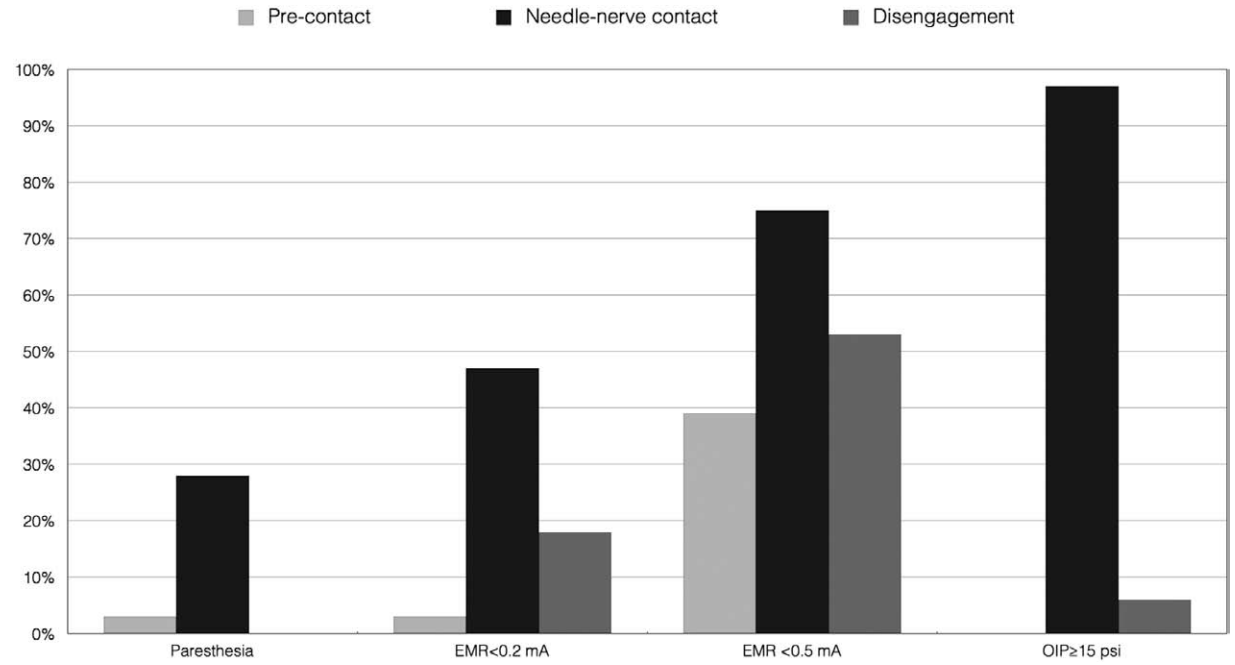

Fig. 3. Incidence of paresthesia, electrical motor response, and opening injection pressure with three needle–nerve conditions: precontact, needle–nerve contact, and disengagement. EMR = electrical motor response; OIP = opening injection pressure.

Table 1. Peak Opening Injection Pressure (psi) and Minimum Current (mA) for Three Needle–Nerve Conditions by Root (C5, C6, C7) of the Brachial Plexus

	psi	*P* Value*	mA	*P* Value*
Precontact				
C5	8.4 ± 2.2	<0.001	0.7 ± 0.5	0.004
C6	8.8 ± 2.5	<0.001	0.6 ± 0.3	0.001
C7	9.0 ± 1.6	<0.001	0.5 ± 0.3	0.18
Needle–nerve contact				
C5	22.4 ± 4.2		0.3 ± 0.3	
C6	19.9 ± 3.7		0.2 ± 0.1	
C7	19.0 ± 3.4		0.3 ± 0.3	
Disengagement				
C5	9.0 ± 3.9	<0.001	0.6 ± 0.4	0.07
C6	9.2 ± 3.1	<0.001	0.5 ± 0.5	0.02
C7	8.1 ± 1.1	<0.001	0.7 ± 0.4	0.09

* Data are mean ± SD, and are available on 15 subjects for the C5 root, 14 subjects for the C6 root, and for 7 subjects for the C7 root. *P* values in the precontact condition pertain to paired comparisons between the precontact and needle–nerve contact conditions for the C5, C6, and C7 roots of the brachial plexus. Similarly, *P* values in the disengagement condition pertain to paired comparisons between the disengagement and needle–nerve contact conditions for the C5, C6, and C7 roots of the brachial plexus.

interaction of root with position was observed. As data on position did not meet the assumption of sphericity (Mauchly W = 0.228, $P = 0.025$), the Greenhouse–Geisser test of within subjects effects is reported for psi among positions ($F_{(1.129, 6.773)} = 92.563$; $P < 0.001$). Bonferroni corrected *post hoc* tests revealed that psi did not differ between the precontact and disengagement positions. However, psi in the needle–nerve position was higher both compared with that in the precontact position (mean difference, 12.110 ± 1.051; $P < 0.001$; 95% CI, 8.653 to 15.566) and with that in the disengagement position (mean difference, 12.331 ± 1.371; $P < 0.001$; 95% CI, 7.825 to 16.838) (table 1).

