Numerical Characterization of Ultrasound Elastography for the Early Detection of Deep Tissue Injuries

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science

by

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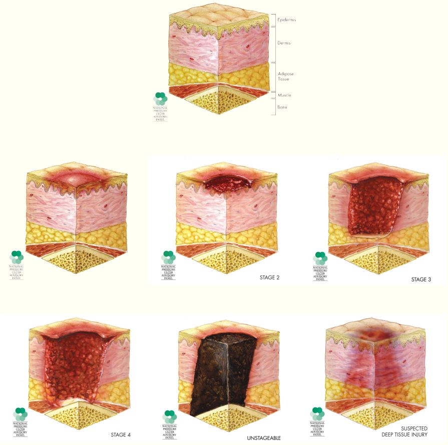
Contents

Introduction

Pressure Ulcers

- Pressure ulcers are secondary injuries
  - People with reduced mobility
- Skin breakdown due to moisture, shear / friction
- Categorized by NPUAP in stages
  - From shallow to deep



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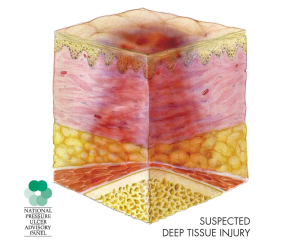
Deep Tissue Injuries

- Not all PU form “top-to-bottom”
  - Deep tissue injuries (DTI) form “bottom-to-top”
  - Eventually break out into stage III – IV pressure ulcers
- Tissue damage due to pressure and deformation
- Almost impossible to detect clinically



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Deep Tissue Injury Detection

- T_2^*-weighted MRI in research settings
- Risk assessment scales in clinical settings
  - Norton, Braden, and Risk Assessment Pressure Sore scales

Filling the Gaps

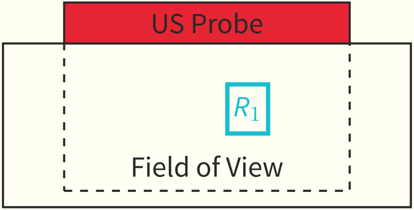
	DTI	B-Mode	QS USE	ARFI	Shear	FEM	Phantom	Animals	Humans	Characterization	Clinical
PU Risk scales	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓
T_2^* MRI	✓	—	—	—	—	✓	✓	✓	✓	✗	✗
Aoi et al.	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓*
Deprez et al.	✓	✗	✓	✗	✗	✓	✓	✓	✗	✗	✓
This work	✓	✗	✓	✓	✓	✓	✓	✗	✗	✓	✓

What?

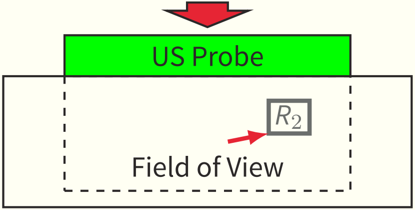
Quasi-Static Ultrasound Elastography

Introduction

- Earliest form of ultrasound elastography
- Apply manual pressure to tissue
  - Measure localized deformation of tissue
- Magnitude of deformation related to stiffness
  - $\downarrow$ deformation $\approx \uparrow$ stiffness $\approx \uparrow$ damage magnitude



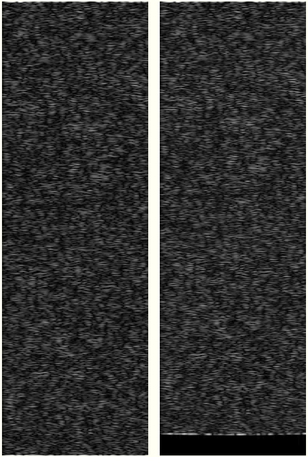
Pre-compression image



Post-compression image

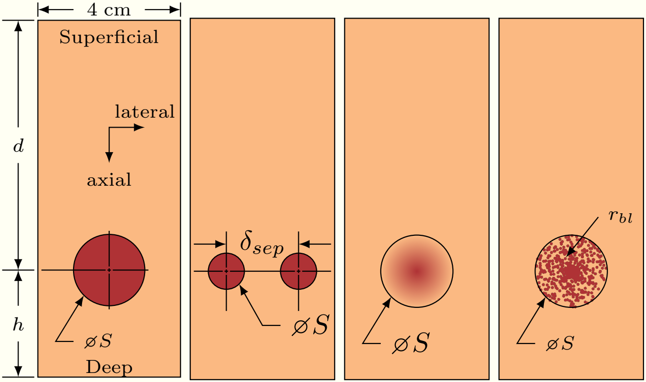
Tracking Localized Deformation

- "Noise" isn't actually noise
  - Scattering centres anchored in tissue
- Track motion of scattering centres between pre/post compression
  - Under assumptions of motion

