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Topical Review Article: Nerve localization techniques for peripheral nerve block and possible future directions

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Short Title: Nerve localization techniques for PNB

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1 **Abstract**

2 Ultrasound guidance is now a standard nerve localization technique for peripheral nerve block (PNB).
3 Ultrasonography allows simultaneous visualization of the target nerve, needle, local anesthetic injectate
4 and surrounding anatomical structures. Accurate deposition of local anesthetic next to the nerve is
5 essential to the success of the nerve block procedure. Unfortunately, due to limitations in the visibility of
6 both needle tip and nerve surface, the precise relationship between needle tip and target nerve is unknown
7 at the moment of injection. Importantly, nerve injury may result both from an inappropriately placed
8 needle tip and inappropriately placed local anesthetic. The relationship between the block needle tip and
9 target nerve is of paramount importance to the safe conduct of peripheral nerve block. This review
10 summarizes the evolution of nerve localization in regional anesthesia, characterizes a problem faced by
11 clinicians in performing ultrasound guided nerve block and explores the potential technological solutions
12 to this problem.

13

1 **Background**

2 Peripheral nerve block (PNB) procedures involve the placement of a needle and local anesthetic next to
3 target nerves. The success of PNB is determined principally by the location of the needle tip and the
4 subsequent location of administered drug(s). ‘Regional anesthesia always works—provided you put the
5 right dose of the right drug in the right place’¹. In determining the ‘right place’ to deposit local anesthetic,
6 reliable nerve localization techniques are required which permit accurate and safe needle placement in the
7 immediate vicinity of the peripheral nerve. Injection too far from the nerve risks block failure², injection
8 within the nerve risks nerve injury³.

9 Perioperative nerve injury may occur following anesthesia and surgery^{4,5}, with contemporaneous
10 estimates of nerve injury following PNB of 4-6 per 10,000 blocks⁶⁻⁸. Although rare, iatrogenic nerve
11 injury can result in permanent sensory and motor dysfunction with neuropathic pain. These devastating
12 complications can have catastrophic physical, psychological, social and economic consequences for the
13 injured party.

14 The peripheral nerve is a complex highly heterogeneous structure with variable micro anatomical
15 architecture from root to terminal branch. Figure 1 illustrates the key components of a peripheral nerve.
16 Nerve injury may occur via a number of mechanisms, some of which relate to the block procedure and
17 others relate to the perioperative environment. Procedure-related nerve injury involves three interrelated
18 mechanisms⁹. Firstly, if placed within the nerve, the block needle itself may cause direct trauma with
19 disruption of nerve fascicles and intraneural blood vessels¹⁰. Even without direct fascicle or vessel injury,
20 intraneural needle placement has been shown to cause inflammation within the nerve, with subsequent
21 demyelination and impairment of nerve function^{11,12}. Secondly, local anesthetic injection may cause harm.
22 Injection of local anesthetic within a nerve may cause a spike in intraneural pressure, which can impair
23 neural blood flow resulting in hypoxia and cell death (intraneural, extrafascicular injection)¹³. Should the
24 needle tip pierce the perineurium, as little as 0.5 ml of injectate may be sufficient to rupture the fascicle
25 (intraneural, intrafascicular injection)¹⁴. Finally, local anesthetic agents are known to be directly

1 neurotoxic via mechanisms which are as of yet poorly understood. Local anesthetic related neurotoxicity
2 is known to be concentration dependent, with higher concentrations being more injurious^{15,16}.
3 Interestingly, observational models of intraneural needle placement and local anesthetic injection have
4 demonstrated that not all intraneural injections result in clinically apparent nerve injury^{17,18}.

5 Although there is no universal consensus on the ‘right place’ to inject local anesthetic, it is intuitive that
6 the avoidance of intraneural needle placement is desirable, and that this strategy might result in safer
7 regional anesthesia. Innovative technologies are required to assist clinicians in avoidance of needle nerve
8 contact and intraneural needle placement during the performance of PNB. The following paragraphs
9 outline the evolution of nerve localization techniques used during PNB, describe the current limitations of
10 these techniques in detecting accidental nerve puncture and investigate possible future directions for
11 nerve localization.

