Comparison of success rates, learning curves, and inter-subject performance variability of robot-assisted and manual ultrasound-guided nerve block needle guidance in simulation

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Editor’s key points

- A novel robot assistance nerve block system has been recently developed and tested in patients.
- This study investigated the role of this system in training in ultrasound-guided nerve blocks.
- The robot system reduced inter-subject variability, with faster learning of needle placement than manual techniques.
- This new approach to regional anaesthesia training may increase learning rates; it needs further evaluation.

Background. This study focuses on a recently developed robotic nerve block system and its impact on learning regional anaesthesia skills. We compared success rates, learning curves, performance times, and inter-subject performance variability of robot-assisted vs manual ultrasound (US)-guided nerve block needle guidance. The hypothesis of this study is that robot assistance will result in faster skill acquisition than manual needle guidance.

Methods. Five co-authors with different experience with nerve blocks and the robotic system performed both manual and robot-assisted, US-guided nerve blocks on two different nerves of a nerve phantom. Ten trials were performed for each of the four procedures. Time taken to move from a shared starting position till the needle was inserted into the target nerve was defined as the performance time. A successful block was defined as the insertion of the needle into the target nerve. Average performance times were compared using analysis of variance. P < 0.05 was considered significant. Data presented as mean (standard deviation).

Results. All blocks were successful. There were significant differences in performance times between co-authors to perform the manual blocks, either superficial (P = 0.001) or profound (P = 0.0001); no statistical difference between co-authors was noted for the robot-assisted blocks. Linear regression indicated that the average decrease in time between consecutive trials for robot-assisted blocks of 1.8 (1.6) s was significantly (P = 0.007) greater than the decrease for manual blocks of 0.3 (0.3) s.

Conclusions. Robot assistance of nerve blocks allows for faster learning of needle guidance over manual positioning and reduces inter-subject performance variability.

Keywords: learning curves; medical robotics; regional anaesthesia; robot assistance; robotic anaesthesia; simulation

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Robot assistance has been present in surgery for more than a decade, with robots such as the Da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA, USA) being commonly used today by surgeons in the fields of gynaecology and urology. The mechanical robots that provide this robot assistance have been shown to provide an increased precision of movements, improve patient outcome,¹ ² and reduce perioperative morbidity.³  

Studies have demonstrated that surgical, robot-assistance skills are relatively easy to acquire by novices.⁴ ⁵ In fact, a study by Brinkman and colleagues⁶ in 2013 showed that more than half of the novices achieved expert-level proficiency with a robot assistance system after only 10 operations. Additionally, robot-assisted surgery has been found to help achieve shorter learning curves and better accuracy than manual or laparoscopic surgery.⁶ ⁷ A prospective study of robotic vs laparoscopic surgery in 2006 concluded that not only does robot assistance in surgery lower the learning curve for both standard tasks and actual operations, but also that prior surgical knowledge (for open or laparoscopic procedures) is not necessary to learn how to perform robotic procedures.⁸  

While all of these studies focus on robot assistance in surgery, little research has been done on robot assistance in anaesthesia. This lack of research into robot assistance for
anaesthesia is due to an absence of any such systems designed specifically for this field. As several studies have indicated a lowering of the learning curve for robotic vs manual surgery, a similar trend could be expected for robot-assisted anaesthetic procedures. Having recently developed the first robot-assisted nerve block system (Magellan robotic nerve block system) and tested it in patients, we set out to compare the success and learning rates, performance times, and inter-subject performance variability of ultrasound (US)-guided, robot-assisted vs US-guided, manual nerve block needle guidance in simulation on a nerve block phantom. The hypothesis of this study is that robot assistance will result in faster nerve block needle guidance skill acquisition than traditional, manual nerve blocks.

**Methods**

The Magellan robotic nerve block system used in this study is composed of a Tuohy standard nerve block needle mounted on a robotic arm (JACO robotic arm, Kinova Rehab, Montreal, QC, Canada) that is controlled via a software control centre and joystick. The graphical user interface for the system (the Magellan cockpit) features a view of the US video feed and a camera view of the needle insertion area (visible in Fig. 1).

In this study, five co-authors (J.M., C.P., N.T., M.W., C.Z.) each performed four different US-guided nerve block needle placement procedures on two different nerves of an US nerve phantom (Blue Phantom Select Series Peripheral Nerve Block Ultrasound Training Model, Blue Phantom, Redmond, WA, USA) (Fig. 2). This phantom features a superficial nerve at a depth of 1 cm and a profound nerve at a depth of 2.5 cm. It is made of a material that provides for realistic US image characteristics of human peripheral nerves and blood vessels. Half of the procedures were manual, while the other half were robot-assisted. Each procedure was repeated for 10 trials by each user and all procedures involved an ‘out-of-plane’ nerve block where the needle is inserted perpendicular to the US beam.

The four procedures performed were a manual, US-guided nerve block needle placement of the superficial nerve; a manual, US-guided nerve block needle placement of the profound nerve; a robot-assisted, US-guided nerve block needle placement of the superficial nerve; and a robot-assisted, US-guided nerve block needle placement of the profound nerve. Refer to Figure 2 for the identification of the superficial and profound nerves.

