Technical Report

Robotically Assisted Nerve and Facet Blocks:
A Cadaveric Study[1]

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Rationale and Objectives. This study was performed to evaluate the feasibility of using a joystick-controlled robotic needle driver to place a 22-gauge needle for nerve and facet blocks.

Materials and Methods. Biplane fluoroscopy and a robotic needle driver were used to place 12 needles into the lumbar paraspinal region of an embalmed female cadaver (age at death, 98 years). Small metal BB nipple markers (1 mm in diameter) were inserted percutaneously to serve as targets. Six needles were then placed near the nerve root, and six were placed near the facet root. Anteroposterior and lateral radiographs were obtained after each needle placement to assess its accuracy.

Results. All needles were placed within 3 mm of the target BB. The average distance was 1.44 mm ± 0.66 (standard deviation).

Discussion. A robotic needle driver can be used to place needles accurately in the nerve and facet regions. Clinical studies are required to investigate the advantages and disadvantages of this system for interventional procedures involving needles.

Key Words. Interventional procedures, experimental; spine, interventional procedure; cadaver.

Percutaneous spine interventions are performed with freehand passage of instruments, such as needles or trocars, from the skin surface to the spinal anatomy. By using imaging modalities such as x-ray fluoroscopy or computed tomography (CT), the physician identifies the skin entry point and the target to define the desired needle trajectory. The physician then aligns the instrument in his or her hand and partially inserts it toward the target. The instrument is then released, and the instrument position is checked with imaging to confirm proper targeting. As required, the physician may adjust the instrument in a freehand manner and then advance it further. This process of advance and check is repeated until the instrument is at the targeted portion of the spine.

The main problem with this approach is that the unaided human system can be inaccurate in lining up the instrument and staying on course. Additionally, when the physician releases the instrument, it may drift or tilt away from the desired path. For the past 2 years, our research group has been investigating technology developments to improve the precision of these minimally invasive spine procedures. As part of this research, we have been collab-

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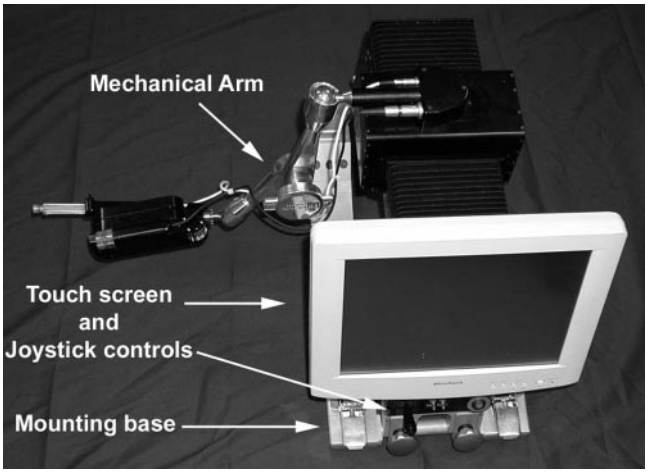


Figure 1. Robot, including touch screen, translational mechanism, and needle driver end effector.

orating with the URobotics (Urology Robotics) Laboratory at Johns Hopkins Medical Institutions to apply a robotic needle driver in spine interventions. This robot was originally developed for percutaneous renal access with fluoroscopic guidance (1) and has also been considered for prostate biopsy with CT guidance (2). The robot is shown in Figure 1.

As an initial clinical application in the spine, we have chosen to evaluate the use of the robot in needle placement for nerve and facet blocks. While the robot is not necessary for this procedure, the procedure is a good starting point to investigate the possible role of robotics in minimally invasive interventions that require precision placement of instruments such as needles. Our long-term goal is to develop an integrated robotic system that is directly linked to x-ray fluoroscopy and CT and helps the physician guide the instrument to the target in a more direct, precise, and controllable manner. This long-term goal will be pursued through research work involving a series of increasingly complex prototypes and clinical evaluation.

