



Three-Dimensional Ultrasound Synovial Blood Flow Volume Assessment in Thumb Osteoarthritis Patients

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Abstract—The basal thumb joint is commonly affected by osteoarthritis, which impacts hand function. Inflammation and changes in blood flow are known to be involved in the disease process and progression. The role of inflammation and blood flow in thumb osteoarthritis is not fully understood. Ultrasound imaging is used to assess the soft tissue features of the disease but remains limited to two-dimensional visualization. The development of three-dimensional ultrasound for thumb osteoarthritis assessment provides comprehensive visualization and volumetric measures. This study investigated three-dimensional ultrasound measures and their associations with existing imaging and functional measures of thumb osteoarthritis. Our results showed lower pain and higher functional scores in thumb OA patients with synovial blood flow volumes using Superb microvascular imaging. This work demonstrated differences in pain and functional measures, while radiographic grading of patients with and without synovial blood flow was similar. These quantitative measures of synovial blood flow enable assessment and monitoring of vascular changes within the joint. Further investigation into the three-dimensional blood flow volume measures over time can improve the understanding of blood flow changes and their role in disease progression.

Keywords— Ultrasound, Osteoarthritis, Doppler Imaging, Thumb Joint

INTRODUCTION

The basal thumb joint is a common site of osteoarthritis (OA), causing pain and reduced hand function. Inflammation of the joint lining, synovitis, contributes to pain and progression of OA [1]. This includes blood flow changes and increased stromal vascularization [2]. However, there is limited understanding of the role of angiogenesis in OA and its progression.

Ultrasound (US) imaging provides point-of-care assessment of soft tissue features of OA with inexpensive and fast imaging. US can be used to assess features of synovitis and detect blood flow with Doppler technologies, including Power Doppler (PD) and the novel Superb microvascular imaging (SMI) [3,4]. Doppler assessment techniques are limited to 2D visualization, which limits the assessment of the entire synovial vasculature. 3D US assessment enables comprehensive visualization of the joint and volumetric measures of soft tissue features of the disease, including inflammation. Previous work used 3D US to investigate measures of inflammation in thumb OA patients but did not compare blood flow changes with existing disease measures [5]. Therefore, this work aims to assess 3D US Doppler measures of synovial blood flow and investigate the association of blood flow measures with functional, pain, and existing radiographic measures of thumb OA.

METHODS

3D Ultrasound Imaging System

A 3D US hand and wrist imaging device with Doppler capabilities was developed and used for 3D US image acquisition. The device has a motorized assembly and translates a linear US transducer over a region of interest. The device can acquire conventional B-mode images, as well as Doppler images using PD or SMI. Any commercially available US transducer can be used, and for this work, a 14L5 linear transducer and Canon Aplio i800 US machine were used for 3D US image acquisition. The 3D US images were taken of the dorsal aspect of the basal thumb joint region.

Imaging Protocol and Analysis

Nineteen thumb OA patients were recruited to investigate 3D US quantitative measures of joint inflammation. Study participants provided written informed consent prior to participation and the protocol was approved by the Research Ethics Board at Western University.

3D US B-mode, PD, and SMI images five centimeters in length were acquired. Synovial tissue volumes of all 3D US images were manually segmented every 0.25mm. PD and SMI Doppler signal voxels were automatically counted with software to determine the volumes of the Doppler signal within the synovial tissue volume segmentation (Fig. 1). Functional and patient pain assessments, including pinch grip force, patient rated wrist evaluation (PRWE), and visual analog scale of pain pressing the fifth digit, were completed during the imaging session. Thumb OA patients with and without US-detectable PD and SMI synovial blood flow volumes were compared based on functional measures, pain measures, US synovial tissue volumes, and Eaton-Littler radiographic grades.

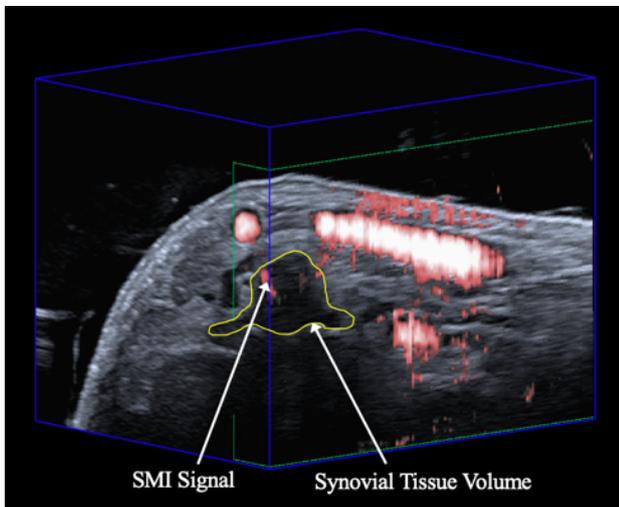


Figure 1: 3D US SMI image of thumb OA patient with outlined synovial tissue volume and SMI signal in red.

RESULTS

3D US Imaging

3D US images were acquired for the thumb OA patients. PD and SMI signals were detected within the region of joint inflammation and 3D blood flow volumes were determined.

Thumb OA patients had an average synovial tissue volume of $280.4 \pm 161.7 \text{ mm}^3$. The patients had an average synovial blood flow volume of $4.71 \pm 7.72 \text{ mm}^3$ with PD imaging and $1.97 \pm 2.96 \text{ mm}^3$ with SMI imaging.

Blood Flow Volume, Pain and Functional Measure Comparison

Differences were observed between thumb OA patients with and without US-detectable SMI synovial blood flow volumes. Twelve thumb OA patients had no detectable SMI synovial blood flow volume, and seven thumb OA patients had detectable SMI synovial blood flow volume. Thumb OA patients with detectable SMI synovial blood flow had higher synovial tissue volumes, higher functional testing scores, and lower pain scores, than patients with no detectable SMI synovial blood flow. Eaton-littler grades remained similar between the two patient groups.

CONCLUSION

In this study, 3D US quantitative measures of synovial blood flow were determined, and differences in pain and functional measures were present in thumb OA patients based on SMI blood flow volumes. Additionally, synovial tissue volumes were higher in the group with detectable synovial blood flow, whereas radiographic scoring remained similar between the two groups. These 3D US blood flow measures will be assessed longitudinally to investigate changes in disease progression and the clinical importance of blood flow assessment in OA. This novel quantitative measure of synovial blood flow may provide clinicians with a method to assess patients' inflammation and increase insight into the vascular changes associated with OA.

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CONFLICT OF INTEREST

Authors M. Hutter, R. Mudathir, C. du Toit, A. Kadar, A. Fenster and E. Lalone disclose their involvement with NovaSonix Healthcare.

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