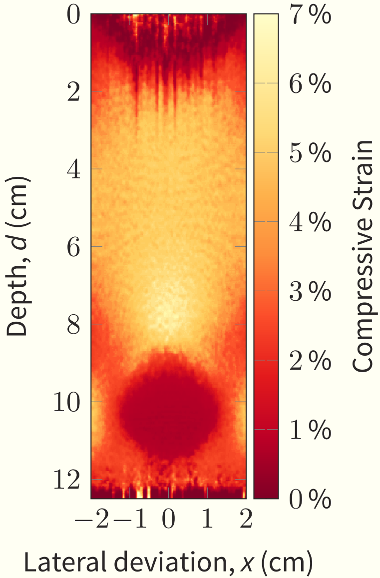


Pre- and Post- Compression B-Mode Images of DTI

Investigated Models



Sample Resultant Elastogram



Sample Characterization Results

- Show 4x4 of characterization plots

Quasi-Static USE Outcomes

- QS USE is capable of DTI detection
- Detection sensitivity less than desirable
- Manual palpation is not ideal
  - Suggest ARFI imaging for machine-induced tissue deformation instead

Acoustic Radiation Force Impulse Imaging

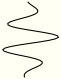
Introduction

- QS USE has low detection sensitivity, manual palpation is difficult and unreliable
- ARFI imaging works on the same principles of QS USE
  - But uses transducer-generated force to displace tissue
- $\uparrow$ repeatability, $\uparrow$ inter-operator reliability
- By imparting acoustic energy to the tissue, body force is generated:

$$\left|\vec{F}\right| = \frac{2\alpha I}{c}$$

How ARFI Imaging Works

- Normal ultrasound is only a couple periods long ($\approx$ 2 ms)



- ARFI imaging uses continuous beams ($\approx$ 100 ms)

- Acoustic energy is absorbed by tissue and causes deformation

Sample ARFI Results

- 4x4 of sample ARFI results

ARFI Imaging Outcomes

- ARFI more reliable than QS USE

Shear Wave Speed Quantification

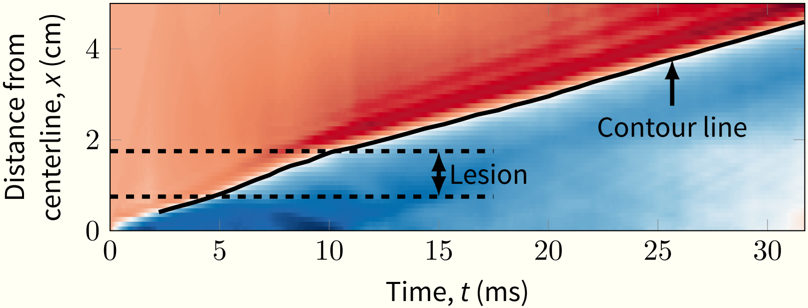
Introduction

- QS USE and ARFI only provide qualitative measures of stiffness
- Measuring shear wave speed allows quantifiable calculation of stiffness
  - Can be used to accurately track over time and give absolute references
- Uses ARFI pulses to generate shear waves in tissue
  - Measure shear wave speed $\rightarrow$ calculate stiffness:

$$c_T = \sqrt{\frac{\mu}{\rho}} \rightarrow \mu = c_T^2 \rho$$

Measuring Shear Wave Speed

1. Induce ARFI at desired depth
   - Shear waves radiate outward, like “ripples in a pond”
2. Monitor deformation along a line extending from the focal point using B-mode
   - Calculate speed of shear wave along this line



Conclusions

Experimental Validations

- Experiments carried out using a Siemens ACUSON S2000™ ultrasound machine with a Siemens 9L4 transducer
- Used a CIRS QA Phantom 049 soft tissue model with stiffness-varying spherical lesions
- Compared parametrically-identical experimental results to simulation
- Got this ($\rightarrow$) characterization curve
- It works!

Comparing Methods

Recommendations

Additional Slides

Additional Slides

- backup 1

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- herp