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Abstract

X-Ray-free neuro-endovascular training using optically tracked 3D-printed phantoms

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Endovascular interventions for cerebrovascular diseases require extensive training due to their technical complexity and high-risk nature. Virtual reality simulators offer repeatable, risk-free practice but often either lack anatomical realism and accurate haptic feedback, or are expensive, limiting skill transferability to clinical settings [1,2]. While physical phantoms using 3D-printed patient-specific vasculature provide superior anatomical fidelity and realistic device-vessel interactions, they typically require fluoroscopic imaging for visualization, exposing trainees and instructors to ionizing radiation.. This radiation dependency limits training frequency and accessibility. Hybrid approaches combining physical phantoms with alternative imaging modalities remain underexplored [3]. This study developed a radiation-free hybrid system combining modular patient-specific vascular phantoms with optical tracking for endovascular training.

3D-printed transparent modular phantoms were created from contrast-enhanced computer tomography data (Formlabs Form 4, Clear resin) with flattened walls at camera positions to reduce distortion. Three cameras tracked colored instruments via color segmentation and background subtraction; 3D positions were estimated through ray-surface intersection. A C-arm simulator generated fluoroscopy-like projections using CT data from the Visible Human Project. The system tracked multiple instruments simultaneously and delivered radiation-free, realistic fluoroscopy projections. Additionally, force sensors tracked the forces applied to the aneurysm wall to warm about its puncture. Limitations included optical dead zones at vessel bifurcations, limited range of vessel diameters, and phantom transparency.

This hybrid system enables radiation-free endovascular training with patient-specific anatomy, supporting multiple training scenarios and device validation.

AUTHOR'S STATEMENT

Authors state no conflict of interest. In accordance with ethical standards, we confirm that we have obtained ethical approval 20-121A, 03.04.2020 for the use of the medical data included in this study. The authors would like to thank D. Wendt and T. Gartmann for their contribution to the construction and production of parts. The presented work was supported by the EU (EFRE) and the State of Schleswig-Holstein, Germany (Project: Diagnostic and therapy methods for Individualized Medical Technology (IMTE) – Grant: 124 20 002 / LPW-E1.1.1/1536) and by the Fraunhofer Internal Programs under Grant No. SME 40-08039

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