12 **The Evolution of Nerve Localization**

13 The first reports of regional anesthesia appeared in the 1880s^{19,20}. Nerve localization techniques were
14 based upon anatomical landmarks and formal surgical dissection. Percutaneous techniques using hollow
15 needles subsequently developed, relying on needle-to-nerve contact and paresthesia to confirm needle
16 location at or within a target nerve. Proponents of this technique claimed high success rates without
17 adverse sequelae, even suggesting that the absence of paresthesia was an indicator of likely failed block:
18 ‘No paresthesia, no anesthesia’²¹. By the mid-20th Century tactile cues of fascial clicks and pops became
19 important with reports of successful block without deliberately seeking paresthesia²². Blind needle
20 placement guided by clicks, pops and paresthesia are however poor markers of needle tip location and the
21 presence of paresthesia infers needle to nerve contact (if not needle into nerve puncture). Neither
22 paresthesia nor tactile feedback reliably defines the relationship between needle tip and target nerve
23 during blind PNB techniques.

1 **Electrical Nerve Stimulation**

2 Stanley J. and L. Charlotte Sarnoff reported the use of prolonged peripheral nerve block for the treatment
3 of hiccups in 1950²³. In 1962 Greenblatt and Denson used a small portable transistorized nerve stimulator
4 to perform PNB heralding the entry of electrical nerve stimulation (NS) into regional anesthesia²⁴. By
5 1969 nerve stimulators for delivery of nerve block were readily available and in widespread use²⁵.

6 Nerve localization with NS requires an electrical circuit between a constant current generator, the block
7 needle (the cathode) and the patient (the anode is a conductive electrode placed on the skin surface)^{26,27}.
8 Short electrical pulses result in nerve cell depolarization causing either paresthesia or muscle
9 contraction²⁸. According to Ohm's law (Equation 1), the current required to cause nerve depolarization is
10 inversely proportional to the distance between needle and nerve²⁶. This, it was thought, allowed indication
11 of needle position relative to the nerve being stimulated.

$$\text{Current } (I) = \frac{\text{Voltage } (V)}{\text{Resistance } (R)}$$

12 **Equation 1: Ohm's Law**

13 Paresthesia or muscle contraction using a current of between 0.30 and 0.50 mA is taken to indicate the
14 desired nerve location for drug administration²⁸. Responses at stimulation currents of <0.2mA are thought
15 to indicate intraneural needle placement. Recent data have questioned the validity of a simple
16 interpretation of Ohm's law in living tissue. Significant inter-individual variation exists as to the
17 minimum stimulation threshold of peripheral nerves²⁹. Intraneural needle placement does not always lead
18 to nerve stimulation³⁰. Individual electrophysiological sensitivities, nerve structural diversity and varying
19 properties of perineural tissues may account for these observations³¹⁻³³, each suggesting that NS is a
20 somewhat insensitive tool in the detection of needle nerve contact^{32,34,35}.

1 Using a conceptual framework, based upon the physics of electricity, assumptions were made as to
2 proximity relationship between the needle tip and the target nerve. Unfortunately the sensitivity of this
3 technology in identifying needle nerve contact is poor.

4 **Ultrasound Guidance**

5 Ultrasonography permits visualization of block needle, target nerve(s) and local anesthetic injectate^{36,37}.
6 This allows accurate paraneural needle placement, which in turn facilitates rapid onset PNB and high
7 block success rates using small volumes of local anesthetic³⁸. Ultrasound (US), as a nerve localization
8 technique, permits a detailed and person specific examination of the anatomy involved in PNB.

9 Medical US utilizes sound waves in the frequency range of 3 to 15 MHz. Nerve visualization requires the
10 use of probes with the capability of producing US at 10-15MHz. Ultrasound at these frequencies provides
11 excellent spatial resolution, allowing the discrimination of nerve architecture. The ultrasonographic
12 appearance of nerves varies with anatomical location and the quantity of connective tissue within the
13 nerve. Nerve roots are usually circular and have a bright hyperechoic surface a dark hypoechoic center
14 (Fig. 2), while nerves further in the periphery (median nerve in the forearm) have a more honeycomb
15 appearance (Fig. 3). Knowledge of the unique appearance of nerves at specific locations permits the
16 anesthesiologist to readily identify and target the correct nerve(s) for specific procedures. Due to its
17 watery consistency the injected local anesthetic behaves like a contrast medium enabling visualization of
18 its distribution around the nerve³⁶. A thorough understanding of how the US image is constructed is
19 required to appropriately interpret images to guide needles during PNB. A description of the challenges in
20 image interpretation and common image-related anomalies has been published^{39,40}.

