

MR Image Overlay Guidance System (MR-IOS): System Evaluation for Clinical Use
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Purpose

A clinical augmented reality guidance system was developed for MR imaging guided musculoskeletal and spine interventions (Magnetic Resonance Image Overlay System, MR-IOS) [1]. The MR-IOS was used in conjunction with a laboratory system “*Perk Station Platform, PSP*”; a training platform for percutaneous needle based interventions [2]. The purpose of this study was to assess the MR environment compatibility, technical accuracy, technical efficacy and operator performance of the MR-IOS.

Methods and materials

MR environment compatibility of the MR-IOS was assessed by comparing the signal-to-noise ratios (SNR) based on NEMA standards while the MR-IOS was in an active and inactive state. To obtain the SNR value, a set of two-dimensional axial T1-weighted fast spin echo MR images (TR/TE, 550/8.8; field-of-view, 250 x 250 mm; section thickness, 5mm; flip angle, 90°; pixel bandwidth, 150.0) of a phantom were acquired on a 1.5-Tesla MR imaging system (Magnetom Espree, Siemens Healthcare). Data Analysis for SNR values were compared by One Way Analysis of Variance (ANOVA) [3].

The technical accuracy was assessed by the parameters of skin entry error, angle error, depth error, and target error. Skin entry error was defined as the Euclidean distance of the planned and actual skin entry point. Angle error (degrees) was defined as the included angle of the planned and actual needle paths. The depth error (mm) was defined as the distance between the target locations and the needle tips along the needle trajectory. The

target error (mm) was defined as the Euclidean distance of the planned and actual position of the needle tips. Data were assessed by comparing the planned needle paths with the true locations of the needles based on MR images (1.5-Tesla MR imaging system Magnetom Espree, Siemens Healthcare) and CT images (DynaCT, Siemens Healthcare) using the PerkStation module of 3D Slicer [4]. Data were obtained with an in-room preclinical experiment including 62 needle insertions on a spine phantom.

Technical efficacy was measured by comparing the success rates of needle insertions with two different image guidance techniques. The efficacy was tested in-lab by running an experiment with 40 operators, separated into two groups (freehand N=20 versus MR-IGS guided N=20) with each operator placing needles at 10 predefined targets into a geometric phantom. The phantom consisted of 3 mm diameter targets embedded in transparent gels, polyvinyl chloride-based plastisol (M-F Manufacturing Company Inc., Fort Worth TX, USA). Success was defined as physical contact of the intended target and the puncture needle tip.

Operator performance was assessed by comparing total procedure times, total needle path distance, presumed tissue damage, and speed of individual insertions. Procedure time (s) was defined as the total time spent on each insertion; starting with planning of the needle path and ending when operator indicated the final position of the needle tip. The total needle path distance (mm) was defined as the total distance of the needle tip travel inside the phantom. The presumed tissue damage (mm^2) was defined as the approximate area from two consecutive needle tip position including entry to final needle tip position [5]. The speed of insertion was defined as the ratio of the path to the total time inside the phantom. All insertions were tracked and recorded by using an electromagnetic (EM) tracking system (NDI Aurora, Northern Digital Inc., Waterloo, ON, Canada). The results were analyzed and evaluated offline based on the recorded needle insertions data.

The study used the Perk Station software as an interactive module on the 3D Slicer program. The software was used to calibrate, plan the insertions, validate and evaluate the results. In-room quantitative variables were expressed as mean \pm standard deviation (SD). Comparisons between two groups were measured by Mann-Whitney rank sum test, and were expressed as mean \pm standard error of the mean (SEM). The statistical analysis was performed with a statistical software package (JMP version 7.01, SAS Institute).

The experimental setups of the in-room and in-lab studies are shown in Figure 1.

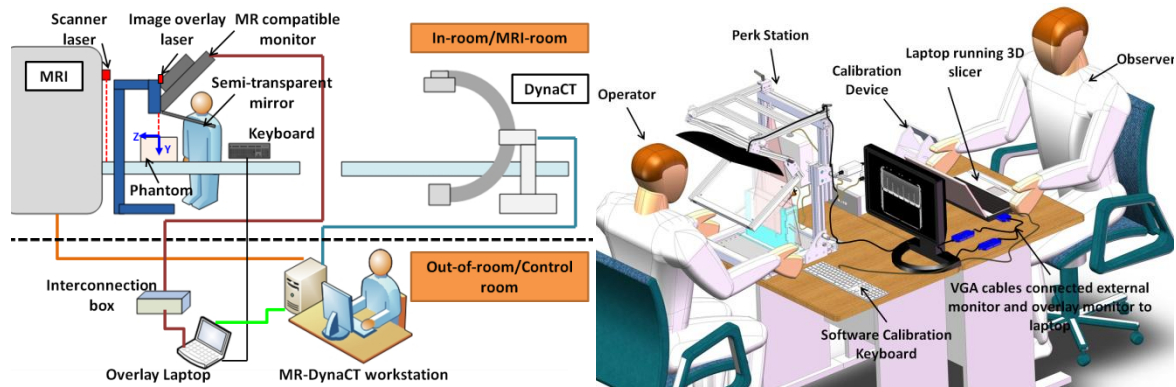


Figure 1: Experimental setup; (left) MR-IOS setup for preclinical experiments and (right) *PSP* setup for in-lab experiments.

Results

MR environment compatibility assessment showed an SNR difference of 2.04% on MR images obtained with the MR-IOS in the active and inactive state. There was no perceptible change in image quality or uniformity. Technical accuracy assessment showed mean entry error of 1.6 ± 0.6 mm, depth error of 0.7 ± 0.5 mm, angle error of 1.5 ± 1.1 deg, and target error of 1.9 ± 0.8 mm. Technical efficacy of MR-IOS was confirmed by success rates of 80.95 % as compared to freehand insertion success rates of 35.0% with a statistically difference ($p = 0.031$). Operator performance showed average total procedure time of 40.3 ± 4.4 (s) for freehand and 37.0 ± 3.7 (s) for MR-IOS, needle path distances of 152.6 ± 15.0 for freehand and 116.9 ± 8.7 mm for MR-IOS, presumed tissue damage of 7417.2 ± 955.6 mm for freehand and 6062.2 ± 678.5 mm for MR-IOS, speed of insertion of 5.9 ± 0.4 mm/s for freehand and 4.3 ± 0.3 mm/s for MR-IOS. There was no statistically significant different results in the total procedure time ($p = 0.584$) and in presumed tissue damage between two groups ($p = 0.347$). There was a significant different results in total needle path distance ($p = 0.074$) and in the speed of insertion ($p = 0.003$) between two groups. The results showed the advantage of MR-IOS guided in keeping the users' hands steady during needle insertion, as indicated by the total needle path distance and the presumed tissue damage.

Conclusion

MR-IOS is compatible with an MR environment, technically accurate, technically efficacious, and improves operators' performance.

References

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