Dual-Scan Photoacoustic Tomography for the Imaging of Vascular Structure on Foot

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Introduction

- Chronic leg ulcers, a common disease associated with peripheral vascular disorders, are affecting approximately 6.5 million Americans [1]. Patients with ulcers commonly suffer from decreased mobility and lower quality of life.
- Revascularization surgery is one of the most effective treatments for ischemia-related foot ulcers, as it restores blood flow and perfusion to the ulcer region.
- Thus, the ability to monitor the perfusion change before and after surgery is important for physicians to evaluate the success of the surgery. However, current clinical tests fail to meet this need.

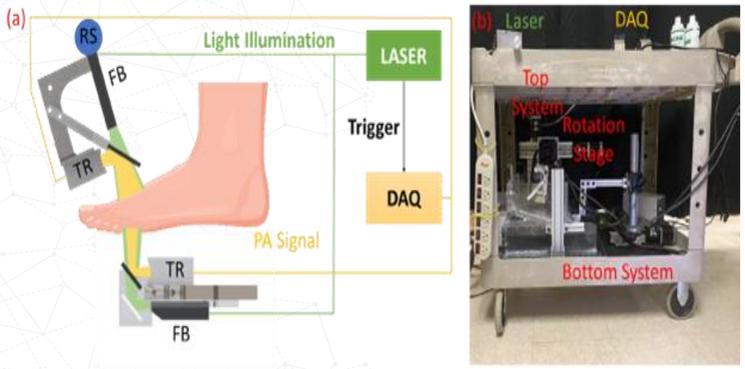

Figure 1. Experiment setups of the dual-scan imaging system. (a) A schematic drawing of the dual-scan PAT system. (b) A photograph of the system. All equipment is installed on a cart except the portable laser.

- Here we developed a dual-scan 3D PAT system for imaging the vascular structure of the foot (Figure 1).
- The system is capable of imaging both the dorsal and plantar sides of the foot simultaneously to reduce imaging time.
- The performance of the system is demonstrated through phantom imaging and human tests. Our results indicate that the system has high potential for clinical translation.

System Design

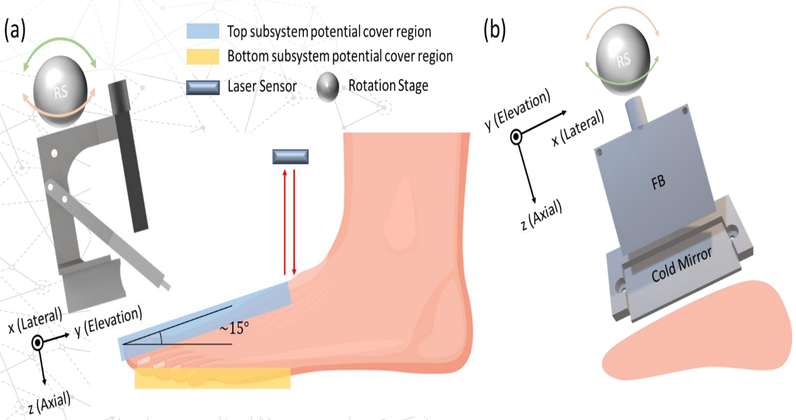

Figure 2. The schematic drawings. (a)&(b) A schematic drawing in axial-elevation

- The foot height change measurement result from a laser distance sensor reading will be used to guide the most suitable movement.
- Articulating-based ball stage is capable of manual adjustment along the lateral and elevation directions for patients with different foot sizes.
- A laser distance sensor is used to measure the foot height and ensure that the transducer always stays in focus during scanning.

System Performance

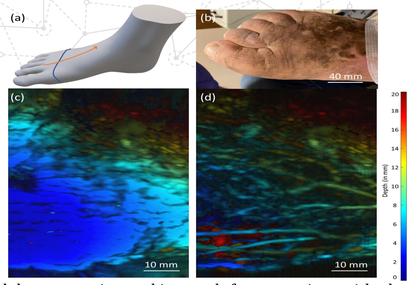

Figure 3. Skin removal demonstration and its result from a patient with ulcers on the right foot.

- In figure 3, a photo of the right foot from a patient with ulcers. Strong skin signals are shown in Figure 3c.
- The skin removal algorithm allows us to visualize the vessel structure more clearly (Fig. 3d).

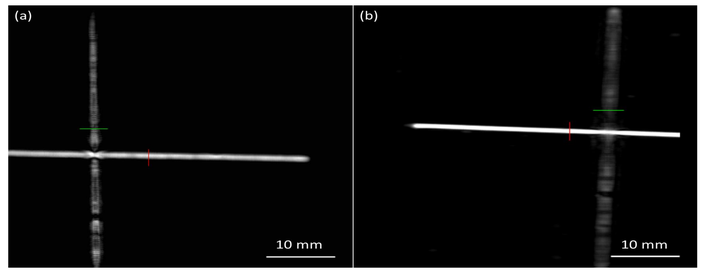

Figure 4. Spatial resolution quantification based on 0.2 mm width cross-line phantom

- The lateral resolution was quantified to be 0.89 mm and 0.67 mm for the top system and bottom systems, respectively, as shown in Figure 3(c) - (d)
- In Figure 3 (e) and (f), the elevation resolution is 1.2 mm, and 0.94 mm for the top system and bottom system, respectively.
- The resolution is quantified by Full-Width at Half Maximum(FWHM).

