Augmented Reality Visualization Using Image-Overlay for MR-guided Interventions: Performance Assessment of Paravertebral Sympathetic Perineural Injections in Cadavers at 1.5 Tesla

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Keywords: augmented reality, image overlay, MR-guided, interventional MR imaging, sympathetic blocks

Purpose

Percutaneous injections to the paravertebral sympathetic nerve plexus' of the thoracic, lumbar, and lumbosacral spine are frequently applied minimally-invasive, diagnostic and therapeutic procedures in the management of chronic pain. Because of the close proximity of needle paths and targets to critical organs such as the lungs, ureter and bowel, procedures are frequently performed under x-ray fluoroscopy and computed tomography guidance. However, the procedure-related exposure to ionizing radiation and the associated health risks are concerning and urge interventionalists to use alternative guidance techniques. Interventional magnetic resonance (MR) imaging guidance is advantageous in this regard because it uses non-ionizing radiation and further favorable visualizes para- and prevertebral structures, but operator access to the patient inside the bore of the magnet is limited, which complicates workflow and targeting. Augmented reality navigation represents a powerful concept to overcome these limitations. Therefore, we prospectively assessed the performance parameters of a novel augmented reality Image-Overlay system for the navigation of MR-guided paravertebral sympathetic injections in human cadavers at 1.5 Tesla.

Methods

A prototype augmented reality Image-Overlay system was used in conjunction with a clinical 1.5-Tesla MRI system (Magnetom Espree, Siemens Healthcare, Erlangen, Germany). Twelve nonembalmed, full torso human cadavers (seven woman, five men; age range at death, 50-99 years; mean age at death, 75 years) were used, including 4/12 (33%) small (living body mass index, 16-18.5 kg/m^2), 4/12 (33%) medium (18.5-25 kg/m^2) and 4/12 (33%) large (25-30 kg/m^2) subjects. A total of 23 lumbosacral levels (46 needle insertions; each level was targeted bilaterally) were prospectively planned targeting the paravertebral thoracic sympathetic plexus (9/23, 39%), the paravertebral lumbar sympathetic plexus (8/23, 35%), and the presacral hypogastric plexus (6/23, 26). High-resolution MRI data sets (three-dimensional Sampling Perfection with Application optimized Contrasts using different flip angle Evolutions (SPACE) sequence; repetition time [TR], 1000-1100; echo time [TE], 34; flip angle [FA], 120; number of averages [Av], 2; echo train length [ETL], 73; slice thickness [ST], 1 mm; number of slices [SL], 240; field of view [FOV], 192 x 192 mm; base resolution , 192 pixels; phase resolution [PR], 100%; bandwidth [BW], 751 Hz) were used for planning of needle paths using the PerkStation module of 3D Slicer software (Figure 1). Vertebral levels for puncture were chosen individually based on the MRI planning volume. MR-compatible 20 Gauge needles (MReye®, Cook Medical, Bloomington, IN) of 10 or 15 cm lengths were used with adjustable clip-on depth gauge for planned insertion depth. Needles were placed by one operator under augmented reality assisted MRI navigation. Turbo spin echo MR images (TR, 1200; TE, 12; FA, 120; Av, 1; ETL, 17; ST, 3 mm; SL, 5; FOV, 256 x 224 mm; BR, 320 pixels; PR, 100%; BW, 252 Hz) were used to assess and document needle tip positions (Figure 2). Injectants consisted of 5 ml of Gadolinium-DTPA-enhanced saline using a dilution factor of 1:250. Gradient echo real-time MR imaging (TR, 9.3; TE,3.5; FA, 60; Av, 1; ST, 5 mm; FOV, 256 x 224 mm; BR, 256; PR, 56%; BW, 180 Hz) was used to monitor injections (Figure 3). T1-weighted, fat suppressed MR images (TR, 500; TE, 12; FA, 120; Av, 1; ETL, 17; ST, 3 mm; SL, 7; FOV, 256 x 224 mm; BR, 320 pixels; PR, 100%; BW, 252 Hz) were finally obtained to visualize the Gadolinium-enhanced injectants. Technical performance parameters assessed included number of intermittent MR imaging control steps required to place a needle, needle adjustment rates, target error of the final needle tip location, rate of inadvertent puncture of non-targeted vulnerable structures, successful drug delivery rate, and procedure time. Needle adjustment

rate included removal and new placement (reinsertion), change of needle trajectory (trajectory change), and straight needle withdrawal for depth (withdrawal). The target error was defined as the Euclidean distance between the planned and final position of the needle tip based on the PerkStation. Procedure time was defined by target level (n=23) and included the lengths of times of planning of the needle path, needle placement, MR imaging control of needle position and injection of the contrast agent of both injections. Variables were expressed as frequencies and proportions, and as the median with range in parentheses.

Results

All planned punctures (46/46, 100%) were carried out. The thoracic sympathetic plexus (9/23, 39%) was targeted at the T4 (8/9, 89%) and T5 (1/9, 11%) levels, the paravertebral lumbar sympathetic plexus (8/23, 35%) was targeted at the L2 (6/8, 75%) and L3 (2/8, 25%) levels, and the presacral hypogastric plexus (6/23, 26) was targeted at the L5-S1 (6/6, 100%) level. Needle guidance with the Image-Overlay system was technically feasible in all three cadaver sizes. An average of 2 (1-5) intermittent MR imaging control steps were required to place a needle. Needle adjustments included 9/46 (20%) trajectory changes and 6/13 (13%) advancements. No reinsertions were required. The average target error was 3.9 ± 1.7 mm (range, 1.1 - 6.8 mm) [coefficient of variance: 10.2 ± 4.5%; range, 1.6 - 20.9%]. No punctures of non-targeted vulnerable structures occurred. Successful drug delivery was achieved to all targets (46/46, 100%). The median procedure time was 36 min (16-52 min).

Conclusion

Augmented reality navigated MR-guided paravertebral sympathetic perineural injections using the Image-Overlay system provided efficient imaging guidance for accurate targeting and needle punctures resulting in a high success rate of adequate drug deliveries to the paravertebral sympathetic nerve plexus'. The safety profile was favorable with no inadvertent punctures of vulnerable anatomic structures. Our results support further evaluation with clinical trials.

Figure 1. Virtual needle path (white line) to the right parasympathetic lumbar nerve plexus (Target) using the Perk Station.

Figure 2. Axial turbo spine echo MR image of the L3 lumbar level demonstrates the tips of the needles (white arrows) at the left and right paravertebral sympathetic nerve plexus.

Figure 3. Frame of an axial gradient echo real-time MR imaging sequence for monitoring of the injection shows the needles (white arrows) and the hyperintense injectant (gray arrows) accumulating at the right and left lumbar paravertebral sympathetic nerve plexus.