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Robot-Assisted Regional Anesthesia: A Simulated Demonstration

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Abstract

Recent advances in robotically assisted telesurgery offer expert surgical care for the geographically remote patient. Similar advances in teleanesthesia will be necessary to bring comparable perioperative care to the geographically remote patient. Although many preliminary investigations into teleanesthesia are underway, none involve remote performance of anesthesia-related procedures. Herein, we describe the placement of ultrasound-guided nerve blocks into an ultrasound phantom using the da Vinci multipurpose surgical robotic system (Intuitive Surgical, Sunnyvale, CA). Both single-injection and perineural catheter techniques were successfully performed by an operator who was not physically present at the bedside.

Telemedicine has improved access to consultant-level medical care by minimizing geographic limitations. Similar advances in telesurgery may offer expert surgical care for the geographically remote patient. Current technologies allow expert surgeons to operate either in the same room, or simply along the same data connection as the patient.¹⁻³ Historically, such surgical advances were preceded by similar advances in anesthesia.

True to this paradigm, early investigations into teleanesthesia are already underway. Remote vital sign monitoring, automated anesthetic drug titration, and delivery, herald exciting

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AUTHOR CONTRIBUTIONS

PJT helped design and conduct the study, analyze the data, and write the manuscript. This author has seen the original study data, reviewed the analysis of the data, and approved the final manuscript. SJB helped conduct the study and write the manuscript. This author has seen the original study data, reviewed the analysis of the data, and approved the final manuscript. IL helped design and conduct the study and write the manuscript. This author has seen the original study data, reviewed the analysis of the data, and approved the final manuscript. APB helped design and conduct the study, analyze the data, and write the manuscript. This author has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files. SP helped design and conduct the study and write the manuscript. This author has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.

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forays into teleanesthesia.⁴ However, none of these efforts involve remote performance of regional anesthesia-related procedures.

Herein, we report the first demonstration of a robotically assisted simulated nerve block placement under ultrasound (US) guidance. This effort culminated in the simulated placement of a single-injection nerve block, and placement of a perineural catheter, into a US phantom under real-time US guidance.

METHODS

Equipment Compatibility

Instead of a procedure-specific device, this simulation used the multipurpose da Vinci Surgical System Type S (DVS) (Intuitive Surgical, Sunnyvale, CA). This system incorporates 4 separate robotic arms, with 1 that is mated to a high-definition stereoscopic camera. The workstation allows the person performing the procedure to view the robot's camera output, control the limbs, and receive simultaneous video input from third-party sources. At our institution, the DVS operator console remains within the same room as the DVS, but is located in a corner facing away from the DVS and patient. The DVS is already in widespread clinical use for a variety of urologic, gynecologic, and cardiothoracic surgical procedures.⁵

Before simulated nerve block placement, we first verified the ability of the DVS to grasp, manipulate, and appropriately connect equipment involved in a peripheral nerve block. The DVS was able to grasp and manipulate the needle (StimuQuik 90 mm, 21 gauge; Arrow International, Reading, PA), connect a luer-lock syringe to the needle's injection port, attach the needle's stimulator lead to a peripheral nerve stimulator (Stimuplex-HNS12; B-Braun Medical, Inc., Bethlehem, PA), and operate the peripheral nerve stimulator. The DVS was able to stabilize and provide minor adjustments to the US probe (S-Nerve, HFL38x transducer; SonoSite, Bothell, WA). However, initial placement of the US probe required manual assistance.

Single-Injection Simulation

After this test of equipment compatibility with the DVS, we next attempted a simulated, US-guided single-injection nerve block into a US phantom (Select Series Nerve Block Ultrasound Phantom BPNB150; Blue Phantom, Redmond, WA). The US phantom was placed underneath the DVS on an operating room stretcher. After manual placement of the US probe, the simulated perineural structures within the phantom were identified, and the US probe was stabilized with the DVS. Manual control of the US probe was then relinquished to the DVS for further stabilization and fine-movement localizations of pertinent structures.

All relevant equipment for nerve block placement was placed adjacent to the phantom, within reach of the DVS. Using small graspers, the block needle was then picked up from the operating room bed and advanced at a 45-degree angle to the phantom in-line with the US transducer (Fig. 1). To permit simultaneous visualization of US and DVS camera video output, the US was connected to the DVS using the TilePro video system (Intuitive

Surgical). The DVS operator could thus monitor the needle position in both real space and US space without turning away from the DVS console (Figs. 2 and 3). The phantom did not permit modeling of nerve stimulation thresholds, although the DVS video capabilities permit input of additional video sources that may be directed toward relevant anatomic structures.

