Development and Feasibility Testing of a Combined SFDI and LSI Device for Noninvasive Assessment of Cutaneous Radiation Exposure

Gordon T. Kennedy[a], Emily Gu[b], Ritesh Jina[a], Thinh Phan[a], Brandon Jones[b], Christopher A. Campbell[a]
Gregory P. Holmes-Hampton[b] and Anthony J. Durkin[a]
[a]Beckman Laser Institute and Medical Clinic, [b]Armed Forces Radiobiological Research Institute (AFRRI) Uniformed Services University (USUHS)

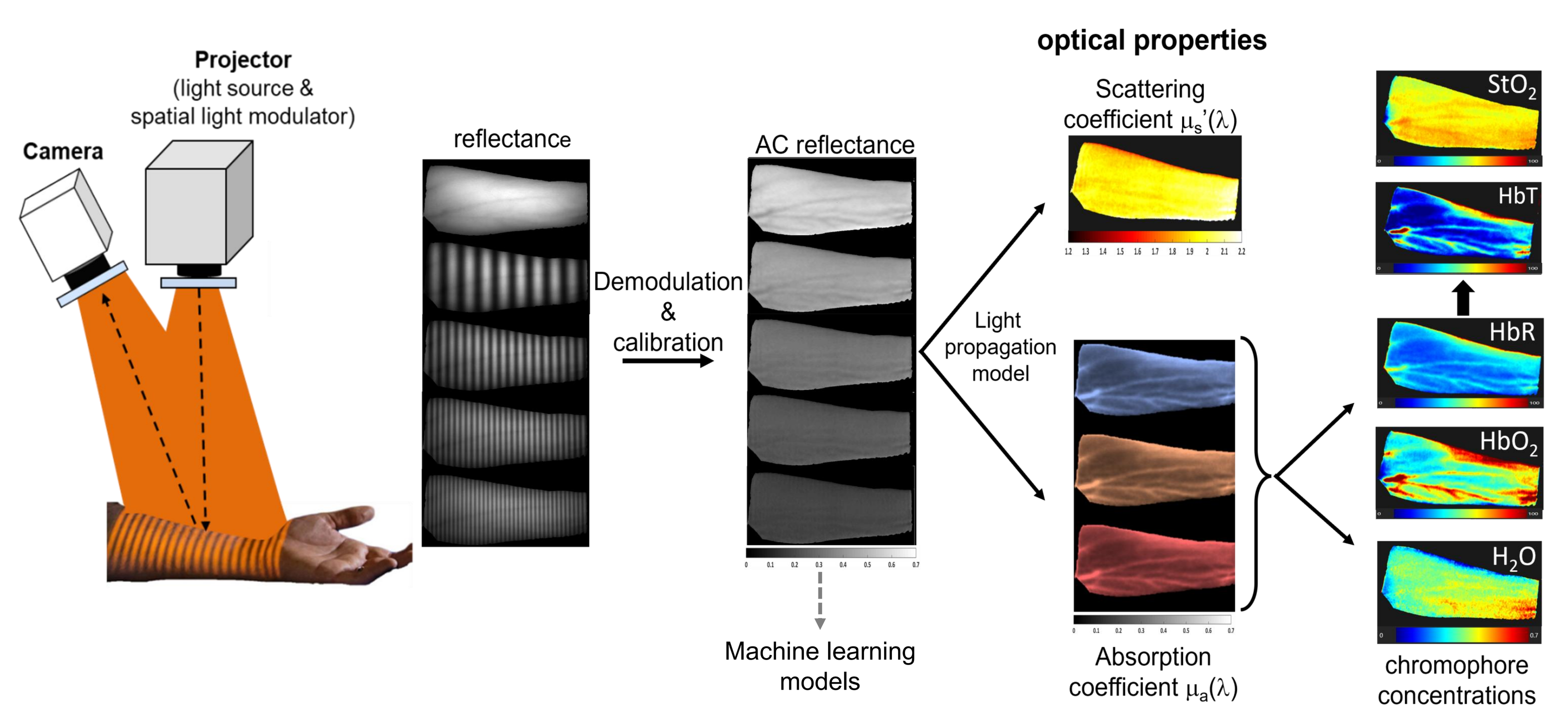
Learning Objectives

- Describe the design and fabrication of a novel, integrated imaging platform that combines SFDI and LSI for coincident structural and metabolic mapping.
- Explain the utility tissue optical properties such as the reduced scattering coefficient (μ_s') as an early objective biomarker for identifying latent tissue damage before it is visible to the unaided eye.
- Evaluate the feasibility of using portable, tablet-controlled optical technologies for rapid triage of Cutaneous Radiation Injury in high-stakes or resource-limited environments.

