Best Practice & Research Clinical Anaesthesiology 33 (2019) 499–505

Contents lists available at ScienceDirect

Best Practice & Research Clinical Anaesthesiology

journal homepage: www.elsevier.com/locate/bean

10

Recent technological advancements in regional anesthesia

Sudipta Sen, Assistant Professor [a],
Michelle Ge, Assistant Professor [a],
Amit Prabhakar, Assistant Professor [b],
Vanessa Moll, Assistant Professor [b],
Rachel J. Kaye, Medical Student [c],
Elyse M. Cornett, Assistant Professor [d, *],
O. Morgan Hall, Medical Student and Research Associate [e],
Ira W. Padnos, Assistant Professor [f],
Richard D. Urman, Associate Professor [g],
Alan David Kaye, Professor, Program Director and Chairman [f]

[a] *Department of Anesthesiology, McGovern Medical School, University of Texas Health Sciences Centre at Houston, 6431 Fannin Street, MSB 5.020, Houston, TX 77030, USA*
[b] *Department of Anesthesiology, Division of Critical Care, Emory University School of Medicine, 550 Peachtree Street, 30308, Atlanta, GA, USA*
[c] *Medical University of South Carolina School of Medicine, Charleston, SC, USA*
[d] *Department of Anesthesiology, LSU Health Shreveport, 1501 Kings Highway, Shreveport, LA, 71103, USA*
[e] *Department of Anesthesiology, Louisiana State University School of Medicine, Room 656, 1542 Tulane Ave, New Orleans, LA 70112, USA*
[f] *Department of Anesthesiology, LSU Health Sciences Center, Room 656, 1542 Tulane Ave., New Orleans, LA 70112, USA*
[g] *Department of Anesthesiology, Perioperative and Pain Medicine, Harvard Medical School, Brigham and Women's Hospital, 75 Francis St, Boston, MA 02115, USA*

Keywords:
regional anesthesia
nerve blocks
ultrasound
optical spectroscopy

Just two decades ago, regional anesthesia was performed blindly with dubious outcomes and little support from surgeons and patients. Technological advances in regional anesthesia have revolutionized techniques and largely improved outcomes. Ultrasound (US) technology continues to advance and has become more

* Corresponding author.
E-mail addresses: Sudipta.Sen@uth.tmc.edu (S. Sen), Michelle.A.Ge@uth.tmc.edu (M. Ge), amit.prabhakar@emory.edu (A. Prabhakar), vanessa.moll@emory.edu (V. Moll), rachelkaye17@hotmail.com (R.J. Kaye), ecorne@lsuhsc.edu (E.M. Cornett), ohall2@lsuhsc.edu (O.M. Hall), ipadno@lsuhsc.edu (I.W. Padnos), rurman@bwh.harvard.edu (R.D. Urman), akaye@lsuhsc.edu (A.D. Kaye).

https://doi.org/10.1016/j.bpa.2019.07.002
1521-6896/Published by Elsevier Ltd.

affordable. Improvements have come in the form of picture quality, resolution, portability, and smaller equipment. The US technology can identify otherwise unrecognized pathology and can help to optimize patient flow by allowing for more accurate triage and effective treatments and providing timelier interventions. In recent years, several different strategies to help improve and ease US-guided needle identification and placement have been developed, including magnetically guided needle US technology. Three-dimensional (3D) and four-dimensional (4D) US use is another potential way to help improve first-pass success and limit patient harm for regional anesthetics. The advent of echogenic needles and the resulting improvement in needle visualization under US has had a positive impact on physician comfort in performing regional anesthesia and on visualization time of the needle during US-guided procedures. To reduce variability and to reduce the anesthesiologist's workload, the use of robots in regional anesthesia has been assessed in recent years. Peripheral nerve stimulation (PNS) has also demonstrated efficacy in acute and chronic pain settings. Additional research and randomized controlled trials are necessary to evaluate novel technologies.

Published by Elsevier Ltd.

Introduction

Technological advances in regional anesthesia are paramount and have contributed to a revolution in acceptance in clinical practice. These advances are aimed at improving imaging quality and needle localization and thereby reducing the risk of perioperative nerve injury or an unsuccessful nerve block. Mechanical needle and injection trauma, local anesthetic neurotoxicity, and injection pressure are some mechanisms postulated in regional anesthesia-related complications. Ultrasound (US) technology continues to advance and become more affordable, potentially leading to the increasing use of regional anesthesia in developing countries. The improved imaging quality of handheld US devices makes utilization in regional anesthesia feasible with support from surgeons, administrators, and patients [1,2].