Each of the five co-authors had different experience in performing nerve blocks. One author (C.Z.) was an anaesthesiologist with less than a year of experience in regional anaesthesia; the other four co-authors were one anaesthesia resident (N.T.), a PhD candidate with a background in engineering (M.W.), and two undergraduate engineering students (J.M., C.P.) without experience in performing nerve blocks. Experience
levels in using the robotic system also differed: only two co-authors (J.M., M.W.) had prior experience with the Magellan system, acquired during the engineering development of the system.

As this study aimed to compare the success rates, performance time, learning rates, and inter-subject performance variability between robot-assisted and manual, US-guided nerve block needle guidance by novices, the data collected involved the placement of the needle into the nerve and ignored the important steps of properly turning on and using the US machine and probe, properly manoeuvring the US probe to find the target nerve, and identifying the target nerve on the US image: all of these tasks were performed by the senior author (T.M.H.) with many years of experience performing regional anaesthesia. The senior author was the only person to manipulate the US machine and probe during all trials and was responsible for indicating when the needle was successfully inserted into the target nerve. Also, he provided a demonstration of proper handling of a needle for performing a manual, ‘out-of-plane’ US-guided nerve block for each of the five co-authors conducting the procedures. This demonstration consisted of an explanation on how to properly hold and manoeuvre the needle, how to position the needle relative to the US probe, an approximate idea of how far from the probe and at what angle to insert the needle in order to correctly target a nerve centred on the US image, and how to properly visualize the needle on the US image. This senior author also provided a 5 min, hands-on demonstration on how to control the robotic system to perform an ‘out-of-plane’ robot-assisted, US-guided nerve block needle placement by demonstrating the controls of the joystick and performing a single successful block. The same demonstrations were made to each author.

The number of successful nerve block needle placements was recorded. A successful nerve block needle placement was defined as an attempt where the needle was inserted into the target nerve. The same starting position was used for each co-author for both robot-assisted and manual procedures. The time from the starting position till the needle was inserted into the target nerve was recorded as the performance time. The number of attempts required to perform the block needle placement was also recorded, where an attempt was defined as the insertion of the needle into the US phantom. Redirects of the needle while inside the phantom were not considered as a new attempt. Inter-subject performance variability was defined as the variance of the average performance times of each author.

Average performance times were compared using analysis of variance in SPSS (IBM SPSS Statistics, IBM Corporation, Armonk, NY, USA). The performance times were analysed to compute the learning rates by calculating a trend line using linear regression in Excel (Microsoft Excel 2007, Microsoft Corporation, Redmond, WA, USA). The mean number of attempts per trial was compared using a Student t-test in Excel 2007. A P-value of <0.05 was considered as showing significant difference. Data normalization for the mean performance times was made by bounding the data between the minimum and maximum mean times. Data are presented as mean (standard deviation). This was a pilot study to determine what effects robot assistance would have on learning rates of the needle guidance step of the US-guided nerve block procedure.

**Results**

All nerve block needle placements were successful for each of the five co-authors. The mean times to perform the manual, superficial nerve block needle placements and manual, profound needle placements for all five co-authors were 4.38 (3.10) and 9.60 (12.26) s, respectively. The mean times to perform the robot-assisted, superficial nerve block needle placements and robot-assisted, profound nerve block needle placements for all five co-authors were 26.78 (13.02) and 24.92 (15.24) s, respectively.

A significant difference in performance times between the five co-authors was found for both the manual, superficial nerve block needle placements (P=0.001) and manual, profound needle placements (P=0.0001), while no significant difference in performance time was noted between the five co-authors for the robot-assisted procedures (for either the superficial or profound nerve).

The mean times of the 10 trials for the manual, superficial needle placements were 7.08 (6.04), 3.51 (1.32), 3.34 (0.91), 4.82 (0.76), and 3.11 (0.84) s for J.M., C.P., N.T., M.W., and C.Z., respectively. The mean times of the 10 trials for the manual, profound trials were 19.4 (23.61), 3.74 (0.86), 3.74 (1.59), 12.11 (4.59), and 9.05 (6.77) s, for J.M., C.P., N.T., M.W., and C.Z., respectively.

The mean times of 10 trials for the robot-assisted, superficial needle placements were 23.01 (9.21), 22.99 (8.35), 26.76 (9.09), 27.18 (8.36), and 33.96 (22.94) s for J.M., C.P., N.T., M.W., and C.Z., respectively. Similarly, the mean times for the robot-assisted, profound trials were 17.48 (5.83), 20.84 (14.98), 28.38 (11.79), 33.91 (25.53), and 24.00 (5.59) s, for J.M., C.P., N.T., M.W., and C.Z., respectively.