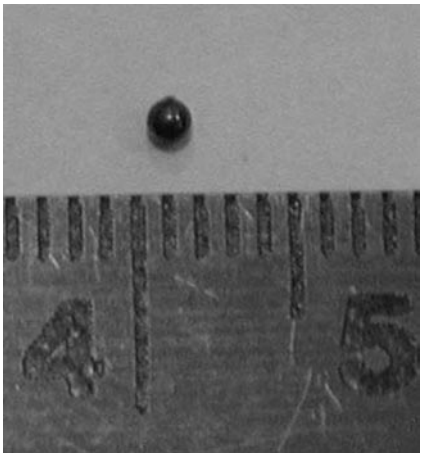
In September 2001, a cadaver study was performed in the interventional suite at Georgetown University Hospital, Washington, DC, to investigate the feasibility of using the robotic device to place needles in the paraspinal region. The results of that study are reported here.

MATERIALS AND METHODS

An embalmed female cadaver (average size; age at death, 98 years) was placed on the interventional table in a supine position. For targets, 1-mm metal BBs (nipple markers, Fig 2) were placed in the lumbar spine from L1 to L4. Twelve BBs were placed, as shown in the Table, with six on each side; the locations were as close as possible to the nerve roots and facets. The BBs were placed with an 11-gauge, 5-inch Bone Temno biopsy needle (Allegiance Healthcare, McGraw Park, Ill). The imaging equipment used for this study was the same used in routine clinical practice, a biplane digital angiography unit (NeuroStar T.O.P.; Siemens, Iselin, NJ).

The robot is mounted on the interventional table with a custom-designed locking mechanism. It is initially posi-

Figure 2. Target metal BB (diameter, 1 mm).



Study Results

Trial No.	Level	Distance from Target (mm) Anteroposterior Fluoroscopy	Lateral Fluoroscopy	Root Mean Square*
Nerve				
1	Right L4	1.10	1.70	2.02
2	Right L3	0.00	1.71	1.71
3	Right L2	0.00	0.80	0.80
4	Left L2	1.75	1.34	2.20
5	Left L3	2.50	0.19	2.51
6	Left L4	1.40	0.74	1.58
Facet				
1	Left L1-2	0.26	0.29	0.39
2	Left L2-3	0.96	1.53	1.81
3	Left L3-4	1.49	0.19	1.50
4	Right L3-4	0.70	0.13	0.71
5	Right L2-3	0.80	0.00	0.80
6	Right L1-2	0.00	1.19	1.19
Mean ± SD†		0.91 ± 0.79	0.82 ± 0.65	1.44 ± 0.66

*The root mean square distance is the square root of [(anteroposterior distance)^2 + (lateral distance)^2].

†SD = standard deviation.

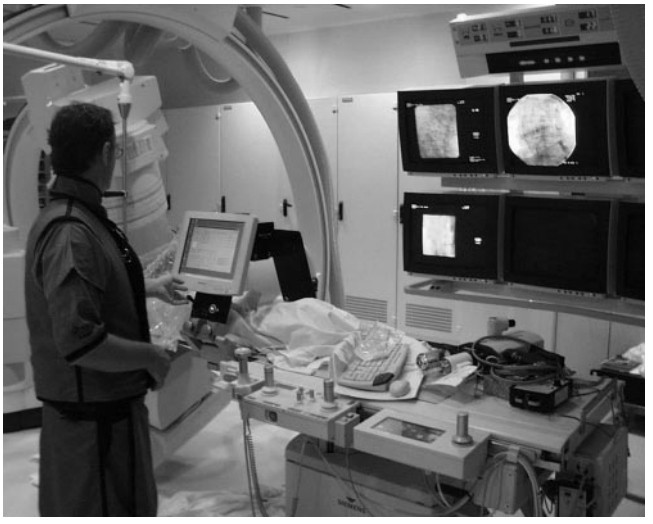


Figure 3. Physician operating joystick to control robot in cadaver study.

Figure 4. Close-up view of robot and cadaver.

tioned near the skin entry point by loosening the passive gross positioning mechanism and moving the needle driver end of the robot by hand. After this initial positioning, the mechanism is locked and the robot is switched to operation by physician control.

The physician controls the robot by manipulating the joystick on the control panel. Different modes of operation can be selected, such as translational motion of the entire unit or rotational motion of the end effector. The system was designed to limit motion to one mode at a time, making it easier for the physician to understand the action of the joystick. An emergency stop button is prominently located next to the joystick as a precaution and may be used at any time to shut down the system. The physician remains in control of the device at all times and may revert to the usual manual technique at any time. Figure 3 shows the operation of the robot with the joystick.