Administration of D5W did not increase or decrease the minimum threshold currents to elicit EMR. Paresthesia was present with needle–nerve contact in 10 of 36 instances (28%); a single report of paresthesia was recorded during injection in the precontact condition (3%) (fig. 3).

All clinical interscalene blocks using 20 ml of 0.5% ropivacaine were successful. There were no reported instances of paresthesia during needle positioning or local anesthetic injection. One patient reported postoperative paresthesia in the forearm, which lasted for 3 days after the procedure. The patient had no other motor or sensory deficits, and resolution was complete on postoperative day 4.

Discussion

Despite ultrasound guidance, neurologic complications continue to be reported with nerve blocks.[1,2,7,9,10,20] Needle–nerve trauma and/or intrafascicular injections are among the likely mechanisms leading to neurologic injury during peripheral nerve blockade. Therefore, preventing needle–nerve contact and forceful injection (high pressure) against the nerve roots could help prevent development of neurologic symptoms. In our study, needle–nerve contact was associated with high opening injection pressure (≥15 psi). In contrast, extraneural (1-mm distant) needle placements were associated with low opening injection pressure (<15 psi). Moreover, opening injection pressure and pressure throughout the injection procedure remained below 10 psi during administration of the 20-ml local anesthetic used for the surgical blockade. The low injection pressure even with large volumes of local anesthetic is not surprising, given the high compliance of extraneural adipose tissue and capacitance of the interscalene space.

Our findings have important clinical implications. Most importantly, monitoring the opening injection pressure prevented the initiation of injection in all but one instance of needle–nerve contact. On halting the injection process when opening injection pressure reached 15 psi, commencement of injection was possible only when the needle tip was withdrawn from the nerve root. Therefore, limiting opening injection pressure to 15 psi reliably detected needle–nerve contact *and* prevented injection when the needle tip was positioned too close to vulnerable neural structures. This is particularly germane to clinical practice because ultrasound guidance alone does not appear to be a fail-safe monitor to prevent neurologic injury.[1,2,9,10,21] Ultrasonography requires technical skill, adequate sono-anatomy, and high-quality ultrasonographic equipment.[8,22] For these reasons, inadvertent placement of the needle tip against the nerve before injection can occur undetected by ultrasound, particularly with multiple injection techniques that are common in clinical practice. Subsequent forceful injection, especially with a beveled needle tip that may be partially lodged in the epineurium, may result in nerve inflammation or structural nerve damage.

Our study did not attempt to investigate intraneural injection, and our findings should not be interpreted as support for injection pressure monitoring as a method of preventing intraneural injection. While several authors have reported that intraneural injections may not always lead to nerve injury, and some even advocate injecting intraneurally,[23,24] the safety of intraneural injections is highly controversial, with many experts arguing that intraneural injections are associated with unacceptable risk.[22,25] In our study, we took all known precautions to avoid an intraneural injection. First, we set a conservative cutoff point for opening injection pressure at 15 psi, which is substantially less than the intrafascicular pressure used in animal models and the roots of brachial plexus in human cadavers.[12,19] Second, all patients were awake, and no injections were allowed to commence if they reported pain, paresthesia, or EMR, which was present at 0.2 mA or less.

As reported by other investigators, neither paresthesia nor EMR to nerve stimulation were always present during needle–nerve contact in our study. This is consistent with reports of other investigators who also question the reliability of paresthesia and nerve stimulation to detect needle–nerve contact.[26] However, an EMR at 0.2 mA or less occurred in almost

half of instances of needle–nerve contact. Therefore, electrical nerve stimulation may detect needle–nerve impingement that may be missed on ultrasound, and thereby alert the operator to reconsider further needle advancement.[15,27] However, ultrasound-guided nerve blocks often entail several needle redirections and multiple injections of local anesthetic, which may preclude reliability of nerve stimulation and/or paresthesia. In such cases, opening injection pressure can serve as a reliable indicator of injection into dense tissue media that is unaffected by patient's level of sedation or multiple injections of local anesthetic. This might be particularly useful when ultrasound imaging is not optimal or when trainees/novices are performing the block.[6] To highlight this, although all our needle–nerve manipulations were performed in healthy patients by experienced anesthesiologists, we were not able to delineate clearly by ultrasound 9 of the 45 (20%) potential target roots. Thus combining opening injection pressure monitoring and nerve stimulation may yield additional information on needle–nerve relationships, independent of quality of ultrasound image or patient's sedation level.