21 **Ultrasound Guidance versus Nerve Stimulation: Nerve Injury and Needle Nerve Contact**

22 When compared with NS, US-guidance is superior from the perspective of success rates, onset times,
23 number of needle passes and limiting local anesthetic dose⁴¹⁻⁴⁸. It is not known whether this superiority
24 translates into improved patient safety. The definition of what constitutes a nerve injury is somewhat

1 ambiguous, ranging from transient paresthesia lasting less than 12 hours to motor deficit extending
2 beyond 48 hours. Multiple factors including patient co-morbidities, surgery type and duration and
3 circumferential limb tourniquets make the interpretation of published literature on adverse outcomes
4 following PNB difficult. Data comparing the frequency of complications during PNB performed with
5 either US or NS is sparse⁴⁹.

6 International regional anesthesia registries collecting prospective outcome data have reported the
7 frequency of transient nerve injury as 4-6 per 10,000 blocks^{6-8,50,51}. The Dartmouth registry⁵¹ provides
8 some insight into the relationship between block location, dose and injury. More than half of the injuries
9 reported arose following interscalene block, and high volume injectate (30ml) was used in all reported
10 injuries. Fredrickson and Kilfoyle reported prospective data on neurological symptoms in 1000 patients
11 following ultrasound guided peripheral nerve block (USGPNB) at 10 days, 1 and 6 months. Neurological
12 symptoms were identified in 8%, 4% and 0.6% at each time point respectively, although symptoms were
13 minor and deemed to be unrelated to USGPNB⁵². Liu and colleagues, reported prospective data from
14 patients undergoing shoulder surgery under USGPNB and identified 0.4% with neurological symptoms at
15 1 week post procedure⁵³. Liu also identified the frequency of unintentional intraneural injection during
16 USGPNB as 42/257 (17%) without reported postoperative neurological symptoms⁵⁴.

17 Detecting needle-to-nerve contact is problematic. Macfarlane, Bhatia and Brull examined several animal
18 models for needle-to-nerve contact and intraneural injection. They concluded that neither NS nor US are
19 sensitive enough to be reliable³². Vassiliou and co-workers studied whether combining US and NS
20 achieved a higher rate of “close needle tip placements” than either modality alone, concluding better
21 needle placement with the combined approach⁵⁵. Steinfeldt explored the relationship between needle
22 nerve contact and needle type^{11,12}. Needle nerve contact, with or without nerve puncture, results in an
23 inflammatory response which may contribute to impaired nerve function. In determining the relationship
24 between intraneural needle placement, ultrasound and NS currents (0.2-0.5 mA), Robards et al concluded
25 that the absence of a motor response to NS does not exclude intraneural needle position⁵⁶.

1 The American Society of Regional Anesthesia and Pain Medicine (ASRA) practice advisory on
2 neurologic complications states: “No nerve localization or monitoring technique has been shown to be
3 clearly superior in terms of reducing the frequency of clinical injury” because “There are no animal or
4 human data to support the superiority of one nerve localization technique—paresthesia, nerve stimulation,
5 ultrasound—over another with regards to reducing the likelihood of nerve injury”⁵⁷.

6 **Summary**

7 Nerve localization methods have evolved from blind needle placement using endpoints such as
8 paresthesia, nerve stimulation and ultrasound-guidance. Nerve injury can occur when PNB needles, local
9 anesthetic or both are placed within the substance of a peripheral nerve. The relationship between needle
10 and nerve immediately prior to injection is therefore of critical importance. The following paragraphs
11 discuss methods that may be used in the future to achieve more accurate information on needle tip
12 location.

13 **Future Directions for Nerve Localization Techniques and Extraneural Needle Placement**

14 **Inline Pressure Monitoring**

15 The injection of solution into a non-distensible space will cause pressure within that space to rise. This
16 might be appreciated by the operator as relative ease or difficulty with injection, and can be measured
17 using the compressed air injection technique⁵⁸ and commercially available inline pressure manometers
18 like B-smart (Concert Medical, Needham, MA). Compressed air techniques rely on subjective feedback
19 from the syringe and are subject to significant inter-individual variability. The use of automated injection
20 pressure monitoring might limit inter individual variability and improve the objectivity of this strategy to
21 limit needle to nerve contact⁵⁹. Hadzic et al. studied the relationship between injection pressure and
22 neurological outcome of subgluteal sciatic block in an animal model. High injection pressures (> 20 psi)
23 irrespective of needle tip location cause both clinically and histologically evident nerve injuries¹⁴. In
24 humans undergoing interscalene block, Gadsden et al studied the relationship between opening injection

