

An image-guidance system for vascular malformation treatment: Concept, design and evaluation on a patient-specific phantom

Marius Schwalbe¹, Christian Hansen²

Stefan Weber¹, Huanxiang Lu¹

¹ARTORG Center for Biomedical Engineering, University of Bern, Switzerland

²Computer-Assisted Surgery Group, Faculty of Computer Science, University of Magdeburg, Germany

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Purpose

Minimally-invasive endovascular procedures have become the standard treatment for vascular malformations, such as arterio-venous malformations (AVM) or venous malformations (VM, see Figure 1). These procedures are performed by accurately positioning either a catheter or a percutaneous needle within the malformation's nidus and delivering coils or toxic sclerosants (e.g. ethanol) in order to close the malformation.

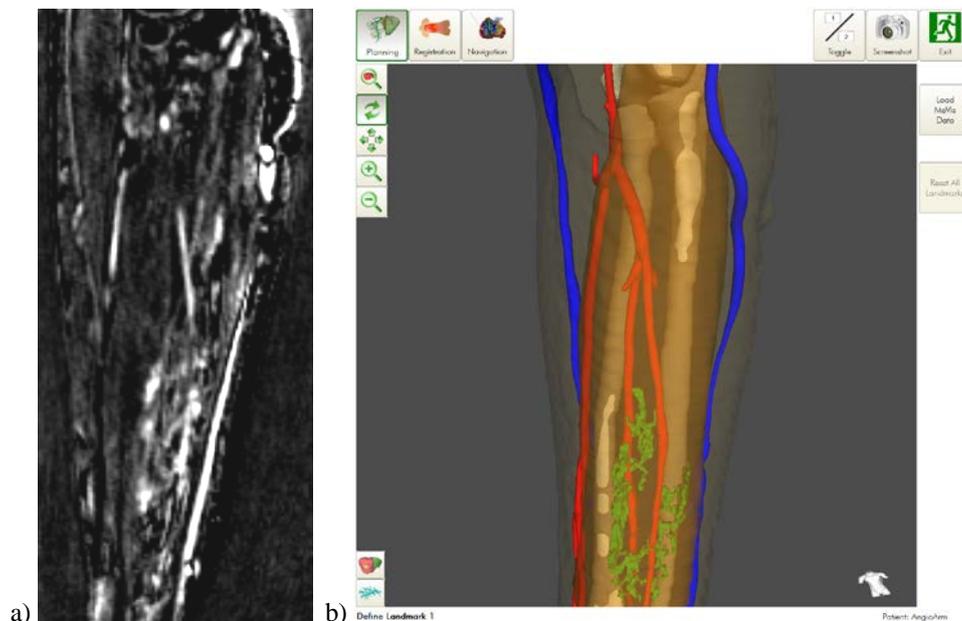


Figure 1: a) Subtracted FLASH MRI of a venous malformation in the flexor digitorum superficialis muscle of a right forearm; b) 3D reconstructed model of the same patient showing the main arteries, the cephalic and basilica vein and the malformation in the navigation system.

These procedures are carried out under general anesthesia and during multiple sessions in order to avoid ischemic and cardio-pulmonary complications. Throughout the procedure, catheter and needle placement can only be controlled by bi-planar digital subtraction angiography. This eventually leads to high doses of contrast agent, resulting in potential renal failure and extensive radiation exposure. Moreover, limited spatial orientation (since only 2D fluoroscopy is available) renders intervention outcome and duration unpredictable, especially in complex cases [1].

We hypothesize that the introduction of an electromagnetic (EM) tracking instrument guidance approach utilizing a preoperative 3D images to patient registration will result in faster and more accurate positioning of instruments relative to the target nidus when compared with standard AVM or VM procedures.

Methods

Preoperative 3D Modeling

Based on different MRI sequences, a patient-specific 3D model is extracted. The arteries and veins is extracted from a time resolved subtracted FLASH MRI sequence using a dedicated planning software called AngioPlan based on the development platform MeVisLab (MeVis Medical Solutions AG, Germany). The bones, the muscle and the skin are segmented using thresholding and manual selection from a coronal FLASH MRI sequence (matrix size = $448 \times 364 \times 96$, TR = 6.44 ms, TE = 3.00 ms) with an isotropic resolution of 1 mm. In addition, the venous malformation is manually segmented in Amira (Zuse Institute Berlin, Germany) from a coronal fat saturated VIBE MRI sequence (matrix size = $448 \times 364 \times 80$, TR = 3.10 ms, TE = 1.16 ms) with pixel size of 0.89 mm and slice thickness of 1.1 mm.