Our study has several limitations. First, for ethical reasons, we did not insert the needles into the roots of the brachial plexus. Instead, we used needle–nerve contact as determined by ultrasound visualization and confirmed by gentle displacement of the nerve root by the needle. Therefore, we do not know whether opening injection pressure would remain high also within the nerve roots. However, Orebaugh *et al.*[19] have reported that injections within the root of the human brachial plexus in fresh cadavers resulted in injection pressures greater than 20 psi, fascicular injury, and risk for the injectate into the epidural space. Second, we did not commence injections when pressure within the monitoring system reached 15 psi. Thus we do not know whether breaching this pressure threshold to force injection would have resulted in neurologic consequences. Nonetheless, Steinfeldt *et al.*[5] have established that forceful needle–nerve contact alone in porcine models of axillary brachial plexus block results in significant neural inflammation, even without injection. Therefore, it is possible that a forceful injection during needle–nerve contact in patients could cause or exacerbate nerve inflammation and postblock neurologic symptoms. In addition, forceful injection at the point of needle–nerve contact may carry an increased risk for intraneural or partial intrafascicular injection. Third, for consistency in our study, we used one needle size and one injection speed; thus other needle types, sizes, and injection speeds could have yielded different results. To decrease or eliminate the data dependency on needle size and injection speed, we focused our study on the *opening injection pressure*, the pressure that must be overcome before injection can commence. Importantly, until the opening pressure is reached, pressure within the syringe, tubing, and needle is equal throughout the system, regardless of the size of the fluid passages or the speed of injection (Pascal's law). Therefore, using opening pressure as the endpoint, results should be expected to be similar with a reasonably similar range of needle diameters, lengths, and injection speeds. Fourth, while a low opening injection pressure appears to be sensitive in ruling out needle–nerve contact, it is likely nonspecific. For example, needle tips abutting fascial planes, or within low-compliance tissue such as tendon, ligament, or bone may also result in high opening pressures. We took care to ensure passage of the needle through the prevertebral fascia to reduce the likelihood of a falsely increased opening pressure due to fascial tenting. However, although injection pressure cannot differentiate between tissues, high opening pressure under those circumstances may indicate an injection into an incorrect tissue plane. Current ultrasound technology may lack the resolution to differentiate epineurium from perineurium in each root. As such, it is possible that a needle appearing to indent the epineurium of a root has in fact contacted the perineurium of a fascicle. However, we believe that this distinction is of little clinical relevance, because injection against either of these structures should be avoided. Therefore, opening pressure greater than 15 psi should prompt the halting of injection in clinical practice, regardless of the cause. Finally, our results are applicable to the interscalene brachial plexus; the relationship between needle–nerve contact and opening injection pressure may be different in nerves that have substantially different neural architecture, such as the femoral nerve or the sciatic nerve.

In summary, all extraneural injections were possible with opening injection pressure less than 15 psi. In contrast, at needle–nerve contact, limiting injection pressure to 15 psi prevented injections from occurring in all except one instance. Our data suggest that monitoring of opening injection pressure and EMR may be helpful adjuncts in detecting needle–nerve contact during the administration of interscalene brachial plexus blocks. Future large-scale studies are needed to determine whether routine monitoring of opening injection pressure and EMR reduces the risk for neurologic injury.

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Competing Interests

The authors declare no competing interests.

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Appendix

IRB # 11–154

Can injection pressure monitoring predict the distance from needle to nerve during peripheral nerve blockade?

Patient label

Postoperative Questionnaire/Pain Assessment

	POD #1	POD #7
What time did you first begin to experience pain?		
What medications have you taken for your pain since leaving hospital?		
On a scale of 0–10, 10 being the worst pain imaginable and 0 being no pain, what is your score currently? What was your worst pain score and when was it?		
Have you felt nauseous or have you vomited over the last 24 h?		
Have you experienced any headaches or dizziness?		
Do you have any feelings of numbness, tingling, or pins-and-needles in your arm or hand?		
When were you able to first flex your elbow?		
Do you have any weakness in your arm or hand?		
Does your grip strength feel normal?		
Are there any other symptoms that you are concerned about?		

Numeric Rating Scale-11 for Pain Assessment. 0 = no pain; 1–3 = mild pain; 4–6 = moderate pain; 7–9 = severe pain; and 10 = worst imaginable pain.
POD = postoperative day.