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Measurement of planar stresses in porcine Achilles tendons using the VIC-EDU digital image correlation system

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ABSTRACT: The validation of finite element results using pointwise measurement through strain gauges or thermocouples is popular in engineering. However, this preferred method presents a serious bottleneck in that finite elemental results are typically full field, yet the analyst must work out the best way to match the results to the pointwise measurements. This is normally done by calculating the average values of the desired quantity over a number of finite elements around the region of interest. It is therefore very hard to achieve good correlation with a high level of confidence. The use of digital image correlation, however, has provided the industry with a much better way of validating the results in that it yields full field measurements. This paper investigates the application of digital image correlation to biological soft tissue. Although it does not report on the finite element validation process, it highlights the challenges that can be encountered when applying the method to biological soft tissue with a special emphasis on producing speckle pattern.

1 INTRODUCTION

During tensile testing of soft biological tissue, it is sometimes necessary to understand the spatial evolution of the stresses on the tested tissue because it allows the accurate characterization of the biological tissues, organs, and their interactions with biomedical devices (Palancă *et al.* 2016). Biological tissues are typically inhomogeneous and anisotropic (Ngwangwa *et al.* 2022; Ngwangwa *et al.* 2024), which means that localized or pointwise measurements, such as those obtained by strain gauges may not be sufficient (Haddadi and Belhabib 2008). Thus, full-field measurements may provide a much clearer picture of the stress state within these tissues. These measurements may also reveal existence of local damages, such as crack initiation. Computationally, full-field measurements provide a much better way of validating finite element analysis results than pointwise measurements (Lava *et al.* 2020).

This paper demonstrates the application of VIC-EDU system for measurement of planar stresses in porcine Achilles tendons, and further highlights the challenges that were encountered in achieving good speckle pattern.

2 MATERIALS AND METHODS

Ten hind leg tendons (two from each animal) were harvested from five different 6 months old Dutch landrace pigs weighing between 50 and 60 kg that were slaughtered at a local abattoir. The limbs were transported in an ice-packed cooler box to the University of South Africa's Biomedical Engineering test laboratory within five-seven hours of slaughter.

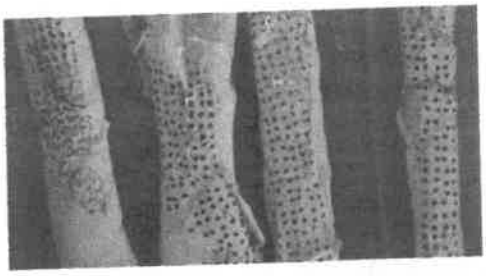

Figure 1. Speckled tendons stored in a saline solution moistened environment to preserve tissue hydration. Notice the challenges with peeling off speckles in the images.

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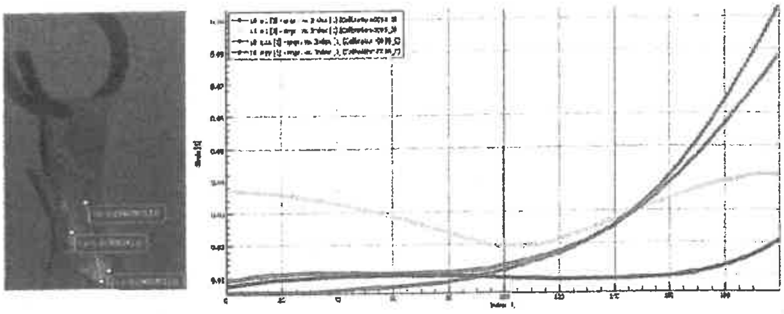

(a) (b)

Figure 2. Full field strain results measured through the VIC-EDU system (a) shows the tissue testing and overplotted strain measurements (b) showing the evolution of principal strains plotted along the slice L0 and L1 shown in (a).

In order to enhance the contrast of the speckle pattern, the specimens were thinly spray painted with speckle paint. A combination of speckling and tissue preservation posed huge challenges as can be observed from the speckling quality on some of the tendons in Figure 1. In the current study the paint was allowed to dry in air for approximately 2h. Acid free permanent waterproof archival black ink was used to speckle the painted side.The system was calibrated using a standard spotted 14 cm x 10 cm target which resulted in achieving an overall standard deviation score of 0.018 with camera 1 and camera 2 residual scores of 0.12 and 0.013, respectively.

3 RESULTS AND DISCUSSION

A ramped load was applied from zero to 80 N. The reported strain results display contour plots in two-dimensions along two line slices (L0 and L1) in Figure 2. The principal engineering strain evolution were shown for both lines while the other two sets represent engineering strains in longitudinal (eyy) and circumferential (exx) directions. The results show that the strains were a maximum at the bottom. According to the line slice L0, the maximum principal strain is around 0.09 while the maximum principal strain along L1 is approximately 0.04 at the bottom of the test tendon. The minimum strain of 0.009 occurred at the top of the specimen. The strain evolution along the two lines shows that from top to bottom, principal engineering strains are much higher along L1 than L0 up to approximately two-thirds of the length of the test region (which is about 147 data points).

Another important observation is that the strain evolution is nonlinear along these slices. For both slices the strain evolutions tend almost exponentially upwards. These results can be used to validate finite element analysis results.

4 CONCLUSIONS

The VIC-EDU system has been successfully used to measure the biaxial and principal strains of the pig tendon tissue. The preparation process for the speckle pattern was particularly challenging for this study since the painting was susceptible to peeling off under excessive moist.conditions while attempting to preserve tissue hydration. New innovative ways for speckling of such tissues are currently under investigation within the team.

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