1 pressure and needle-to-nerve contact. In this study, high opening pressure (≥ 15 psi) consistently detected
2 needle-to-nerve contact⁶⁰. Thus the use of in-line pressure monitoring might alert the clinician to
3 intraneural and intrafascicular needle placement, potentially preventing nerve injury. High opening
4 pressure may be caused by factors other than intraneural needle placement - needle obstruction, tissue
5 compression and injection into a tendon, not just needle to nerve contact. Such non-specificity might
6 negatively influence operator behavior and impact block performance. Further clinical validation is
7 required to define the true utility of this inline injectate manometry during PNB.

8 **Advances in Ultrasound Imaging**

9 Marhofer et al. published a two part review on “Fifteen years of ultrasound guidance in regional
10 anesthesia”. Part 1 of the review concluded “if experience in other technological fields is to be used as a
11 yardstick of the pace of development, the next 15 years will see an exponential increase in the quality of
12 both 2D images and 3D ultrasound images”⁶¹. In using conventional B-mode US, the clinician is provided
13 with a narrow two dimensional representation of underlying anatomy. To guide a needle this 2-D image
14 must be cognitively processed and appropriate visuospatial interpretations made. A three dimensional
15 image might permit better nerve surface identification, and assist identification of appropriate needle path
16 and endpoint. Real-time 3D US imaging (also known as 4D where 3D alone refers to static 3D images
17 that can be collected and manipulated at a later stage⁶²) has been used for: (1) continuous sciatic block at
18 the popliteal fossa⁶³; (2) axillary brachial plexus block; and (3) radial nerve block⁶⁴. Future progression of
19 3D ultrasonography is likely to bring a wider image volume and thus more information to the clinician.
20 The absolute advantage of this technology is the ability to manipulate imaging planes without moving the
21 probe⁶⁵. Although it is believed that 3D US imaging will further enhance the use of US for PNB
22 procedures, this imaging modality requires a new image interpretation skill set. Currently clinicians learn
23 two dimensional cross sectional anatomies as undergraduates. The application of anatomical
24 representation using 2D US is somewhat intuitive. Three dimensional imaging in real-time is as of yet an
25 unknown entity, as are the skills required to safely perform PNB using such a modality⁶¹. A recent

1 publication on 3D US imaging to evaluate local anesthetic spread and perineural catheter placement,
2 suggests that the complexity of the technique coupled with an increased amount of information, could
3 limit the practicality and cost effectiveness in daily clinical practice⁶⁶. Further studies are required to
4 determine the true role of 3D/4D US imaging in peripheral nerve block.

5 **Multiplaner Magnetic & Robotic Needle Guidance**

6 Magnetic needle guidance permits needle tracking and prediction of needle trajectory. Using a magnetic
7 field and sensors on the needle and ultrasound probe, real-time overlay of needle trajectory and needle tip
8 location on the 2D ultrasound image is achieved⁶⁷. This technology may prove useful in assisting needle
9 guidance from point A to point B, but it does not assist in determining the relationship between the needle
10 tip and nerve. It is therefore not useful in either detecting or preventing needle to nerve contact.

11 Robotic devices have been developed to assist with the performance of complex skills during surgery.
12 Robotic assistance in bench models of regional anesthesia has been reported in which robots advanced the
13 needle toward a target^{68,69}. This may prove useful limiting needling errors associated with PNB
14 performance⁷⁰. There are, however, no data to validate the use of robotics within the context of clinical
15 PNB performance, and none to suggest better definition of needle nerve relationship.

16 **Optical Reflectance Spectroscopy**

17 Optical reflectance spectroscopy has been used to differentiate tissue types at needle tip. This technique
18 uses optical fibers to carry visible and near-infrared light to the tissue in contact with the needle tip.
19 Tissues absorb and reflect light differently depending on their composition. Sensing fibers in the device
20 detect reflected and scattered light over a set spectrum of wavelengths. The quantity of light absorption
21 and scatter by natural chromophores such as hemoglobin, water and lipids in a tissue at particular
22 wavelengths is dependent on cell size and molecular structure. It is these characteristics that define the
23 optical properties of a tissue⁷¹. After some calculation the absolute optical properties of tissues are
24 quantified and subsequently absolute absorber concentrations can be determined i.e. concentration of

1 deoxygenated hemoglobin, oxygenated hemoglobin and water⁷². Based on the quantities of different
2 chromophores in a specimen the tissue type can be identified. Differences in chromophore volume
3 fractions are determined using diffusion reflectance spectroscopy⁷³.