New developments in ultrasound technology

Pocket size ultrasounds

Portable US devices have evolved and improved as technology continues to advance. Improvements have come in the form of picture quality, resolution, portability, and smaller equipment size. In the past, US utilization was limited to formal hospital settings largely related to their lack of portability. However, in recent years, US technology has been miniaturized into functional pocket-sized variations and as smart device attachments. This development has the potential to significantly change the way clinicians perform physical exams to diagnose and treat medical conditions. A small study looked at the impact of the addition of US exams on diagnosis and treatment. The US evaluations were incorporated into routine bedside physical exams, lasted less than 10 min, and focused on cardiac and abdominal screening. Findings were significant for approximately 1 in 5 patients who had their original diagnosis corrected by US findings, which subsequently led to a different but correct treatment pathway [3]. Other relevant findings included confirmation of the primary diagnosis in 20% of patients and identification of a separate clinically significant pathology in 9% of patients [3]. The ability to identify otherwise unrecognized pathology can help to optimize patient flow by allowing for more accurate triage and provide timelier interventions.

Pocket-sized US devices allow for the rapid evaluation of the heart, lungs, abdomen, and major vasculature in any setting to increase diagnostic accuracy. Numerous studies have shown that limited training is required for clinicians of all backgrounds and experience levels to reliably replicate images and identify pathology [4,5]. One of the more common uses is for the capture of echocardiographic images. Miniaturized US devices can help to assess right and left heart function and identify left ventricular hypertrophy, valvular abnormalities, pericardial effusions, and aortic root size [6]. Lung US can quickly identify a pneumothorax by the lack of pleural sliding or a significant effusion resulting in hypoxia. Despite these benefits, it is also important for clinicians to know the limitations of pocket-sized US use. Pocket-sized US devices are not meant to replace the need for a formal US exam [7]. Compared to high-end machines, limitations include lack of sensitivity and specificity, the need for proprietary software, and potential increase in incidental findings. While pocket-sized US devices are not meant to replace formal and more advanced US exams, they can be used to identify patients who need a formal exam. Pocket-sized US devices have been shown to have significant benefit in pre-hospital settings, emergency departments, ICUs, and standard medical floors. As clinicians become more facile in point-of-care US, pocket-sized US devices and smart phone attachments have the potential in future to become as essential to a physical exam as a stethoscope.

Advanced needle tracking and guidance for ultrasound

Accurate and precise needle control is imperative to ensure adequate analgesia when performing regional anesthesia techniques under US guidance. Despite improvements in needle echogenicity, clinicians can still have difficulty with tip visualization due to the necessity of the needle being appropriately aligned with the US beam. In recent years, several different strategies have been postulated to help improve and ease US-guided needle identification and placement. One of the more promising modalities is magnetically guided needle US technology [8]. A magnetically guided system provides a real-time virtual needle overlay on the US image regardless of the needle insertion angle or position relative to the transducer. The magnetic components are already incorporated into many commercially available needles. Several studies using magnetic-guided US technology have yielded promising results thus far. When performing a variety of regional techniques on phantom models, clinicians have been found to have quicker completion times and higher first-pass success with magnetic-guided US technology than with conventional US [8,9]. While these results are promising, more research and larger trials on human subjects are needed before broader implementation.

Three-dimensional ultrasound

Three-dimensional (3D) US use is another potential way to help improve first-pass success and limit patient harm from regional anesthetics. 3D imaging is already a component of advanced US devices used for interpretation of transesophageal echocardiography. However, currently, the conventional two-dimensional (2D) US remains standard of practice for regional techniques. Very limited case reports are available to evaluate the merit of 3D US use for peripheral nerve blocks [10]. Potential benefits of using 3D US include more accurate perineural catheter placement, better visualization of local anesthetic spread, and a better way for clinicians to identify anatomical variations. Larger studies and much more research are needed to further validate the use of 3D US for regional techniques.

New developments in needle technology

An integral part of performing nerve blocks is the needle. The advent of echogenic needles and the resulting improvement in needle visualization under US guidance has had a positive impact on physician comfort in performing regional anesthesia and visualization time of the needle during US-guided procedures [11]. The information below aims to discuss recent advancements in needle technology that could become fixtures in the practice of regional anesthesia in the future.