Significance/Motivation

- Cutaneous Radiation Injury (CRI) poses a significant challenge for early triage.
- Subsurface tissue damage often occurs during a latent period before visible clinical signs appear.
- Current clinical grading methods are subjective and are based on visual and tactile examination.
- These are reactive, only identifying injury after visible symptoms such as erythema or necrosis have developed.
- Spatial Frequency Domain Imaging (SFDI) and Laser Speckle Imaging (LSI) are non-contact, widefield imaging techniques that provide quantitative information on sub-surface structural and hemodynamic properties of skin.
- SFDI and LSI have shown capability in quantitatively determining burn severity and thermal contact and directed energy burns.
- These imaging modalities have potential to report on latent CRI injury before it becomes clinically apparent.

Spatial Frequency Domain Imaging (SFDI)



- Light at multiple wavelengths having a range of sinusoidally varying intensity patterns at various spatial frequencies is projected onto *in-vivo* tissue region of interest.
- The backscattered light is imaged using a camera and calibrated reflectance maps are calculated using a calibration sample with known optical properties.
- A model of light propagation in tissue can be used to calculate the tissue properties of reduced scattering coefficients, absorption coefficient, tissue chromophore concentrations and tissue oxygen saturation.

Feasibility Study: Methodology

- Göttingen miniature swine model of CRI developed at AFRRI (N=4).
- Dorsal regions (6 sites per animal) were exposed to 50Gy of 6MeV electrons.
- Irradiated sites measured weekly to 120 Days post irradiation using the cart-mounted combined LSI SFDI platform.
- Periodic non-invasive skin assessments (e.g. Kumar scoring) and histopathological analysis were used to assess wound severity.

Combined SFDI & LSI Tissue Imager

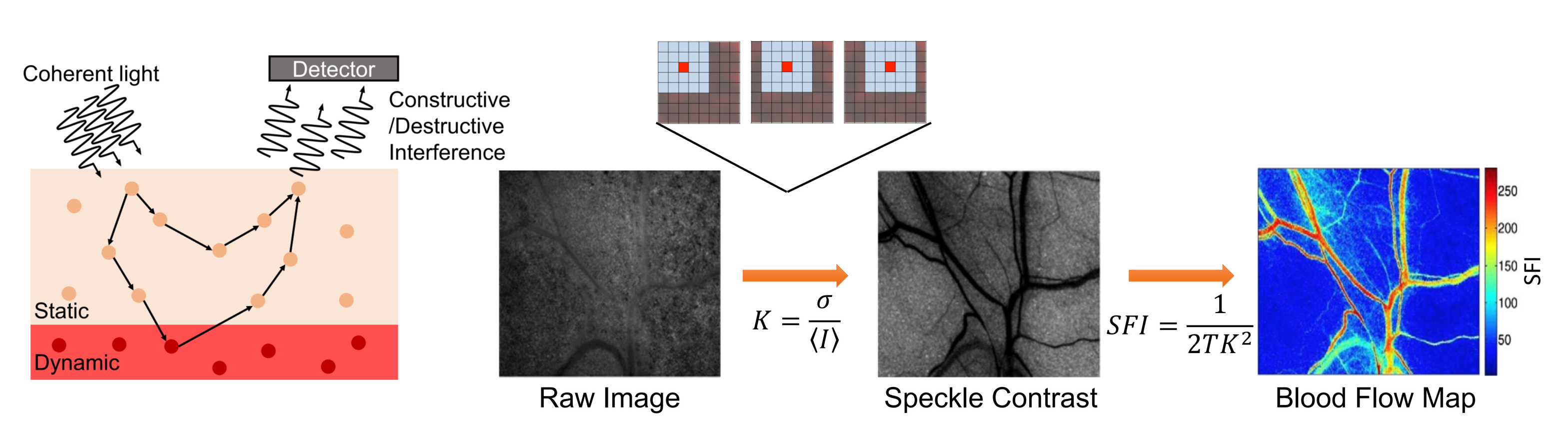
SFDI system parameters

- 5 planar wavelengths centered at: 471, 526, 621, 731 & 851 nm
- 851 nm light modulated (f_x = 0.12 mm^{-1})
- Field of view: 300 x 220 mm
- Acquisition ~ 3 s