Perineural Catheter Placement Simulation

Having simulated placement of a single-injection nerve block, we attempted placement of a perineural catheter. We first manually opened a 60-cm, 19-gauge stimulating catheter kit (StimuCath; Arrow International) and manually removed all packaging from this kit. No medication ampoules were opened via the DVS because of concern for damage to the DVS. The DVS then unwound the stimulating catheter and removed its cap. A stimulating clip was placed on the Tuohy needle. US transducer placement on the phantom proceeded as noted above, and the Tuohy needle was advanced at a 45-degree angle to the phantom using an approach out of plane with the US transducer. After entry into the phantom, the Tuohy needle was directed by the DVS to a cavitary structure within the phantom under real-time US guidance. Visualization was again assisted by the TilePro video system as described above. The stylet was then removed, and the perineural catheter advanced into the needle 4 cm beyond the needle tip. The needle was then removed from the phantom over the catheter while the catheter remained fixed in position. The catheter stylet was then removed from the catheter to permit complete removal of the Tuohy needle from the indwelling perineural catheter. An injection port adaptor was then manually placed over the free end of the perineural catheter (Video 1 clip, see Supplemental Digital Content 1, <http://links.lww.com/AA/A159>).

DISCUSSION

This simulation proved that robotic-assisted regional anesthesia is feasible using existing clinical equipment. The DVS easily adapted off-the-shelf equipment for US-guided placement of both single-injection and perineural catheter-based nerve blocks. Additionally, the DVS easily connected and adjusted nerve stimulation equipment, suggesting that similar techniques could be applied to a stimulating needle or catheter-based approach to robotically assisted nerve block. No permanent modifications to robotic or nerve block equipment were required for successful completion of this simulation.

The geographic independence of the DVS lies in part with its video system. Aside from the stereoscopic high-definition display, we were easily able to add video from the US video output directly to the workstation viewport. We displayed the workstation view on a supplemental monitor to assist with communication during this simulation. As with prior experience with robotic urologic procedures involving multiple sensory modalities, the robot operator did not have to divert attention away from the workstation to check on the robot's status when using this multiple-input video system.^{6,7}

Although the DVS completed the majority of tasks without manual intervention, several steps were not robotically feasible. Most of these tasks, such as initial placement of the US transducer, were limited by graspers that were too small for the target objects. Other actions,

such as opening of medication ampoules, required too much force for the DVS to safely apply, and other procedures would have benefited from more robotic arms.

Although most robotic actions were intuitive for the DVS operator, several actions easily completed with the human hand were not so easily mimicked by the robotic grasper. Those tasks requiring in-line manipulation of rigid structures, such as styletting the Tuohy needle, required both proper camera angles and advanced 3-dimensional movement skills. Repetitive movements over short distances, especially rotational movements such as luer-lock connections, required considerable dexterity. However, the ability to lock a DVS arm in position proved most helpful in many situations. For instance, this capability improved removal of the Tuohy needle over the catheter, and successfully stabilized the US image once transducer placement was optimized.

Despite the considerable capabilities demonstrated in this study by the DVS, obvious questions concerning cost, efficiency, and feasibility abound. Indeed, the multimillion dollar price tag of the DVS system presents a significant barrier to widespread deployment. Two engineers, an anesthesiologist, and a urologist were required to engineer this simulated exercise, underscoring the human support necessary to complete these tasks. Continual patient monitoring, a critical feature during any nerve block placement, was not addressed during this demonstration. Clearly, physician presence would be required for such robotically assisted anesthetic procedures to provide ongoing patient care and manage potential complications. Even if optimized for anesthetic practice, robotic-assisted anesthetic procedures are not likely to become a part of routine anesthetic practice.

This study demonstrated that a multipurpose surgical robot could be adapted for simulated nerve block placement. However, significant limitations limit robotically assisted nerve block placement to the strictly experimental realm for the foreseeable future. Simultaneous development of task-specific robots, and methods for use with generalized robotic platforms, may be warranted in view of the contradictory features inherent to each approach. Regardless of the approach, future studies will be necessary to optimize robotic interfaces with other nerve block equipment.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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APPENDIX: VIDEO CAPTION

Video 1: Video demonstrating the manipulation and placement of a perineural catheter. Stabilization of the needle, catheter, and guide-wire was significantly enhanced by the third arm, which could be locked into position during coordinated movements with the other robotic arms. Such stabilization was also quite helpful during removal of the Tuohy needle over the catheter.

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Figure 1.

The da Vinci system permitted simultaneous visualization of both ultrasound imagery and needle manipulation external to the phantom surface, and this video output was portable to additional external displays as seen here.

Figure 2.

The simulated robotically assisted nerve block required 2 robotic arms. One arm was used for needle manipulation, and the second supported and provided minute adjustments of the ultrasound probe. A third arm was available to assist with manipulation with other equipment used during nerve block placement. The robotic camera angle permitted simultaneous visualization of the ultrasound probe–phantom interface, and needle position.

Figure 3.

Photographs depicting the external positioning of the robotic arms and ultrasound probe when viewed externally, as well as the operator view combining live ultrasound and camera video into a single viewport. The needle tip (T) can be visualized in close approximation to the simulated nerve (N).