The robot controller is housed in an industrial personal computer chassis that contains all the electronics and safety monitoring devices. The controller includes several safety features, including a watchdog timer board used to monitor system operation. The controller is placed out of the way at the back of the interventional suite and is connected to the robot by 20-ft (6.1-m) cables.

Once the targets were placed, the robotic device was used in an attempt to position a 22-gauge needle within 3 mm of the target (a distance chosen as reasonable for this study by one of the authors [V.W.] and approved in the institutional review board protocol). The typical scenario was as follows: The passive arm was unlocked, and the needle tip was placed within a few centimeters of the skin entry point above the target area. The robot was then set to translational mode with the touch screen. Using the joystick, the physician then moved the tip of the needle to the skin entry point while monitoring the position of the robot visually. The robot was then set to rotational mode with the touch screen. Again using the joystick, the physician oriented the needle to point toward the target point, monitoring the orientation with anteroposterior fluoroscopy. When the physician was satisfied that the needle was pointing toward the target, the robot was set to the needle drive mode with the touch screen. With the joystick, the physician drove the needle toward the target while monitoring the needle depth and trajectory with lateral fluoroscopy. The robot and needle placement are shown in Figure 4.

As each needle was placed, the corresponding anteroposterior and lateral fluoroscopic images were saved in digital format for follow-up analysis. The level, type of block (nerve or facet), and corresponding images were recorded by one of the authors (K.C.), who served as an observer during the study. Images were sent in DICOM (Digital Imaging and Communications in Medicine) format from the angiography unit to a desktop computer running PiView medical imaging software (Mediface, Seoul, Korea). Using the PiView software, another of the authors (D.L.) analyzed all 24 images (anteroposterior and lateral for each of the 12 blocks) and measured the distances from the center of the target to the center of the needle. Representative results for nerve block 4 (left L2) and facet block 1 (left L1 to L2) are shown in Figures 5–8.

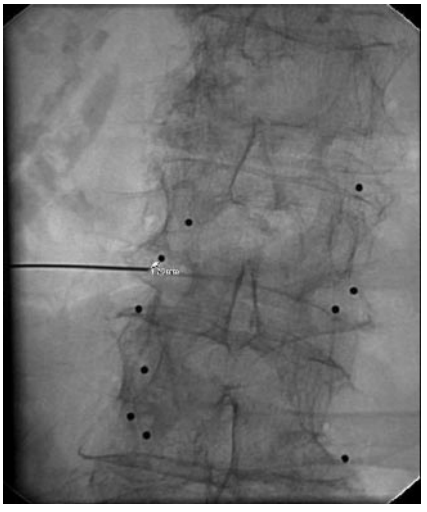


Figure 5. Anteroposterior fluoroscopic image for nerve block at left L2 (needle-to-BB distance, 1.75 mm).

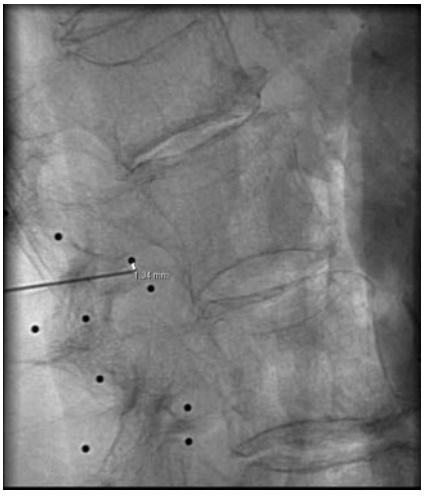


Figure 6. Lateral fluoroscopic image for nerve block at left L2 (needle-to-BB distance, 1.34 mm).

Two assumptions underlie these calculations of distance. First, we assume that the measurement scale on the PiView imaging software is correct to within 10%. This scale is based on the pixel-to-millimeter value from the DICOM header in each image, which comes from the Siemens NeuroStar system and is based on a measurement plane near the isocenter of each C-arm. In our experience, objects near the isocenter will be within 10% of the measured values. Second, in calculating root mean square values, we assume that the anteroposterior and lateral views are orthogonal, a good assumption for this cadaver study. Finally, the distance calculated is a slight overestimation, since the craniocaudal distance component is present on both the anteroposterior and the lateral views.