The aggregate mean number of attempts per trial before succeeding for all five co-authors were 1.06 (0.13), 1.28 (0.30), 1.18 (0.08), and 1.1 (0.07) for the manual superficial, manual profound, robot-assisted superficial, and robot-assisted profound nerve placements.
needle placements, respectively (Fig. 3). There was no significant statistical difference in the average number of attempts per trial between manual and robot-assisted nerve block needle placements for either the superficial or the profound nerve.

The aggregate mean times for each of the 10 trials for all five co-authors are shown in Figure 4 for both the manual and robot-assisted, superficial nerve block needle placements and Figure 5 for both the manual and robot-assisted, profound trials. The equations on these graphs model the rate at which the performance time for the corresponding procedure changed from one trial to the next: a negative slope denotes a decrease in the time to perform a nerve block needle placement for each consecutive trial.

The average decrease in time between consecutive trials for all co-authors for robot-assisted nerve block needle guidance trials was significantly \( P = 0.007 \) greater than the decrease seen for the manual procedures at 1.8 (1.6) vs 0.3 (0.3) s, respectively.

As the performance time ranges between the robot-assisted and manual needle guidance trials differed, the data were also normalized and the trend lines re-calculated. Figure 6 illustrates that the magnitude of the normalized average decrease in time between consecutive trials for the robot-assisted procedures was greater than the manual procedures (for both the raw and normalized data).

**Discussion**

This study demonstrates that the use of a robot-assisted nerve block system can result in faster nerve block needle guidance
skill acquisition. Robot assistance reduces the variability in nerve block needle guidance time between subjects, while maintaining similar success rates and requiring a similar number of attempts before the needle was successfully placed.

The first forays into robot assistance in anaesthesia involved the use of the Da Vinci Surgical System by Tighe and colleagues in 2010 for performing a nerve block in simulation on an US nerve phantom and a simulated fibreoptic intubation on an airway trainer mannikin. Afterwards, specific robot-assistance systems were developed in our lab for both tracheal intubation and nerve blocks: the Kepler intubation system and Magellan robotic nerve block system. Both of these systems have been used in pilot studies on patients that indicated the feasibility of robot assistance in anaesthesia.

When compared with laparoscopic surgery, robot assistance for prostatectomies has been shown to provide a shorter learning curve and a decrease in the number of mistakes for surgical novices. In this study, users learned to perform nerve block needle guidance faster with the robotic system than they did manually. However, similar to the trend between manual and robot-assisted nerve blocks seen in this study, robot-assisted prostatectomies are known to take longer than their open (manual) counterparts. Unlike the surgical operative times that take multiple hours, the nerve block times are under half a minute whether they are robot-assisted or performed manually, making the difference in time a moot point. The increased time, which is due to the slower speed of the robotic arm, could actually provide for a more accurate and well-planned approach of the needle.

This study demonstrates that the use of a robot-assistance system to perform nerve block needle guidance can reduce inter-subject variability for the time required to insert the needle into the target nerve. There is a high variability present in the amount of time it takes for anaesthesiologists to learn how to properly perform an US-guided nerve block. Hypothetically, combining the robot assistance evaluated in this study with automatic US nerve identification could further reduce this variability.

The reduction in variability between the rate of acquisition of the skill of inserting the needle into the target nerve seen in this study is possibly due to the use of a joystick as a control mechanism: while the skill to manipulate a needle and the associated anxiety or stress of inserting it through the skin of a patient may vary from person to person, the ability to understand how to manipulate a joystick may be shared more equally among the population.

Another important impact of using robot assistance for performing nerve blocks may be the reduction in fatigue: a study by Sites and colleagues of anaesthesia residents learning regional anaesthesia skills identified fatigue as one of the five greatest problems faced while performing a nerve block. An important benefit of robotic systems is that they never fatigue and their use has been shown to reduce operator fatigue as robot-assistance systems developed for anaesthesia are analogous to their surgical counterparts, they could logically afford this same benefit to anaesthesiologists.

There are several limitations to this study. The faster learning rate identified in this study is for only one part of a complicated and multi-stage procedure: the effect that robot assistance would have on the rate of acquisition of all of the necessary skills for performing nerve blocks is not quantifiable from the limited scope of this study. Another limitation of the study is that specific failure criteria, such as descending the needle beyond the nerve and/or entering a blood vessel, were not noted. Also, this study was conducted on a single US phantom and by a small number of people (co-authors): the use of additional phantoms or cadavers and the inclusion of a greater number of volunteers would provide for a better data set. Further testing of the Magellan system is planned on cadavers that will include a greater number of participants and will attempt to quantify the difference in learning curves for the entire nerve block procedure between robot-assisted and manual methods using the CUSUM model, a model commonly used for measuring the learning curve of anaesthetic and surgical procedures.

In conclusion, robot assistance decreases inter-subject performance variability and allows for faster learning of needle guidance vs traditional, manually performed nerve blocks.

Online video
The video associated with this article can be viewed from the article at British Journal of Anaesthesia online. The video shows the use of the robot-assisted nerve block system to perform a block on a nerve phantom.

Declaration of interest
None declared.

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References
Learning curves of robotic vs manual nerve block needle guidance