LSI System parameters

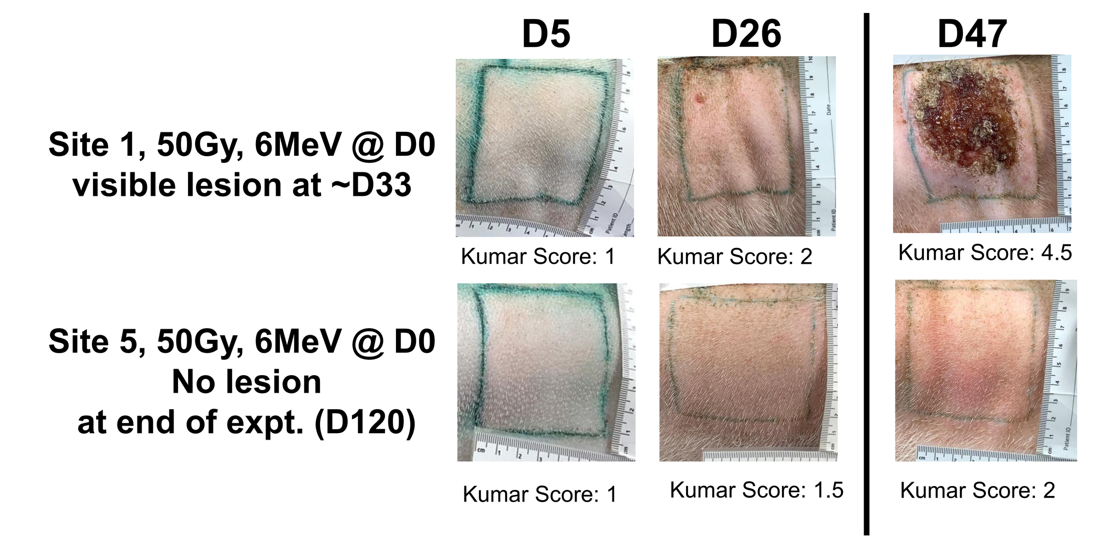
- Laser wavelength: 809 nm
- Field of view: 120 x 175 mm
- Exposure: 20 ms (~ 50 Hz frame rate)
- Acquisition: ~ 2 s (100 frames)

Laser Speckle Imaging (LSI)