Healthy Volunteer Result

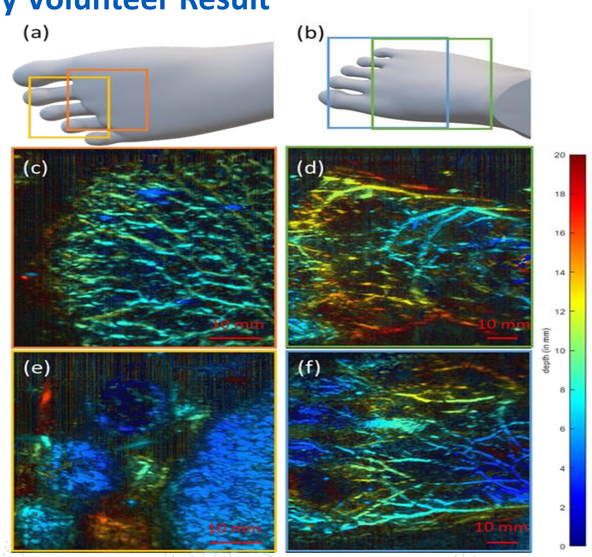

Figure 5. Experiment results from the healthy volunteers.

- We recruited 4 healthy volunteers with a mean age of 25 and a standard deviation of 3.
- Based on our observation as shown in Figure 5 and Boyko's work [3], the artery is mostly concentrated on the foot plantar side, and the venous mostly appear on the instep side.

Preliminary in-vivo results

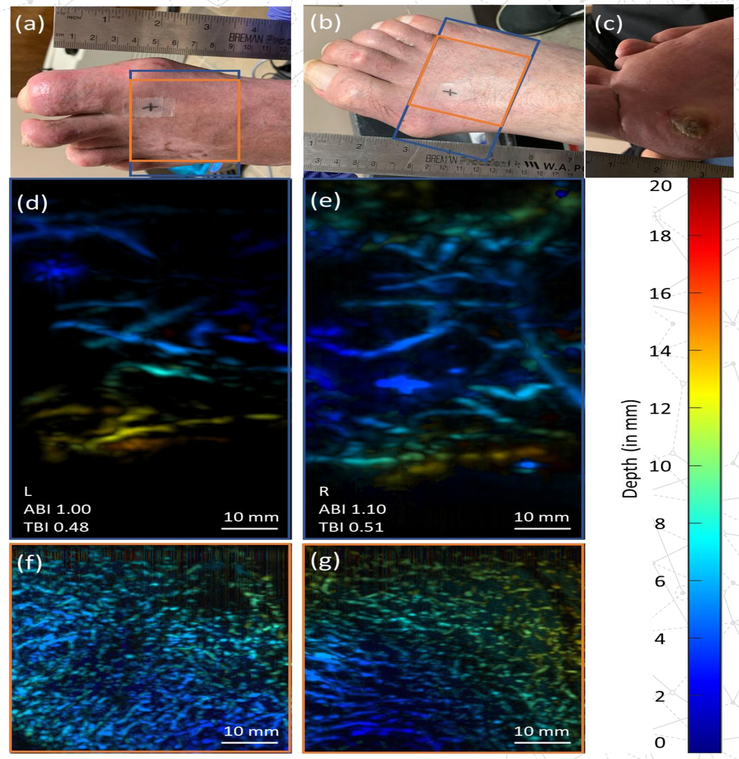

Figure 6. In-vivo results from a patient with an ulcer at the plantar side of the left foot.

- A 68-year-old male with a chronic ulcer is observed on the bottom of the left foot (Figure 6a-c).
- PA images (Fig. 6d-g) indicate that The current system can cover at least 70% and 60% of regions of the dorsal and plantar sides of the foot, respectively.
- The Ankle Brachial Index (ABI) and Toe Brachial Index (TBI) readings are listed in Figure 6(d) and 6(e).
- The average vessel intensity is quantified for all PA images, the results are 0.98 for the left instep and 0.31 for the left sole, 1.68 for the right instep, and 0.38 for the right sole, which agree with readings from the ABI and TBI test.

Conclusion

- We have developed a photoacoustic system for foot imaging. The system takes 50 seconds to acquire a 3D image of the foot. The 3D image provides insight about the spatial information of vascular structure on the foot, making it easier for clinicians to examine perfusion conditions.

Selected References

1. Wang, Y., et al., A portable three-dimensional photoacoustic tomography system for imaging of chronic foot ulcers. Quantitative imaging in medicine and surgery, 2019. 9(5): p. 799.
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3. Boyko, E.J., M. Monteiro-Soares, and S.G. Wheeler, Peripheral arterial disease, foot ulcers, lower extremity amputations, and diabetes. Diabetes in America. 3rd edition, 2018.

Acknowledgement

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