MEASUREMENTS OF THE MECHANICAL PROPERTIES OF SKELETAL MUSCLE BY ULTRASONIC ELASTOGRAPHY AND SHEARING TESTS

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Introduction

Several experimental studies have investigated mechanical properties of skeletal muscle using *in vitro* or *in vivo* tests [1, 2]. Note that these experimental protocols lead disparate results often due to experimental protocols [3]. To our knowledge, there is few mechanical characterization studies comparing *in vivo* and *in vitro* approaches on the same skeletal muscles.

The objective of this study was to investigated the stiffness of rat flexor carpis ulnaris muscle from shear elastography wave (SWE) (*in vivo*) and pure shear tests (*in vitro*).

Methods

Seven male rats of Wistar strain aged 8 weeks were used in this study. SWE measurements were performed on flexor carpis ulnaris *in vivo* during three conditions: i) the left foreleg was placed 45° from the axis of the body, ii) the elbow was flexed at 90° and, iii) the probe was parallel to the myofibers. Then, mechanical tests were performed on muscle samples (taken from these same rat) based on pure shear tests. Myofibers were orientated parallel to the loading. The hyperelastic Ogden's model was used to identify the mechanical behavior of skeletal muscle *in vitro* [2] :

$$W(\lambda_1, \lambda_2, \lambda_3) = \sum_{p=1}^{N} \frac{\mu_p}{\alpha_p} \left(\lambda_1^{\alpha_p} + \lambda_2^{\alpha_p} + \lambda_3^{\alpha_p} - 3\right)$$

The shear modulus obtained by mechanical tests in vitro is given by : $\mu = \mu_1 \alpha_1 / 2$

Results

Ultrasound acquisition allows to visualize with more precision the different muscles of the rat's forelimb and to obtain a cartography of shear modulus for the whole muscle (Figure 1). Regarding the mechanical test, pure shear responses of FCU muscles are shown in Figure 2 and obtained when muscles fibers were oriented in parallel to the loading. In the first order Ogden's model case, the identification of mechanicals parameters were obtained by an inverse method (Table 1). The ANOVA analysis shown that the difference is not significative (p=0.08).

(n=7)	From SWE measurements	From mechanical shear tests
$\mu\ (kPa)$	5,48 $\pm$ 0,42	4,17 $\pm$ 1,68

Table 1: Shear modulus obtained from SWE (in vivo), and mechanical tests (in vitro) by using first order Ogden's model.

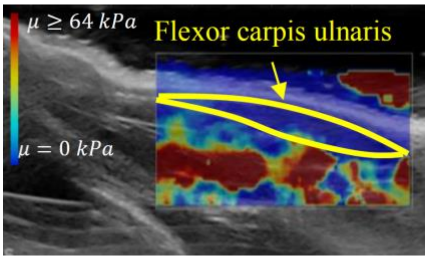

Figure 1: Cartography of shear modulus obtained by SWE on the healthy flexor carpis ulnaris of rat.

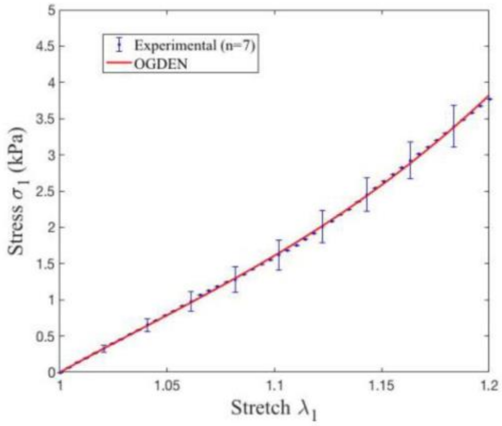

Figure 2: Stress-stretch fitting using first order Ogden's model for pure shear testing.

Discussion

The objective of this study was to compare the mechanical properties of skeletal muscle obtained by SWE and pure shear mechanical testings. The measurements shown a difference about 24% between in vivo and in vitro approaches. This result is probably due to the type of used muscles that doesn't exhibit the lowest variability in measurements. Furthermore, the boundary conditions for pure shearing test should be improved. Thus, we argue that used methodology is important to optimize the mechanical properties measurements of skeletal muscle even isotropy assumption was made in this study.

References

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3. Eby et al., J. Biomech, 46, 2381-2387, 2013.

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