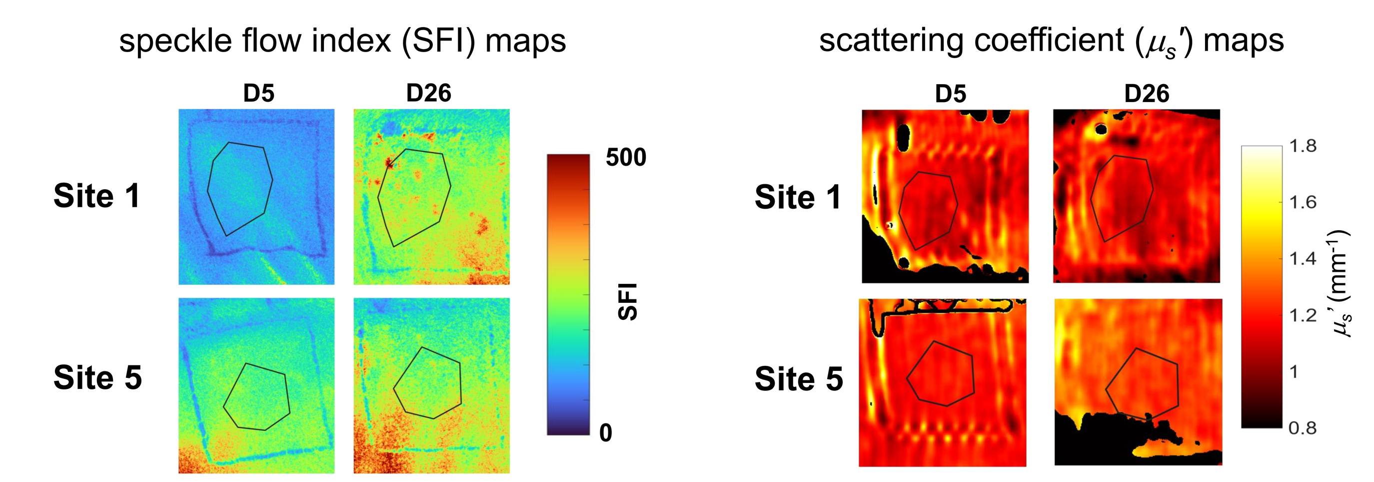


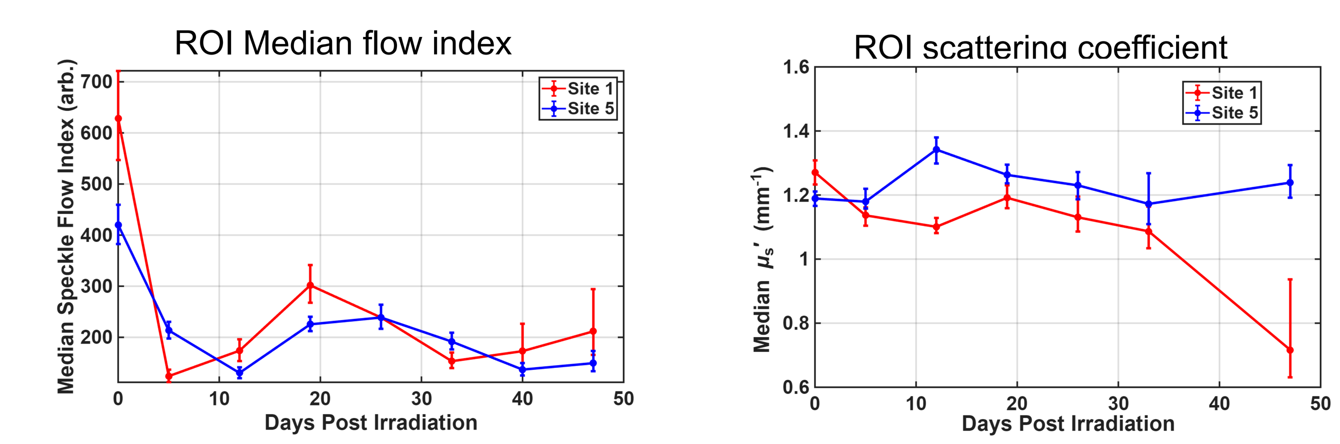
- Coherent laser light reflected from tissue produces a 'grainy' or speckle intensity pattern due to interference caused by scattering from objects in the tissue at different locations and depths.
- If the scattering objects are moving (e.g. blood cells) then the scattering pattern will be dynamic.
- This microscopic motion will cause a blurring of the speckle pattern at the camera.
- The degree of blurring can be calculated by calculating local contrast of the speckle image and converted into flow maps.

Feasibility Study: Imaging Results



Kumar score*	Description
1.0	No effect
1.5	Minimal erythema, mild dry skin
2.0	Moderate erythema, dry skin
2.5	Marked erythema, dry desquamation
3.0	dry desquamation, minimal dry crusting
3.5	dry desquamation, dry crusting, superficial minimal scabbing
4.0	Patchy moist desquamation, moderate scabbing
4.5	Confluent moist desquamation, ulcers, large deep scabs
5.0	Open wound, full thickness skin loss





*Kumar, S. *et al.* Radiation-induced skin injury in the animal model of scleroderma: implications for post-radiotherapy fibrosis. *Radiat Oncol* **3**, 40 (2008).

Summary and Future Directions

- Initial deployment shows promise for detecting objective physiological changes prior to clinical symptoms.
- Preliminary SFDI analysis reveals a decrease in μ_s' at irradiated sites approximately 7–20 days before macroscopic lesions became apparent and Kumar scoring indicated injury, suggesting the system resolves structural changes in the dermal matrix during the latent phase.
- Co-registered LSI data enabled mapping of superficial blood flow, quantifying erythema and has the potential, when combined with SFDI data on oxy- and deoxyhemoglobin concentrations, to provide maps of tissue metabolism.
- Animal experiment refinement. Inclusion of unirradiated control skin region.
- Evaluation of different radiation doses and wound care/treatment regimens.
- Device optimization, ruggedization and miniaturization.

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