The Use of Ultrasound to Quantify Soft Tissue Inflammation due to Blunt Trauma

Alexander V. Stotka, Justin A. McMahon, Parker R. Berthelson, Matthew B. Panzer, Robert S. Salzar

I. INTRODUCTION

Following trauma, the body initiates an inflammatory response characterised by increased vascular permeability, white blood cell recruitment, and tissue swelling [1-4]. This response is essential for clearing damaged cells and facilitating the repair process, but it can also contribute to secondary tissue damage if excessive or prolonged [1-3]. One way to assess injury to the soft tissues is the use of medical imaging. Ultrasound is a cost-effective imaging modality that offers short imaging times, making it a valuable tool alongside MRI and CT. Skilled ultrasound technicians can identify haematomas, muscle strains, and assess injury severity within muscles [5-9]. Although ultrasound alone has limitations in diagnosing injuries, its combined use with MRI has proven effective in clinical assessments [5-10].

Quantifying soft tissue inflammation is crucial for assessing injury severity, monitoring the progression of healing, and evaluating the effectiveness of treatments [2-6]. Changes in tissue thickness can serve as an indirect marker of inflammation, helping to distinguish between acute swelling and longer-term structural changes in the soft tissues. This study utilises ultrasound to measure soft tissue thickness in impacted and control regions, including the skin, subcutaneous tissue and superficial muscle, providing insights into the body's response to trauma and recovery timelines.

II. METHODS

Twenty-two (22) anaesthetised porcine specimens (UVA ACUC 4379-12-21; masses: 43.4 ± 3.5 kg) were impacted on the interior of the right hind leg to induce blunt trauma to the skin and underlying soft tissues. The left hind leg was unimpacted to serve as a direct comparison to the impacted right leg and to show how the tissue would behave in an unimpacted state. The impact location was chosen by palpating the hind leg of the specimen to avoid impacting any abdominal organs or skeletal bones and to maximise contact between the indenter and underlying soft tissues. Impact energy ranged from approximately 50 Joules (J) to 180 J, with survival periods ranging from 1 to 30 days after the impact. Specimens were monitored post-impact for signs of discomfort, with systemic analgesics administered as necessary, as determined by attending veterinarians.

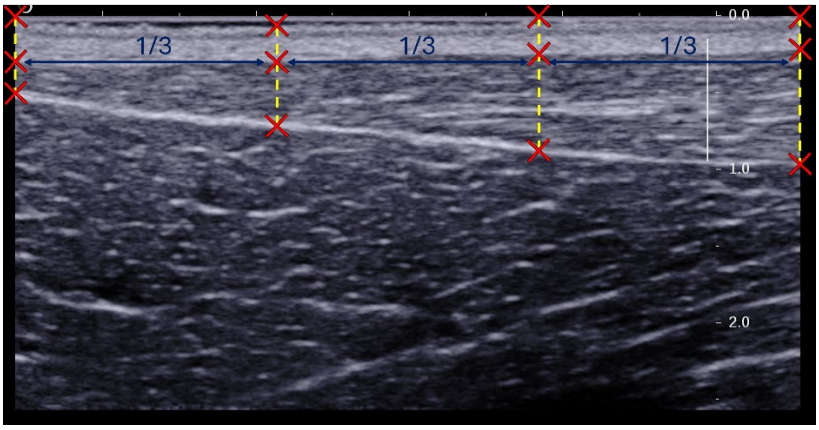

Fig. 1. B-mode ultrasound with tissue thickness measurement locations.

B-mode and shear wave elastography (SWE) ultrasound images were taken at the impact location and an equivalent location on the contralateral leg pre-test, 15 minutes post-test, and on the final day of the survival period. Some specimens had ultrasound images taken at one hour post-impact in addition to the other three

A. V. Stotka (e-mail: qhb9aw@virginia.edu; tel: +1 434-297-8034) is a PhD student, J. A. McMahon is a Mechanical Engineer, P. R. Berthelson is a Mechanical Engineer, M. B. Panzer is the Associate Dean for Graduate Education and Post-Doctoral Affairs, and R. S. Salzar is an Associate Professor in the Mechanical and Aerospace Department at the University of Virginia, USA.

imaging times. Four locations were chosen across the ultrasound image, spaced at equal intervals, to measure tissue thickness. Figure 1 shows these locations, with the yellow line and red X's indicating the points selected to bound the superficial skin and subcutaneous tissue from the underlying muscle (Gracilis). Using the scale bar on the right side of the ultrasound image, thickness measurements were found for the soft tissue at each location.

