The influence of sample dimension on apparent dynamic stress strain behaviour in passive skeletal muscle

Hannah Kilroy, Michael Takaza & Ciaran K Simms*

I. INTRODUCTION

The dynamic properties of passive skeletal muscle are important for human body finite element models. Muscle accounts for around 40 to 50% of body weight, and the deformation properties of the tissue determine how loads are transmitted to the bones and organs. Finite element models need both constitutive models for muscle and parameters for these models, and both of these have been the focus of recent research. Due to the complex geometry in vivo, ex vivo tests using simplified cuboid geometries are usually used in drop testing rigs [1-2]. However, the structure of skeletal muscle includes fascicles which are at a length scale of around five millimeters, and recent quasi-static testing has shown that the effective stiffness of samples of 1 cm cubed characteristic length is significantly lower than for cubic samples of 3 cm characteristic length, the latter being a better representation of the tissue in vivo [3]. Accordingly, the goal of this work was to assess whether similar sample dimension effects are observed during dynamic compression testing at rates relevant to automotive impacts.

II. METHODS

Drop tower compression testing of isolated aged porcine muscle samples was performed using a custom designed rig [1], with the impact direction aligned perpendicular to the muscle fibre direction. The compression force was measured using an upper and lower load cell, while the sample strain was measured using optical methods. Samples had a characteristic length of either 1, 2 or 3 cm^3 as shown in Table 1.

Sample Dimension	*N*	Average Impact Velocity (m/s)	Specimen height (cm)	Average Strain Rate (%/s)
1 cm^3	11	1.30 ± 0.08	1	12,991 ± 775
2 cm^3	11	2.46 ± 0.15	2	12,220 ± 795
3 cm^3	11	3.63 ± 0.21	3	12,106 ± 685

Table 1: Test matrix for muscle sample drop tower tests

III. INITIAL FINDINGS

Typical high-speed images of an undeformed and deformed sample are shown in Figure 1.

(a) (b)

Figure 1: Typical high-speed image of an undeformed (a) and 50% deformed (b) sample: (2 cm^3 case).

The corresponding estimated engineering stresses at 50% compression are shown in Figure 2.

*Hannah Kilroy is an MAI Student in Engineering at Trinity College Dublin, Ireland; Michael Takaza is a Ph.D. student in Engineering at Trinity College Dublin; Ciaran Simms is Assistant Professor in the School of Engineering and PI in the Centre for Bioengineering at Trinity College Dublin (ph: 0035318963768, fax: 0035316795554, csimms@tcd.ie).

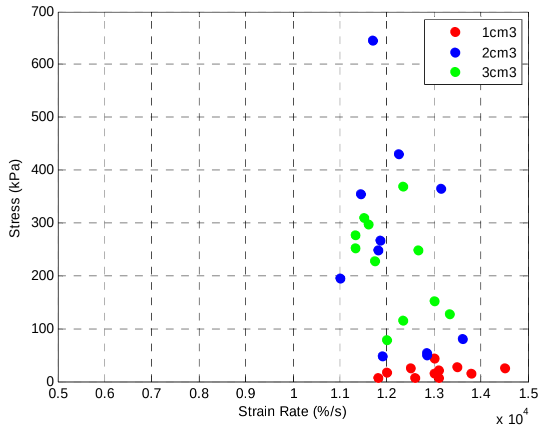

Figure 2. Between-sample engineering stress versus strain rate variation at 50% compression for 1 cm^3, 2 cm^3 and 3 cm^3.

DISCUSSION

The dynamic test results indicate clearly that the apparent stiffness of the tissue increases as the sample size changes from 1 cm^3 to 3 cm^3. Analysis shows that this is not due to the increased inertia effects on the sample, but it does correspond to a smaller percentage of fluid exudation for the larger samples compared to the smaller ones. Larger samples also include a greater number of complete fascicles, and this can also affect the results. Although the tests were performed on aged tissue, and further testing is required on fresh tissue, it is suggested that estimating the stiffness of skeletal muscle using ex vivo samples should be done on the basis of samples that are at least 2 cm^3 in characteristic dimension.

IV. References

[1] Takaza M et al, IRCOBI Proceedings 2012.
[2] Chawla A et al, Biomech Model Mechanobiol, 2009
[3] Blackburn et al, World Congress of Biomechanics, 2014