Analysing Deep Tissue Contusions Resulting from Behind Armour Blunt Trauma

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I. INTRODUCTION

Body armour is designed to dissipate the oncoming ballistic energy that would otherwise directly transfer to a soldier's body. This energy dissipation prevents penetrative injuries but can result in significant backface deformation of the body armour into the body. The high-rate loading between the backface armuor surface and the torso may result in serious injuries to the underlying skin and muscles, in addition to physiological and skeletal injuries. This injury mechanism is referred to as behind armour blunt trauma (BABT).

Musculoskeletal injuries account for 23% of combat-related injuries requiring medical evacuation [1]. Deep tissue contusions resulting from both day-to-day activities and combat-related trauma are the fourth most prevalent musculoskeletal injury seen in infantry combat teams [2]. These contusions, while not as life threatening as penetrating injuries or organ damage, may range from minor pain and transient limited mobility to hematoma formation, necrosis, and myositis ossificans [3-4]. In addition, severe contusions pose a significant infection risk, can form osteophytes, and result in volumetric muscle loss that can alter the material properties of the muscle tissue weeks to months after the impact event [3-6]. Current standards for body armour design do not account for different types of injuries and do not address these tissue-level threats. A methodology was developed to define the relationship between BABT induced deep tissue contusions and the rate of healing in tissue mechanical properties. Through a series of *in vivo* simulated BABT impact tests, the tissue mechanical properties and extent of healing over time were tracked up to 30 days post impact.

II. METHODS

Five anesthetised porcine specimens (UVA ACUC 4379; masses: 45.6 ± 3.4 kilograms [kg]) were impacted on the interior of the right hind leg using a common target energy of 150 Joules (J) and survived for varied lengths of time (1, 5, 12, 20, and 30 days). The left hind leg on each specimen was not impacted to serve as a paired control throughout the same survival window. Prior to impact, the target location was selected on the interior of the right hind leg to avoid impingement of the femur and bowel. The target impact location was then positioned with the barrel of the impactor in direct contact with the leg to prevent off-axis motion of the indenter during the test. Specimens were monitored post-impact for signs of discomfort with systemic analgesics administered, as necessary, as determined by attending veterinarians. Shear wave elastography (SWE) and B-mode ultrasound images were taken at the impact location and contralateral hind leg pre-impact, 15 minutes post impact, and on the final day of the survival period.

On the final day of each survival period, specimens were imaged using magnetic resonance imaging (MRI) and then humanely euthanised using Euthasol. Tissue samples (diameter = 10.2 centimeter [cm], depth = 4.5 cm) from impact and contralateral sites were isolated for further mechanical testing. The excised tissue included both the superficial muscle (Gracilis) and the deeper muscle (Semimembranosus). Quasi-static linear indenter tests were conducted at the centre of each impact site, as well as at a similar location on the unimpacted contralateral sample. This test device was equipped with a flat, cylindrical plate (diameter = 2.54 cm) attached to a linear actuator to quasi-statically compress the tissue while recording the compressive force via a load cell. The tissue samples were tested at 25% strain to assess the force-displacement response of the tissue at each survival time. At the completion of mechanical testing, each muscle within the tissue sample was bisected to visually inspect the contusion capsule size within the Gracilis and Semimembranosus.

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III. INITIAL FINDINGS

Quasi-static mechanical testing (25% strain) at the contusion centres of each tissue sample produced distinct mechanical property trends across the range of survival times. As shown in Figure 1, unimpacted tissue samples demonstrated a linear increase in peak force from day 1 to day 30 due to normal growth over time. In the impacted tissue, an initial stiffening response occurred between day 1 and day 5, resulting in significantly higher compressive force than that of the unimpacted tissue at day 5. This stiffening was followed by softening between day 5 and day 12, with a marginal force increase from day 20 to day 30. The peak forces from the impacted samples remained lower than those from the unimpacted tissue from day 12 to day 30, but the force increase from day 20 to day 30 was similar in both samples. Dissection corroborated these trends. On day 1, the contusion capsule involved both the Gracilis and Semimembranosus with a deep red coloured contusion capsule. The contusion capsule moved deeper into the Semimembranosus on day 5 and was not present in the Gracilis on day 12. At each time point, the contusion capsule shrunk in size and became a lighter red discoloration. By day 20, only slight discoloration remained, disappearing by day 30.

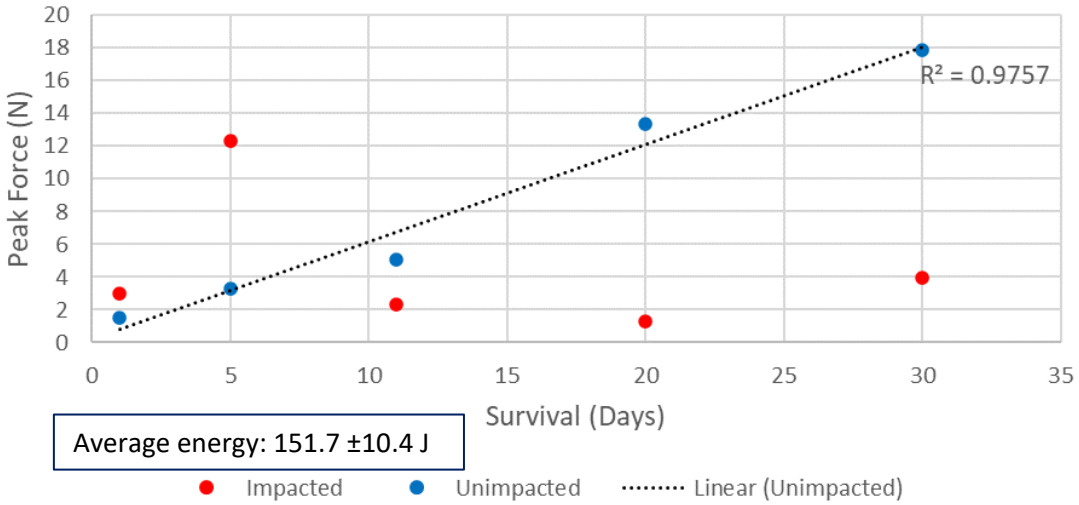

Fig. 1. Peak forces at 25% strain compression test for 150 J target energy impacts.

IV. DISCUSSION

This study developed a methodology for assessing the progression and healing of BABT induced deep tissue injuries. While full muscle stiffness had often not returned to normal within the 30-day period, the mechanical response and dissection indicated the likely healing of the contusion capsule and the beginning of muscle growth between days 20 and 30. By defining the timelines for muscular healing across varied impact energies, return-to-duty timelines may be estimated for Soldiers with BABT-induced deep tissue contusions. Additional analysis of MRI and ultrasound is needed to quantify the size of a contusion capsule and changes in muscle stiffness, respectively, across the survival period.

V. DISCLAIMER

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VI. REFERENCES

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