Optical spectroscopy

By integrating optical fibers into the needle, one could utilize the principles of optical spectroscopy to qualitatively differentiate between the various types of tissue encountered by the needle during a nerve block. As biological tissue has nonuniform intensities (in contrast to a white surface), the resulting varying optical scattering and absorption manifests as absorption peaks that in turn allows the user to differentiate between tissue transitions as the regional needle is advanced during a nerve block [12]. Using human cadavers, Hendriks et al. demonstrated that spectral tissue sensing, utilizing reflectance spectroscopy at the needle tip, can discriminate fascicular tissue from the surrounding tissue [13]. Balthasar et al. utilized a custom-designed needle stylet with integrated optical fibers to detect intravascular needle penetration during sympathetic blocks by quantifying the optical absorption of hemoglobin during each insertion [12]. This has important potential implications for the avoidance of intrafascicular injection and resulting nerve damage while performing a nerve block.

Inline needle pressure monitoring

Intrafascicular injection during a peripheral nerve block can result in serious neural injury. Various sources quote differing pressures at which nerve injury occurs, ranging from 10 to 20 psi [14,15]. Although one can assess difficulty in injecting as a measure of possible needle-to-nerve contact, this is subjective and not necessarily reliable. Automated inline pressure manometers are being trialed to potentially reduce this subjective variability. The BSmart™ and the NerveGuard™ are two devices specialized to detect and thus prevent high injection pressures, albeit in different ways. The BSmart™ is a disposable manometer with pressure gauge readings of less than 15 psi (indicating safe perineural injection), 15 psi (indicating needle-to-nerve contact), and greater than 15 psi (indicating intrafascicular injection). When using this device, it is up to the operator to determine whether or not to proceed with the injection; it is merely an indicator of objective pressure measurement. The NerveGuard™, on the other hand, is marketed as an “automatic injection pressure limiter.” If the system senses a pressure over the preset limit, the inner valve automatically closes, thus preventing flow of local anesthetic. The practice of using inline needle pressure monitoring is not widespread, and whether it reduces the incidence of nerve injury due to intrafascicular injection remains to be seen.

Inline needle pressure monitoring has also been explored in epidural placement. False loss of resistance can pose challenges in accurately accessing the epidural space. Capogna et al. assessed the efficacy of a custom-made epidural simulator using the Computerized Epidural Instrument CompuFlo in obtaining the true loss of resistance [16]. They measured a significant difference between the decrease in pressure due to false and true loss of resistance in both the simulator and human operator groups [16]. In a different study, Capogna et al. utilized the CompuFlo device in assessing its usefulness as an aid in identifying the epidural space for difficult epidural placements and concluded that CompuFlo is a valid tool in finding the epidural space [17]. Separately, Ghelber et al. used a computerized injection pump to obtain pressure readings of the supraspinous ligament, ligamentum flavum, and epidural space during needle advancement in epidural placement. The significantly different pressure readings from the varying anatomical structures obtained by the computerized injection pump demonstrated that this technology may be a useful tool in increasing the rate of successful epidural placements, although more comparative studies are warranted [18].

Robotics and regional anesthesia

Although regional anesthesia procedures are relatively standardized, results may be variable because of the nature of human operation. To reduce this variability and to reduce the anesthesiologist's workload, the use of robots in regional anesthesia has been evaluated in recent years. In a review by Wehbe et al., it is pointed out that the role of robotics in anesthesiology was mostly limited to drug delivery through closed-loop systems, but in 2002, the application of robotics to regional anesthesia was carried out in the form of using a robotic needle driver for spinal blocks [19]. Then, in 2010, Tighe et al. performed a robotically assisted US-guided peripheral nerve block with the da Vinci Surgical System in a simulated environment, with the acknowledgement that this was not a practical

concept [20]. In 2013, Morse et al. designed and developed a computerized system specifically for robot-assisted, US-guided nerve blocks called the Magellan [21]. Hemmerling et al. then implemented Magellan, comprising a joystick, a robotic arm, and a software control system, for performing sciatic nerve blocks on human patients undergoing surgery below the knee [22]. Identification of the nerve was done in standard fashion by a human operator using an US probe, and the actual nerve block was then performed by an experienced operator using the joystick in the remote control center with enhanced video imaging of the nerve block site [22]. Defining a successful attempt as the introduction of the block needle into the nerve sheath, they had a 100% success rate and total performance time of 3–4 min (from starting to search for the nerve with the US to end of injection time). Another study by Morse et al. paid attention to utilizing robotic nerve block systems as training tools to increase the speed of learning and reduce performance variability [21]. The role of robotic-assisted peripheral nerve blocks appears to hold a promising future in the landscape of regional anesthesia; however, additional studies, particularly those comparing manually performed nerve blocks to automated nerve blocks, need to be conducted first.

