A Method to Verify the Instrument Position Realized by a Robotic Assistance System: Feasibility and Accuracy of the Biopsy Trajectory

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Purpose/Introduction

Recently, a robotic assistance system has become commercially available that allows to plan and realize biopsy trajectories inside an MR scanner. The correct position of the application module (AMO) which holds and guides the instrument is verfied near the entry point of the biopsy site by imaging four contrast-filled spherical markers mounted on the AMO. Currently, the geometry of the scan planes for these marker scans needs to be defined manually. Our first goal was to test the feasibility of a marker detection algorithm based on 2D morphological analysis of the signal distribution. The second goal was to determine the accuracy of biopsy trajectories in an experimental setup, in particular, for various marker positions occuring during clinical application.

Materials and Methods

The robotic assistance system (Innomotion, Innomedic GmbH, Herxheim, Germany) is fully MR-compatible and consists of a pneumatically driven six-degrees-of-freedom robotic arm mounted on a C-like support that fits into a standard 60-cm bore [1]. In our experimental series, the AMO (Fig. 1) was imaged with a 1.5T scanner in 13 accurately defined, equally spaced (16 mm) z-positions (±96 mm around the z-coordinate of the magnet isocenter). At each position, images were acquired in transverse and coronal views (Fig. 1). The orientation of the AMO was kept constant. The markers were imaged with spoiled gradient echo sequences (FLASH, FA=50°, coronal: TR/TE=27/3.4 ms, SL=17 mm, pixel spacing=0.39 mm, transverse: TR/TE=19/3.0, SL=50, PS=0.59) in two orthogonal planes and localized in 3D by fitting 2D Gaussian peaks to the smoothed images, respectively.

Reproducibility of the algorithm was evaluated by the differences of the x-coordinates between both scan planes. Deviations in x- and y-position were calculated as the difference between the position value at a given z-position and the respective value at z=0. For the z-deviations, we used the difference between the mean z-distance to the next-neighbor(s) at a given z and subtracted the corresponding value at z=0. The difference vector between the two midpoints of marker pairs M1-M2 and M3-M4 was assumed as biopsy trajectory (specified by the polar angle τ with respect to the +z-axis and the azimuthal angle φ within the transverse xy-plane).

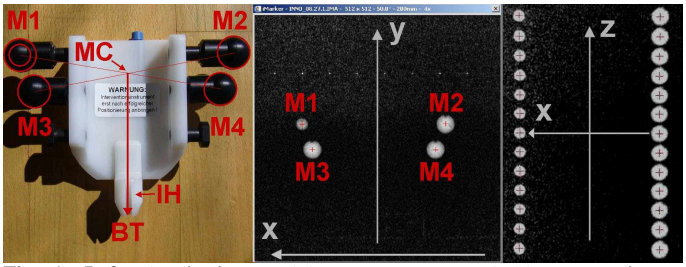

Fig. 1: Left: Application module. IH: Instrument holder, BT: Biopsy trajectory, M1-M4, MC: Markers and Centroid. **Center:** Transverse MR image. **Right:** Overlay of coronal images in 13 AMO z-positions.

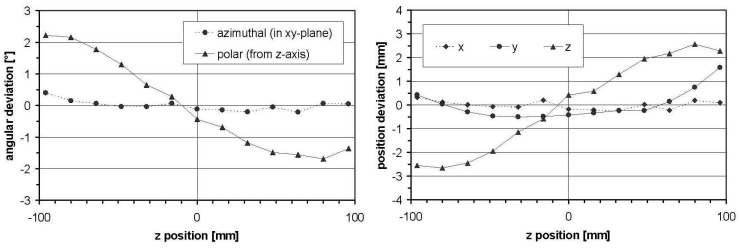

Fig. 2: Left: Angular offset of BT relative to mean BT. **Right:** Corresponding deviations in position coordinates of the insertion point assumed at the tip of the IH and located at a 76-mm distance from the MC (see Fig. 1 left).

Results and Discussion

The average 1D position deviation between orthogonal planes (precision) was 0.12 ± 0.10 mm (μ±SD). At the extreme AMO positions (z=±96 mm), relative marker positions differed by (median, range) 0.43 (0.03-0.78), 1.06 (0.06-2.54), and 0.67 (0.39-0.93) mm for x-, y-, and z-coordinates, respectively. Figure 2 left shows the difference between the values for τ and φ at a given z-position and those of the mean biopsy trajectory (τ=98.22°, φ=269.48°). The latter is the average over all z-positions in this series and differs only slightly from the biopsy trajectory at z=0 (Fig. 2 left). The angular offset is highly asymmetric and yields a SD of 0.16° in the transverse and 1.48° in an almost sagittal plane. The corresponding deviation in the 3D coordinates (xyz) of the insertion point – involving both position and orientation errors – is shown in Fig. 2 right. The average deviations were 0.18, 0.61, and 1.99 mm, respectively.

In general, we believe that the measured deviations in 3D position largely reflect errors of the magnetic gradient fields which vary with the distance from the isocenter. This would explain why the measured differences in y-position are larger than those in x and z when the markers are located around (±54,128,0) mm in reference position. It would also explain why marker pairs M1-M2 and M3-M4 shift in opposite x-directions (not shown here). As a result, the average x-coordinates between these pairs remain almost constant and angular offsets will be restricted to a more sagittal plane. With the biopsy trajectory pointing mostly in the -y and only partially in the -z direction the remaining polar angle variations in the sagittal plane, this may explain the predominant z-deviation of the insertion point.

Conclusion

Marker localization was successful and highly reproducible for all z-positions. The 1D deviation of the needle insertion point, however, varied with the distance of the AMO from the magnet isocenter, most likely influenced by gradient field errors. The average deviation was well below 1 mm for the x- and y- and 2 mm for the z-coordinates. Given that the z working range of the actual device is limited to ±70 mm, that accuracy is considered good enough for clinical interventions. At the same time, this work illustrates how the particular marker configuration and distance from the isocenter may result in anisotropic deviations in the position of the needle insertion point. More accurate results might be obtained by trying to correct for the gradient field errors.

References

[1] Zangos S et al. Eur Radiol, 2006 Oct 10 [Epub ahead of print]