Bimodal 3D Near Infrared and Ultrasound Imaging of Blood Vessels for Real-time Image-Guided Vascular Access

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Introduction: Vascular access is pivotal to a wide range of clinical interventions and is the leading cause of medical injury in the United States. Challenges often arise when attempting to visualize blood vessels beneath the skin, estimate vessel depth and spatial position, or accurately steer the needle. Here we describe a system that combines near infrared (NIR) and ultrasound (US) imaging with real-time computer vision software to map the 3D structure of subcutaneous vessels and track the needle position. The system may be used as a standalone imaging tool to guide needle insertions or coupled with robotic technology to enable automated vascular access.

Materials and Methods: The system (**Fig. 1a**) makes complementary use of multispectral optical detection (to provide a coarse map of the peripheral vasculature under NIR illumination (**Fig. 1b**)) and portable ultrasonography (to analyze a localized vessel region at greater depth and higher magnification (**Fig. 1c**)). The NIR modality takes advantage of the differential absorptivity of deoxyhemoglobin at 760 and 940 nm to provide contrast-enhanced images of otherwise occluded vessels up to 4 mm in depth. The vessels are segmented based on their 2nd-order geometry and reconstructed in 3D using stereovision techniques. The US modality, meanwhile, provides B-mode and Color Doppler representations of the vessel up to 15 mm depths. Longitudinal and axial images are acquired at 18 MHz, and additional image analysis algorithms are implemented to detect the vessel walls, discriminate venous and arterial flow, and segment the needle as it enters the bloodstream. The imaging system operates at >30 fps, and computes vessel and needle positions with ~100 µm spatial resolution.

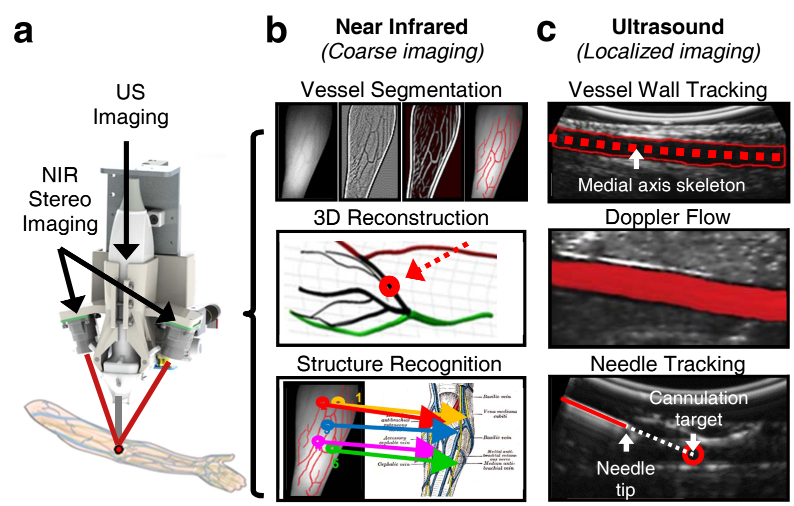

Figure 1. (a) Bimodal 3D imaging system. **(b)** NIR modality and image analysis (segmentation, reconstruction, structure recognition). **(c)** US modality and image analysis (vessel wall segmentation, Doppler flow, needle tracking).

Results and Discussion: Proof-of-concept has been demonstrated *in vitro* and in human imaging pilot studies. In the human studies, we evaluated the NIR and US imaging modalities on 101 patients, and observed a 2-fold increase in the percentage of detected forearm vessels compared to traditional visualization by a clinician. We next compared needle insertion success rates by the clinician on commercial and custom phantoms, observing a 27% increase in first-stick accuracy using the imaging system versus unassisted cannulation.

Conclusion: We have developed a system for subcutaneous vessel imaging that couples optical and acoustic detection with image analysis. Extending current studies, we have initiated clinical trials to compare success rates for vascular needle insertions in difficult patient populations with and without the system. Finally, we have coupled the imaging technology with a portable robotic needle manipulator to perform image-guided vascular access procedures in fully-autonomous fashion.

Acknowledgements: National Science Foundation (Small Business Innovation Research Award 1448550); National Institutes of Health (Ruth L. Kirschstein Graduate Research Fellowship F31 EB018191 from the National Institute of Biomedical Imaging and Bioengineering); National Science Foundation (Graduate Research Fellowship 1243320 from the American Society for Engineering Education); National Institutes of Health (National Research Service Award T32 GM8339 from the National Institute of General Medical Sciences).