Three-Dimensional Ultrasound Synovial Blood Flow Volume and Changes with Exercise in Thumb Osteoarthritis

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MOTIVATION

- Basal thumb joint (CMC1) is a **common** site of **hand osteoarthritis (OA)**[1]
  - Causing pain, loss of function, strength, and mobility
- **Inflammation** is a key factor in OA, promoting **angiogenesis** and changes in synovial blood flow[2]
- Vascular changes in OA are associated with **pain** and OA **symptoms**

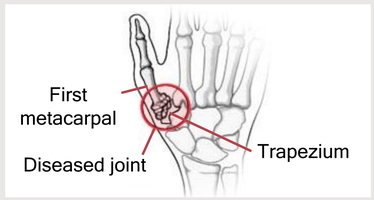

Fig. 1: Anatomy of basal thumb joint.[3]

- Physical therapy treatments improve thumb pain and function[4]
- However, blood flow and vascular changes with exercise are not fully understood in thumb OA

Ultrasound (US)

- US is a non-invasive, point-of-care imaging modality
- Provides **soft tissue** visualization and **blood flow detection** with Doppler methods
- Limitations with 2D US:
  1. High operator dependence[5]
  2. Lack of 3D visualization of the anatomy
- 3D US visualization provides comprehensive visualization of the soft tissues of the joint with 3D quantification

Research Objective: To assess, detect, and quantify synovial blood flow responses to exercise in thumb OA patients using 3D ultrasound (US).

OUR 3D US DEVICE

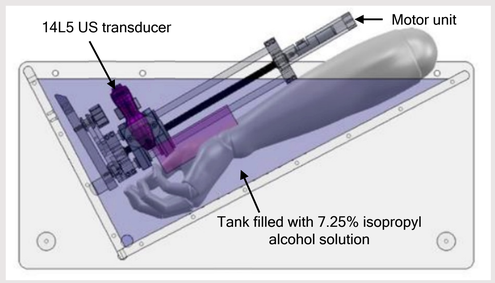

Fig. 2: 3D US hand and wrist imaging system with an attached commercially available US transducer.[6]

- 3D US images acquired by linear motorized motion of the transducer across 5 cm
- Compatible with US Doppler methods, including **Power Doppler** (PD) and **Superb microvascular imaging** (SMI)[7]

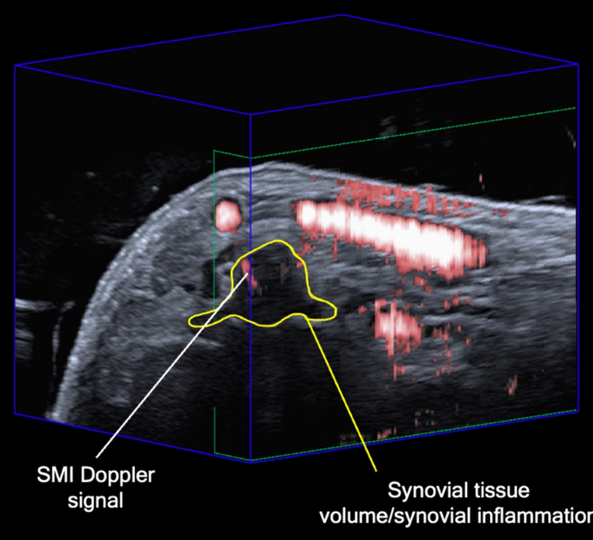

Fig. 3: 3D US SMI Doppler image of a thumb OA patient. Doppler signals are shown as red voxels in the 3D image and the region of synovial tissue volume is outlined in yellow.

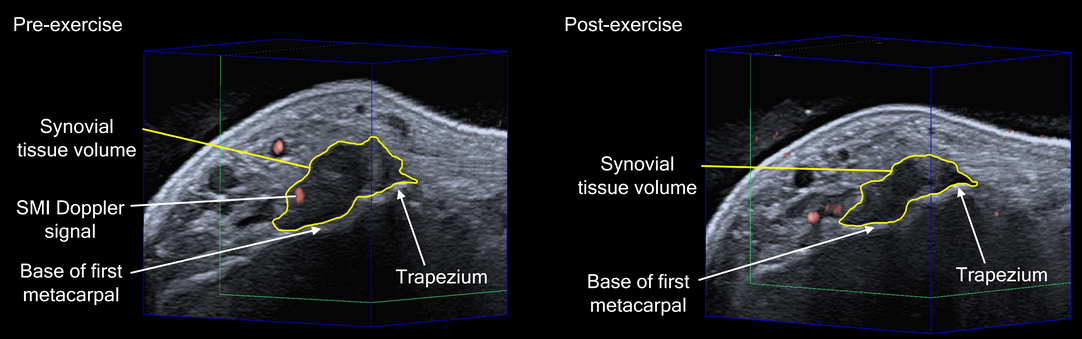

Fig. 4: 3D US Doppler images of thumb OA patient pre- and post-resistance thumb exercises. Doppler signals are shown as red voxels in the 3D image and the region of synovial tissue volume is outlined in yellow.

3D US system can visualize US-detected blood flow in 3D and detect changes with exercise

Table 1: Pain, functional, and 3D US measures of inflammation and blood flow response for thumb OA patients grouped by SMI synovial blood flow detection.

	No Detectable SMI Synovial Blood Flow Volume (n = 8)	Detectable SMI Synovial Blood Flow Volume (n = 5)
Averages		
Synovial Tissue Volume (mm^3)	223.5 ± 81.4	399.0 ± 199.1
Absolute Change in SMI Volume (mm^3)	0.6 ± 0.8	2.5 ± 4.0
PRWE Score	47.9 ± 21.3	25.9 ± 28.6
Pain Pressing Fifth Digit (VAS)	3.9 ± 2.7	2.4 ± 2.6
Pinch Grip	10.1 ± 4.4	12.9 ± 5.3

Differences in 3D US measures of synovial tissue volume, SMI volume change, and pain and functional measures when grouped by SMI blood flow detection

METHODS

Patient Imaging Protocol

- **Thirteen** thumb OA patients were imaged with 3D US using B-mode, PD, and SMI
  - 3D US SMI images were acquired pre- and post-exercise
  - Thumb OA patients performed two **resistance** thumb exercises for thirty seconds each
- **Pain** and **functional** measures were acquired:
  - Patient rated wrist evaluation (PRWE)
  - Pinch grip force
  - Pain pressing fifth digit to thumb (visual analog scale, VAS)

Doppler Signal Quantification

- 3D synovial tissue **volumes** were manually **segmented**
- **Voxels with Doppler** signals were automatically **counted** with software within the segmented regions
- Synovial blood flow volumes were determined for SMI Doppler images

RESULTS

- Thumb OA patient mean synovial blood flow volume was 2.46 ± 3.46 mm^3
- Patients with detectable synovial blood flow with SMI had **higher synovial tissue/synovial inflammation volumes higher changes in SMI volume with exercise, lower pain scores,** and **higher functional scores**

CONCLUSION

- ☑ Detected and quantified thumb OA synovial blood flow volume changes with exercise
- ☑ Different synovial blood flow volumes and changes with exercise in patients with and without **detectable SMI synovial blood flow**

Impact: Our **3D US device** shows potential as a method of **measuring, detecting,** and **monitoring** active joint inflammation and evaluating synovial blood flow changes in thumb OA patients.

Future work:

- Assessing blood flow changes over time and their relationship with pain and disease progression in thumb OA patients

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