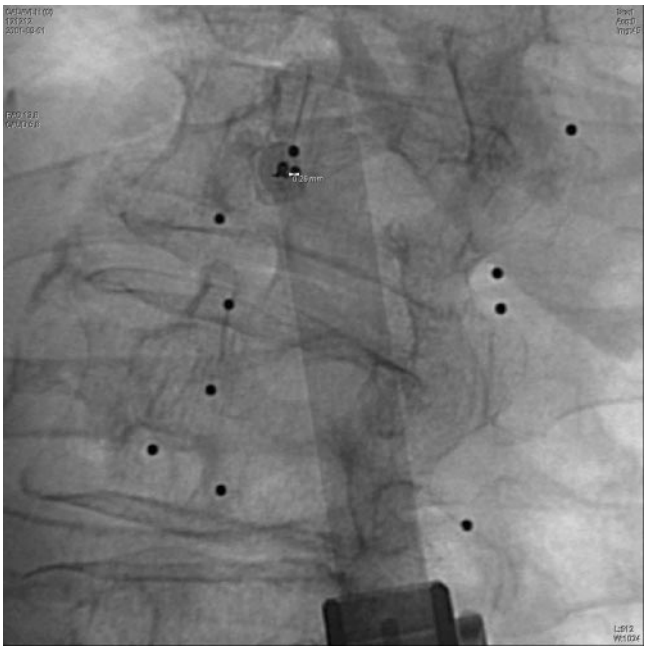


Figure 7. Anteroposterior fluoroscopic image for facet block at left L1 to L2 (needle-to-BB distance, 0.26 mm).

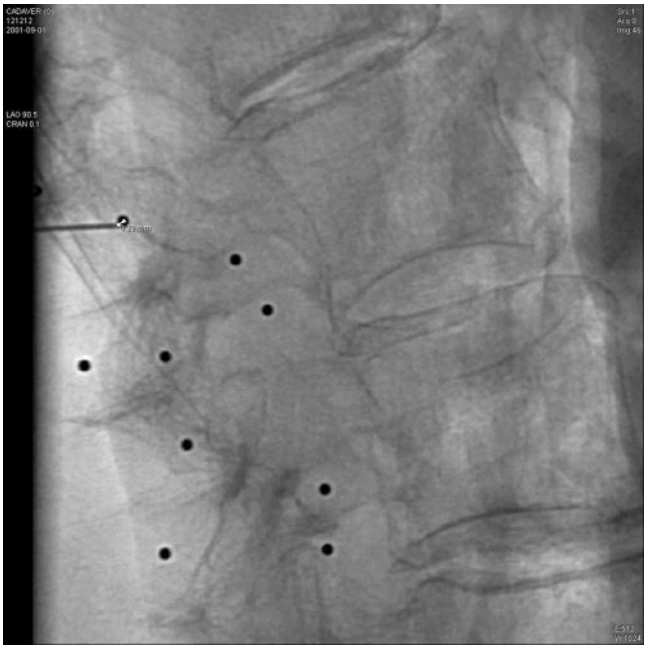


Figure 8. Lateral fluoroscopic image for facet block at left L1 to L2 (needle-to-BB distance, 0.29 mm).

RESULTS

The results of the accuracy study are given in the Table. The average placement accuracy was 1.44 mm ±

0.66 (standard deviation). In most cases the physician was able to drive the needle directly toward the target. In some cases, however, the needle deviated slightly and the physician needed to correct the needle path, by reorienting the needle slightly in the direction opposite to the deviation. When the needle was driven farther into the body, the path would generally move closer to the target.

DISCUSSION

The study data reported here indicate that a physician-controlled robotic needle driver can place needles accurately in the nerve and facet regions of the spine. All the needles were placed without difficulty, and no system failures were observed with the robot. The robotic needle driver has two advantages. First, it is a steady and precise holder for the needle; the needle never deflects or sags when partially inserted, as it tends to do in the current manual procedure, and it can be reoriented and inserted in very precise increments. Second, the physician can view the location and trajectory of the needle in the body in real time, since his or her hand is not in the path of the x-ray beam.

Other methods to aid in needle guidance have been proposed, such as needle holders (3) and a CT-integrated stereotactic arm (PinPoint; Marconi Medical Systems, Cleveland, Ohio). These methods, however, do not give the same degree of precision and incremental motion as the actively driven robot that we tested.

The next step in our research program is a clinical trial of the robot's use in nerve and facet blocks. Institutional review board and Food and Drug Administration approval should soon be finalized for an initial study of 20 patients.

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