Smartphone-based Monitoring of Healing Status in Diabetic Foot Ulcers using Tissue Oxygenation and Thermal Maps

Fernando S. Chiwo[1], Daniela Leizaola[1], Kacie Kaile[1],Maria H. Hernandez[1], Ricardo A. Avila[1], Renato Sousa[1], Jose P. Ponce[2], Stanley Mathis[2,3], Alexander L. Trinidad[1], Nikhil K. Reddy[1], Himaddri S. Roy[1], Manuel I. Leizaola[1], David G. Armstrong[1], Anuradha Godavarty[1]

[1] Optical Imaging Laboratory, Department of Biomedical Engineering, Florida International University, Miami, FL 33174

[2] White Memorial Medical Group, Los Angeles, CA 90033 [3] Clemente Clinical Research, Los Angeles, CA 90033

[4] Southwestern Academic Limb Salvage Alliance, Department of Surgery, Keck School of Medicine of University of Southern California, Los Angeles, CA 90033

INTRODUCTION

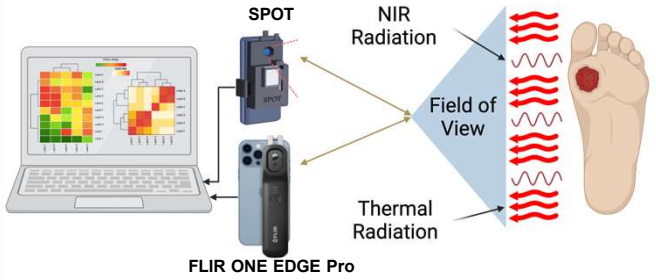
- **Diabetes** is a silent pandemic, with 1 in 3 patients developing **Diabetic Foot Ulcers (DFUs)**, with the highest levels of morbidity and mortality worldwide.
- **Visual Inspection of DFUs** is the gold standard to assess DFUs by assessing size, warmth, smell, and oxygen.
- **Post-pandemic** era led to a critical necessity of tools to monitor the status of DFUs remotely.
- **Imaging technologies** have been used to monitor the healing progress of the wounds, but independently.

OBJECTIVE

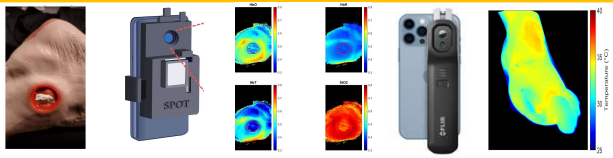
Combine RGB + tissue oxygenation + heat maps to assess the healing status of DFUs using smartphones-based devices.

METHODS

Population: 17 DFU participants with different healing conditions
Clinical Procedure: 4 Weeks of scalpel debridement
IRB-approved study (FIU IRB-13-0092)
Imaging Technology: Smartphone-based NIRS or optical imaging device (SPOT) and a wireless handheld smartphone-based thermal imaging scanner (FLIR ONE EDGE Pro)



OPTICAL-THERMAL DATA PROCESSING AND ANALYSIS



White Light Imaging
Wound size
Wound Color

Tissue Oxygenation Maps
Oxygen supply to the wound
Tissue viability

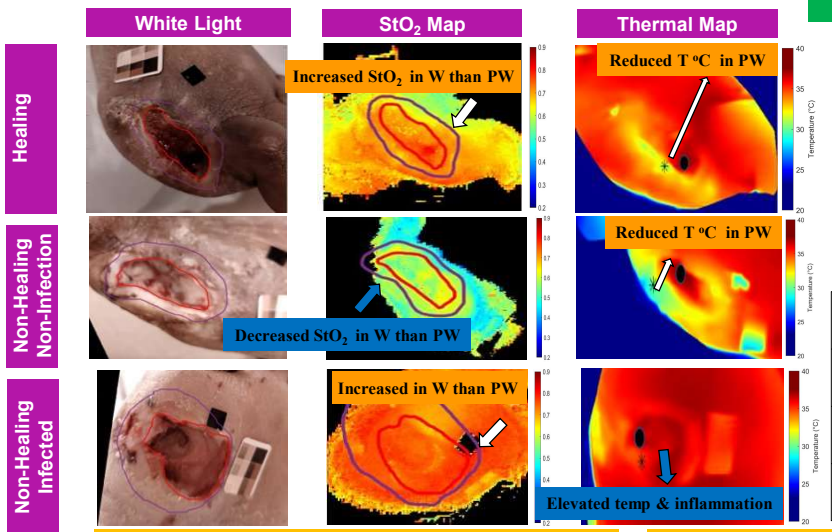
Thermal Maps
Inflammation
Infection (indirect measure)

ACKNOWLEDGEMENTS

Partial funding from NIH Grant No. 1R01-EB033413, FIU-DYF Award (one co-author), FIU-BME CURE Funds, staff at clinical sites.