4 Non-invasive detection of breast cancer using clinical optical tomography and near-infrared spectroscopy
5 has been investigated⁷⁴. Invasive applications of this technology include tissue diagnostics to allow
6 disease states to be detected in vivo with a long term view to replace biopsies and histological analysis but
7 more urgently to provide additional guidance in locating the optimum sites for biopsy⁷⁵. Prostate⁷⁶ and
8 ovarian⁷⁷ cancers have been identified by invasive use of optical reflectance spectroscopy. This technique
9 has also provided stereotactic guidance during neurosurgery⁷⁸. In 1985, a fiber optic needle stylet was
10 used to identify biological fluids such as blood, bile, water, and the reflective intima of a blood or bile
11 vessel at the needle tip allowing for its location to be known during percutaneous diagnostic and
12 therapeutic procedures⁷⁹. More recent studies have demonstrated the ability to identify transitions from
13 subcutaneous fat to skeletal muscle and from the muscle to the nerve target region in vivo on swine and
14 humans using optical impedance spectroscopy. The novel optical needle stylet has also identified vascular
15 needle penetration which would prevent accidental intravascular anesthetic release during the USGPNB
16 procedure⁸⁰. Optical reflectance spectroscopy can differentiate tissue type and detect target nerves
17 accurately. If integrated with USGPNB, procedural short comings, as characterized, might be eliminated
18 and procedural safety improved^{81,82}.

19 **Bioimpedance**

20 All objects will impede electrical current to some degree. When AC is applied to biological material
21 impedance is referred to as bioimpedance. The measurement of tissue bioimpedance could provide
22 valuable information about both tissue type and physiological events of interest⁸³. Several electrodes are
23 used for impedance measurement: a small current is applied to one or more electrode while other
24 electrodes pick up the resulting voltage. As the conductivity in biological materials is electrolytic and

1 based on Na^+ and Cl^- ions, changes in the content of liquid or the ion-concentration lead to changes in
2 bioimpedance. Furthermore, cell membranes have low conductivity; hence the concentration of cells also
3 influences bioimpedance^{84,85}. The cell membrane separates two electrolytic systems i.e. intracellular fluid
4 from extracellular fluid, which gives cells capacitor (energy storing) characteristics^{83,86}. The resistive and
5 capacitive components of biological tissues therefore are well described by the concept of complex
6 impedance⁸⁷. Cell size, orientation and membrane thickness also influence bioimpedance thus increasing
7 its ability to discriminate between tissues⁸⁸.

8 Bioimpedance analysis has long been considered a potential tool for medical diagnostics in many
9 different ways as it offers easy to apply techniques with low costs⁸⁹. Current and potential medical
10 applications for bioimpedance primarily exploit the principle that the content of liquid and the
11 concentration of ions in the sample give different tissue types different and characteristic bioimpedances.
12 Some tissues are very good conductors of electricity, while others are poor conductors. For example bone
13 is a poor conductor with a typical resistivity of $>40 \Omega$ at 10 kHz while muscle is a relatively good
14 conductor of electric charge demonstrating resistivity of 2-4 Ω at 10 kHz⁹⁰. Bioimpedance, the inverse of
15 conductance, can therefore be employed by the same token by measuring the tissue resistance under AC⁹⁰.
16 Investigations and current uses of this technology for medical diagnostics are divided into two categories:
17 (1) invasive applications; and (2) non-invasive applications.

18 Non-invasive applications include Electrical Impedance Tomography (EIT), a form of real-time bedside
19 imaging^{90,91} which has been used in the diagnosis of breast cancer⁹²⁻⁹⁴, epilepsy, acute stroke^{91,95} and
20 measurement of gastric emptying during continuous infusion of liquid feed⁹⁶⁻⁹⁹. EIT imaging is low cost
21 and non-hazardous which permits its use for surveillance over protracted time intervals. Bioelectrical
22 Impedance Analysis (BIA) allows measurement of human body composition mainly to estimate total
23 body water and fat free mass in clinical settings^{100,101}. Skin impedance is used to detect and to classify
24 skin cancer¹⁰²⁻¹⁰⁷ and to diagnose or analyze allergic reactions^{108,109}, diabetes mellitus¹¹⁰, skin
25 irritations^{111,112} and skin moisture¹¹³. Impedance cardiography offers a continuous, non-invasive, operator-

1 independent method of monitoring cardiac output and stroke volume offering a potential tool in diagnosis,
2 treatment and observation of patients^{114,115}.