Percutaneous peripheral nerve stimulation

Neuromodulation has been a pillar of interventional chronic pain management for the past several years, mainly in the form of spinal cord stimulation. To date, there is no concrete evidence as to how neurostimulation causes analgesia, although multiple theories exist. The most popular and commonly accepted is Melzack and Wall's gate control theory, in which it is postulated that the stimulation of large-diameter myelinated afferent peripheral nerve fibers by an electrical current overrides the transmission of pain signals to the central nervous system by small-diameter unmyelinated pain fibers [23,24]. Spinal cord and peripheral nerve stimulators (PNS) have been used with high success in the treatment of chronic pain; however, these are traditionally implanted systems, which make their use in acute postsurgical pain treatment impractical. Recognizing the potential for stimulators playing a significant role in acute post-surgical analgesia, various companies have developed smaller and more flexible electrical leads to allow for landmark or US-guided, percutaneous insertion adjacent to the targeted nerve. Moreover, the traditional implantable generator has been re-engineered into a smaller, lighter unit that can be adhered to the skin near the site of insertion. As such, several studies have been carried out describing the use of these leads as part of a PNS system in the treatment of acute post-surgical pain. Ilfeld et al. utilized US-guided PNS of femoral and/or sciatic nerve(s) for patient's status-post total knee arthroplasty and reported significant analgesia with stimulation both at rest and with range of motion. In a subsequent study, Ilfeld et al. implemented PNS targeting the femoral nerve in ten patients undergoing anterior cruciate ligament reconstruction with patellar autograft. They reported a decrease in postsurgical pain with stimulation; however, it should be noted that a significant percentage of patients required subsequent analgesic supplementation: 50% with opioids and 70% with continuous adductor canal nerve blocks [25]. The sciatic nerve was also targeted with PNS by Ilfeld et al. in patients undergoing hallux valgus procedures. These results suggest that PNS produces a degree of postsurgical analgesia, although, similar to the aforementioned study, 3 out of the 7 patients required rescue analgesia with continuous popliteal nerve block. In addition, there were problems with lead dislodgement and fracture [25]. These studies indicate that PNS may be a feasible option in providing analgesia after surgery, although it may be limited to playing a supplementary role and not as a main analgesic modality. Ongoing research on chronic pain patients with PNS may provide improved options for pain relief and reduced need for opioids.

Conclusion

Technology newly applied to regional anesthesia practices includes real-time 3D imaging, multi-planar magnetic needle guidance, and inline injection pressure monitoring.

In recent years, three- and four-dimensional US has been developed, which offers several advantages over two-dimensional views. Multiple planes of view can be visualized providing information about the spatial relationship between structures and tracking of local anesthetic spread. However, this

technology is currently limited by a slower frame rate and reduced image quality while needle visibility is not enhanced and has not gained popularity in regional anesthesia.

Needle navigation systems have been developed to facilitate performance, improve success rates, and increase the safety of US-guided procedures. Presently, these needle tracking technologies are not commonly used in regional anesthesia but might gain more popularity with increase in clinical studies and affordability [26]. Recently, shorter procedure time and fewer hand movements on a porcine model were described when the needle tip tracking technology was used for an out-of-plane regional anesthesia technique [27]. Optical spectroscopy (diffuse reflectance spectroscopy) for nerve identification is a promising technology [13]. Possibly, a combination of different techniques will be the key to the improvement of needle-based procedures. Optical spectroscopy and robotics, for example, have already been combined for renal puncture and prostate surgery [28].

High injection pressure has been postulated as one of the warning signs of intraneural injection [29]. Low-cost improvised pressure gauge devices have been described, but recently, Saporito described and validated a novel system for continuous monitoring of injection pressure at the needle tip [14]. He demonstrated that to accurately monitor the injection pressure required to overcome tissue compliance, independent from operator, equipment, and injection parameters, measurement at the needle tip itself (and not an inline pressure) is necessary [30]. Percutaneous nerve stimulation utilizing US-guided techniques is an interesting concept to deliver postsurgical analgesia without the risk of local anesthetic toxicity as in peripheral nerve blocks. However, additional research will further need to elucidate the relative benefits and risks.