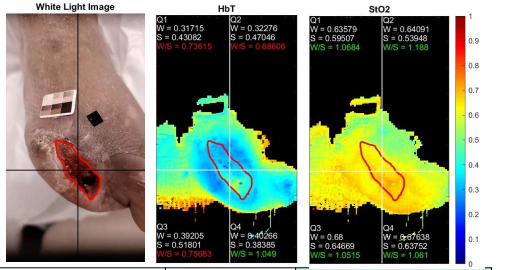
RESULTS: STUDY-1

Can Optical Imaging be complemented with Thermal Imaging to assess DFU healing status? Yes, both techniques are complementary



Optical Imaging can differentiate between healing and non-healing DFU cases by monitoring its StO_2 maps, but not infection

Can Optical Imaging Differentiate Healing & Non-Healing DFUs? Yes, HbT & StO_2 contrast maps differentiate healing status

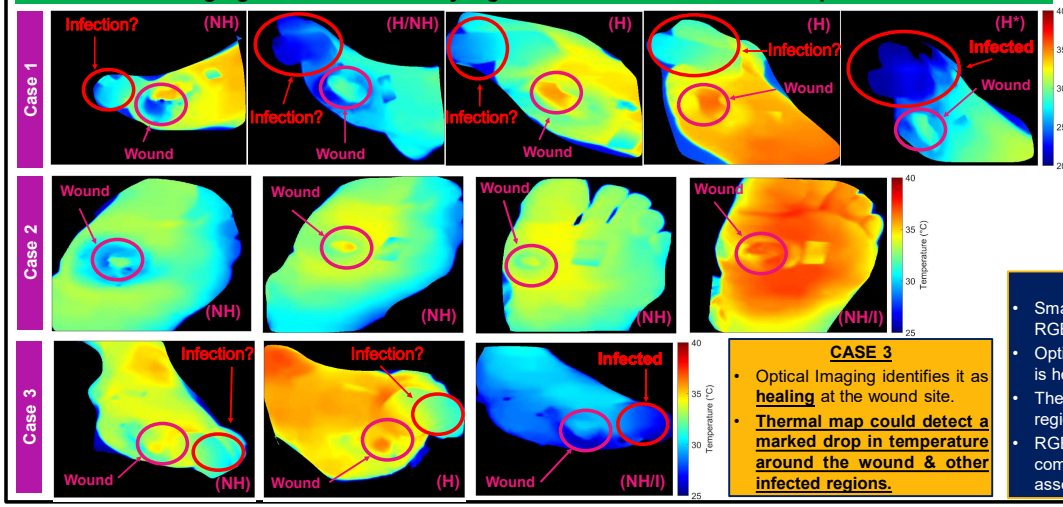


DFU Status (Clinician)	DFU Status (SPOT)	Passing Rate	
Healing (n=16)	Healing	13/16	81.25%
Non- Healing (n=3)	Not Healing	4/5	80%
NH w/ Infection (n=2)			

Thermal Imaging shows a distinct difference in inflammation/infected case, but not between healing and non-healing case

RESULTS: STUDY-2

Can Thermal Imaging be used for early detection of Infections across the weeks? Yes, thermal imaging can detect the early signs of infections that end in amputation



CASE 1
- Optical Imaging identifies as non-healing, but **not as infected.**
- Thermal map marked drop in temperature around **wound** & other **infected regions.**

CASE 2
- Optical Imaging analysis identified it as a **healing.**
- Thermal map shows increased temperature across the foot from **inflammation (& infection)** during last week.

CASE 3
- Optical Imaging identifies it as **healing** at the wound site.
- **Thermal map could detect a marked drop in temperature around the wound & other infected regions.**

CONCLUSIONS
- Smartphone-based platform for combined RGB, optical, and thermal imaging.
- Optical Imaging can detect if the wound is healing from HbT & StO_2 contrast maps
- Thermal imaging can detect infected regions distinctly & possibly early on.
- RGB/Optical/Thermal imaging modalities complement each other for improved DFU assessments.