3 Invasive applications of bioimpedance using needle-type probes may have more relevance to regional
4 anesthesia than non-invasive applications. Many studies relating to invasive bioimpedance measurement
5 suggest that the use of a bespoke probe/needle might aid tissue identification and potentially detect
6 needle-to-nerve contact in regional anesthesia. This concept is been exploited for many medical
7 applications to date. In 1969, impedance measurement was used for detection neural structures during
8 percutaneous cordotomy. Penetration of spinal cord was confirmed by a rise in bioimpedance from that
9 of the surrounding cerebrospinal fluid¹¹⁶. Kalvøy's group during several in vivo investigations
10 determined the position of a needle within different kinds of tissue like muscle, liver, spleen, fat etc.¹¹⁷
11 Various bioimpedance biopsy probes have been trialed for biopsies of brain tumors^{118,119}, pulmonary
12 masses¹²⁰, prostate cancer^{121,122} and renal biopsies¹²³. In 2008 Tsui et al. evaluated the role of impedance
13 measurement in an experimental model of USGPNB. They found a significant difference in bioimpedance
14 between extraneural and intraneural tissue. Consequently the group postulated that bioimpedance
15 measurement could be a useful warning signal to avoid intraneural injection in the future¹²⁴. With this
16 technology's ability to differentiate tissue type with a high degree of accuracy and resolution, the current
17 procedural inability to objectively detect optimum needle tip location for PNB delivery may be resolved
18 by using bioimpedance.

19 **Conclusion**

20 This review has summarized the major advances in PNB nerve localization techniques and how PNB has
21 progressed from landmark based blind procedures to sighted guidance using ultrasound. As PNB
22 techniques have evolved, so have the challenges facing regional anesthesiologists. A reliable method of
23 characterizing the relationship between needle and target nerve immediately prior to injection during PNB
24 is required. The integration of any such solution into PNB procedural skills must (1) solve the problem as

1 characterized; (2) lessen the cognitive burden of the anesthesiologist; (3) improve procedure related
2 outcomes; and (4) not adversely affect patient outcome. To date, technology newly applied to PNB
3 includes real time 3D imaging, multi-planar magnetic needle guidance and inline injection pressure
4 monitoring. This review identified the relationship between needle tip and target nerve as a high priority
5 deficit in PNB techniques, and postulates that optical reflectance spectroscopy and bioimpedance may
6 hold the solution to accurately address this challenge. Until it is known how best define the relationship
7 between needle and nerve at the moment of injection some common sense principles might be
8 appropriate: (1) the desired location for local anesthetic solution is around the nerve and not in it (the
9 paraneural space); (2) use a needle in-plane guidance technique; (3) only advance the needle when visible
10 on ultrasound; (4) target the fascia at the periphery of the nerve, not the center of the nerve; (5) always
11 aspirate the needle before injection; (6) inject small quantities of local anesthetic 0.5-1ml; (7) inspect the
12 target nerve for signs of intraneural injection, and reposition to ensure injection outside the nerve; (8) do
13 not persist to inject if there is resistance to injection; (8) maintain verbal contact with and seek feedback
14 from the patient.

15 In conclusion, the novel application of existing and modifiable technology may assist physicians in
16 overcoming the procedural limitations inherent within ultrasound guided peripheral nerve block.
17 Characterization of these challenges and matching innovative technology may in time improve procedural
18 safety and efficacy.

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22 **Conflicts of Interest**

23 The authors have no conflicts of interest

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Figure Legends

Figure 1: Nerve structure

Figure 2: Interscalene Brachial Plexus: ASM = Anterior Scalene Muscle; MSM = Middle Scalene Muscle; SCM = Sternocleidomastoid Muscle; C5 = fifth cervical nerve root in interscalene groove; C6 = sixth cervical nerve root in interscalene groove.

Figure 3: Median Nerve in the forearm: FDS = Flexor Digitorum Superficialis Muscles; FDP = Flexor Digitorum Profundus Muscles