Most evidence for new technologies originates from phantom studies, case reports, and case series, with few randomized clinical trials. Improved first-pass success and reduced performance time are the most frequently cited benefits, whereas the need for additional and often expensive hardware is the greatest limitation to widespread adoption. Novice US users seem to benefit most, and much potential lies in education [21].

More research and randomized controlled trials are necessary to evaluate novel technologies. A focus on cost-effectiveness will help spread novel technology into the clinical arena.

Practice points

- Ultrasound technology can identify otherwise unrecognized pathology and can help to optimize patient flow by allowing for more accurate triage, effective treatments, and provide timelier interventions.
- In recent years, several different strategies have been developed to help improve and ease ultrasound-guided needle identification and placement, including magnetically guided needle ultrasound technology.
- The advent of echogenic needles and the resulting improvement in needle visualization under ultrasound guidance has had a positive impact on physician comfort in performing regional anesthesia and on visualization time of the needle during ultrasound-guided procedures.

Research agenda points

- Three-dimensional (3D) and four-dimensional (4D) ultrasound use is another potential way to help improve first-pass success and limit patient harm from regional anesthetics.
- To reduce variability and to reduce the anesthesiologist's workload, the use of robots in regional anesthesia has been explored in recent years.
- Peripheral nerve stimulation (PNS) has also demonstrated efficacy in acute and chronic pain settings.

References

*[1] Ramteke JH, Sahu DK, Sonawane A, et al. New technology: handheld ultrasound-assisted localization of epidural space. Saudi J Anaesth 2018;12:365. https://doi.org/10.4103/SJA.SJA_696_17.

[2] Saranteas T, Zafiropoulou F, Kostopanagiotou G, et al. Ultrasound-guided popliteal sciatic nerve block using a pocket-sized ultrasound machine: preliminary evidence. Br J Anaesth 2015;114:336–7. https://doi.org/10.1093/bja/aeu462.

[3] Mjolstad OC, Dalen H, Graven T, et al. Routinely adding ultrasound examinations by pocket-sized ultrasound devices improves inpatient diagnostics in a medical department. Eur J Intern Med 2012;23:185–91. https://doi.org/10.1016/j.ejim.2011.10.009.

[4] Panoulas VF, Daigeler A-L, Malaweera ASN, et al. Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors. Eur Hear J – Cardiovasc Imaging 2013;14:323–30. https://doi.org/10.1093/ehjci/jes140.

[5] Alexander JH, Peterson ED, Chen AY, et al. Feasibility of point-of-care echocardiography by internal medicine house staff. Am Heart J 2004;147:476–81. https://doi.org/10.1016/j.ahj.2003.10.010.

[6] Prinz C, Voigt J-U. Diagnostic accuracy of a hand-held ultrasound scanner in routine patients referred for echocardiography. J Am Soc Echocardiogr 2011;24:111–6. https://doi.org/10.1016/j.echo.2010.10.017.

[7] Sicari R, Galderisi M, Voigt J-U, et al. The use of pocket-size imaging devices: a position statement of the European Association of Echocardiography. Eur J Echocardiogr 2011;12:85–7. https://doi.org/10.1093/ejechocard/jeq184.

[8] Swenson JD, Klingler KR, Pace NL, et al. Evaluation of a new needle guidance system for ultrasound. Reg Anesth Pain Med 2016;41:356–61. https://doi.org/10.1097/AAP.0000000000000390.

*[9] Johnson AN, Peiffer JS, Halmann N, et al. Ultrasound-guided needle technique accuracy. Reg Anesth Pain Med 2017;42:223–32. https://doi.org/10.1097/AAP.0000000000000549.

[10] Clendenen SR, Robards CB, Clendenen NJ, et al. Real-time 3-dimensional ultrasound-assisted infraclavicular brachial plexus catheter placement: implications of a new technology. Anesthesiol Res Pract 2010;2010. https://doi.org/10.1155/2010/208025.

[11] Abbal B, Choquet O, Gourari A, et al. Enhanced visual acuity with echogenic needles in ultrasound-guided axillary brachial plexus block: a randomized, comparative, observer-blinded study. Minerva Anestesiol 2015;81:369–78.

[12] Balthasar A, Desjardins AE, van der Voort M, et al. Optical detection of peripheral nerves. Reg Anesth Pain Med 2012;37:277–82. https://doi.org/10.1097/AAP.0b013e31824a57c2.

[13] Hendriks BHW, Balthasar AJR, Lucassen GW, et al. Nerve detection with optical spectroscopy for regional anesthesia procedures. J Transl Med 2015;13:380. https://doi.org/10.1186/s12967-015-0739-y.