Navigation

An existing optical tracking-based IGS platform dedicated to open surgical and interventional procedures (CAScination AG, Switzerland) was extended with EM tracking (Northern Digital, Canada). For targeting an 18 gauge Chiba-tip needle with a 5DoF sensor in the tip was use (Figure 2a).

Patient-to-image registration is performed by digitizing four landmarks onto the predefined patient's fiducial markers. Specifically, this digitization is performed by acquiring the pose of the EM-tracked needle tip when placed at each fiducial location (Figure 2a). After that, the needle position is co-registered to the coordinate system of the 3D model, allowing for real-time navigation [2].

Evaluation

To evaluate the accuracy and efficacy of the navigation system, a 3D phantom was produced by means of rapid prototyping from the preoperative MRI scans of a patient diagnosed with VM. Five target points of different depths were defined in the malformation's nidus.

Six users were asked to register the phantom to the model and to puncture the five predefined targets using the EM-tracked needle in a given order. Three users had abundant experience of using the system whereas the other three were new to the system. The accuracy was evaluated by measuring the Euclidian distance between the needle tip and the predefined target position recorded in the EM coordinate system. In addition, the efficacy of the system was evaluated by measuring the time needed for registration and targeting.

Results

The registration error was first measured, yielding an accuracy of 0.87 ± 0.28 mm. The overall targeting accuracy was 0.80 ± 0.31 mm. The targeting accuracy between the novice group and expert group was compared, in which no significant difference ($p = 0.204$) was found (Figure 2b). However, the variability of the accuracy exists between the five targets. Target four has a significant larger error (1.05 ± 0.21 mm) compared to other four targets ($p = 0.026$). The overall time used for registration was 164 ± 52 seconds. The time for targeting was 43 ± 18 seconds. No significant difference was observed between the groups and target positions.

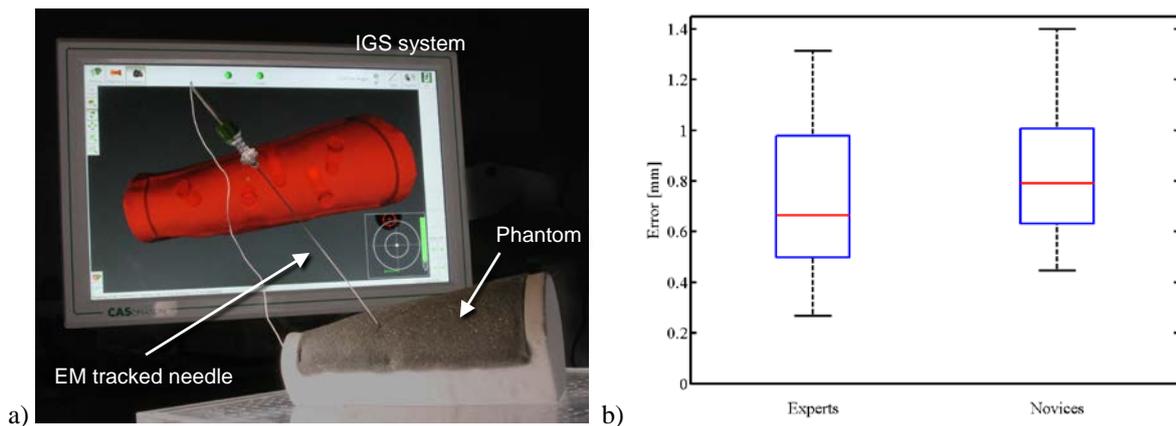


Figure 2: a) The proposed IGS setup; b) Boxplot of expert group and novice group, the difference is not significant ($p = 0.204$).

Conclusions

We demonstrated a concept and design of an image-guidance system dedicated for the treatment of vascular malformation. The proposed method was evaluated by a patient-specific phantom produced from rapid prototyping. The obtained accuracy is less than 1 mm, which indicates that the proposed IGS system has the potential to provide accurate guidance for the malformation treatment. No significant difference was observed between accuracy obtained by the novices and the experts, demonstrating a short learning curve for using the system. In addition, the efficacy measurements show that the overall operation time of the workflow is within five minutes, therefore will possibly not be disruptive to the existing clinical procedure.

For future work, we will focus on developing a more automated planning tool for 3D modeling as well as the investigation of a more clinically applicable registration method.

References

- [1] W. Yakes and I. Baumgartner, "Interventional treatment of arterio-venous malformations," *Gefäßchirurgie*, vol. 19, pp. 325-330, 2014.
- [2] M. Peterhans, A. vom Berg, B. Dagon, D. Inderbitzin, C. Baur, D. Candinas and S. Weber, "A navigation system for open liver surgery: design, workflow and first clinical applications," *Int J Med Robot*, vol. 7, no. 1, pp. 7-16, Mar 2011.