III. INITIAL FINDINGS

Soft tissue thicknesses across all time points are shown in Table I with the mean and standard deviation (mean ± std) reported. Each specimen had 12 ultrasound images taken of the impact and contralateral location, with four thickness measurements taken per image. Throughout the 30-day survival period, the skin and subcutaneous tissues from the control side (contralateral to the impacted side) remained at approximately the same thickness across all time points. This trend was not observed in the muscle tissue (the Gracilis) of the contralateral side as the average thickness increased by 1.4 mm after 30 days. There is a noticeable change in tissue thickness measurements of the impacted side compared to the contralateral side starting at one hour post-impact. Peak inflammation of the skin/subcutaneous tissue peaks at one day post-impact and Gracilis inflammation has equivalent peaks at one hour and five days post-impact. Impacted Gracilis thickness is statistically different ($p < 0.05$) than the contralateral data for all time points from post-test to 12 days post-impact. By 20 days post-impact, the inflammation within the superficial muscle has resolved and the thickness is similar to control data. Impacted skin/subcutaneous tissue thickness remains statistically different ($p < 0.05$) for all time points from one hour to 20 days post-impact. All soft tissue thicknesses returned to normal by 30 days post-impact, with a marginal increase in average skin/subcutaneous tissue thicknesses and a 1.4 mm increase in average Gracilis thickness.

TABLE I

SOFT TISSUE THICKNESS AVERAGES COLLECTED FROM SWE AND B-MODE ULTRASOUND IMAGES

	Skin and Subcutaneous Tissue Thickness (mm)		Gracilis Thickness (mm)	
	Contralateral	**Impacted**	**Contralateral**	**Impacted**
Pre-Test	2.3 ± 0.3	2.3 ± 0.3	5.0 ± 1.4	5.0 ± 1.7
Post-Test	2.3 ± 0.3	2.5 ± 0.4	5.1 ± 1.4	6.0 ± 2.0*
1 Hour	2.3 ± 0.3	2.9 ± 0.5*	5.1 ± 1.6	7.8 ± 3.3*
1 Day	2.2 ± 0.3	5.3 ± 2.7*	5.2 ± 1.4	6.7 ± 2.4*
5 Days	2.4 ± 0.4	3.8 ± 1.2*	5.1 ± 1.3	7.7 ± 2.9*
12 Days	2.6 ± 0.4	3.1 ± 0.8*	5.9 ± 1.9	6.3 ± 1.9*
20 Days	2.3 ± 0.3	2.9 ± 0.5*	5.9 ± 1.7	5.8 ± 2.3
30 Days	2.4 ± 0.3	2.6 ± 0.3	6.4 ± 1.2	6.4 ± 1.8

Note: thickness measurements that are statistically different ($p < 0.05$) at a given time point are noted with an asterisk (*).

IV. DISCUSSION

Inflammation within the muscle can be seen by approximately 15 minutes post-impact when the second set of ultrasound images are taken, but inflammation within the superficial soft tissues is not seen until one hour post-impact. Skin and subcutaneous inflammation peaks at one day post-impact, with a 141% tissue thickness increase compared to control. Gracilis inflammation has two similar peaks at one hour and five days post-impact with a 53% and 51% increase in tissue thickness, respectively. The inflammation response observed indicates that the Gracilis has a slightly quicker inflammation response than the superficial tissues, but the superficial tissues remain inflamed for a longer time than the Gracilis. All tissues returning to normal thickness when compared to the contralateral side indicates that these injuries will resolve within 30 days post-impact. A further study should investigate how inflammation can vary with impact energy within a predictive soft tissues model.

V. REFERENCES

[1] Smith, C., *et al*., *Am J Sports Med*, 2008.
[2] Shephard, R., *et al*., CJPP, 1998.
[3] Strecker-McGraw, M., *et al*., *Emerg Med Clin N Am*, 2007.
[4] Jarvinen, T., *et al*., *Am J Sports Med*, 2005.
[5] Hayashi, D., *et al*., *Insights into Imaging*, 2012.
[6] Paoletta, M., *et al*., *Medicina*, 2021.
[7] Drakonaki, E., *et al*., *J Ultrasonography*, 2019.
[8] Woodhouse, J., *et al*., Semin Ultrasound CT MR, 2011.
[9] Connell, D., *et al*., *Am J Roentgenol*, 2004.
[10] Miyatani, M., *et al*., *Eur J Appl Physiol*, 2004.