[14] Patil J, Ankireddy H, Wilkes A, et al. An improvised pressure gauge for regional nerve blockade/anesthesia injections: an initial study. J Clin Monit Comput 2015;29:673–9. https://doi.org/10.1007/s10877-015-9701-z.

[15] Helen L, O'Donnell BD, Moore E. Nerve localization techniques for peripheral nerve block and possible future directions. Acta Anaesthesiol Scand 2015;59:962–74. https://doi.org/10.1111/aas.12544.

*[16] Capogna G, Coccoluto A, Capogna E, et al. Objective evaluation of a new epidural simulator by the CompuFlo® epidural instrument. Anesthesiol Res Pract 2018;2018:4710263. https://doi.org/10.1155/2018/4710263.

*[17] Capogna G, Camorcia M, Coccoluto A, et al. Experimental validation of the CompuFlo® epidural controlled system to identify the epidural space and its clinical use in difficult obstetric cases. Int J Obstet Anesth 2018;36:28–33. https://doi.org/10.1016/j.ijoa.2018.04.008.

[18] Ghelber O, Gebhard R, Vora S, et al. Identification of the epidural space using pressure measurement with the compuflo injection pump – a pilot study. Reg Anesth Pain Med 2008;33:346–52. https://doi.org/10.1016/j.rapm.2008.01.012.

[19] Wehbe M, Giacalone M, Hemmerling TM. Robotics and regional anesthesia. Curr Opin Anaesthesiol 2014;27:544–8. https://doi.org/10.1097/ACO.0000000000000117.

[20] Tighe PJ, Badiyan SJ, Luria I, et al. Technical communication: robot-assisted regional anesthesia: a simulated demonstration. Anesth Analg 2010;111:813–6. https://doi.org/10.1213/ANE.0b013e3181e66386.

[21] Morse J, Terrasini N, Wehbe M, et al. Comparison of success rates, learning curves, and inter-subject performance variability of robot-assisted and manual ultrasound-guided nerve block needle guidance in simulation. Br J Anaesth 2014;112:1092–7. https://doi.org/10.1093/bja/aet440.

[22] Hemmerling TM, Taddei R, Wehbe M, et al. First robotic ultrasound-guided nerve blocks in humans using the magellan system. Anesth Analg 2013;116:491–4. https://doi.org/10.1213/ANE.0b013e3182713b49.

*[23] Melzack R, Wall PD. Pain mechanisms: a new theory. Science 1965;150(80):971–8. https://doi.org/10.1126/science.150.3699.971.

*[24] Campbell JN, Taub A. Local analgesia from percutaneous electrical stimulation. A peripheral mechanism. Arch Neurol 1973;28:347–50.

*[25] Ilfeld BM, Said ET, Finneran JJ, et al. Ultrasound-guided percutaneous peripheral nerve stimulation: neuromodulation of the femoral nerve for postoperative analgesia following ambulatory anterior cruciate ligament reconstruction: a proof of concept study. Neuromodulation Technol Neural Interf 2018. https://doi.org/10.1111/ner.12851.

[26] Choquet O, Abbal B, Capdevila X. The new technological trends in ultrasound-guided regional anesthesia. Curr Opin Anaesthesiol 2013;26:605–12. https://doi.org/10.1097/01.aco.0000432512.15694.dd.

*[27] Kåsine T, Romundstad L, Rosseland LA, et al. Needle tip tracking for ultrasound-guided peripheral nerve block procedures—an observer blinded, randomised, controlled, crossover study on a phantom model. Acta Anaesthesiol Scand 2019:13379. https://doi.org/10.1111/aas.13379.

*[28] Pinto M, Zorn KC, Tremblay J-P, et al. Integration of a Raman spectroscopy system to a robotic-assisted surgical system for real-time tissue characterization during radical prostatectomy procedures. J Biomed Opt 2019;24:1. https://doi.org/10.1117/1.JBO.24.2.025001.

[29] Neal JM, Barrington MJ, Brull R, et al. The second ASRA practice advisory on neurologic complications associated with regional anesthesia and pain medicine: executive summary 2015. Reg Anesth Pain Med 2015;40:401–30. https://doi.org/10.1097/AAP.0000000000000286.

*[30] Saporito A, Quadri C, Kloth N, et al. The effect of rate of injection on injection pressure profiles measured using in-line and needle-tip sensors: an in-vitro study. Anaesthesia 2019;74:64–8. https://doi.org/10.1111/anae.14415.