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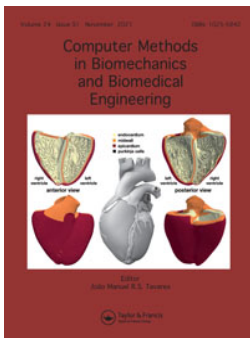
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## Fascia lata mechanical properties during shear tests: preliminary study

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### 1. Introduction

Over the past few years, researches have been conducted to prove the role of deep fascia in transmitting forces between muscles, making those connective tissues important in the management of many acute and/or chronic musculoskeletal disorders. To better understand its mechanical behaviour in relationship with its microstructure, many studies based on ex-vivo experimental characterization of the fascia lata of the thigh have been conducted. Fascia lata is composed of bi-layered and bi-oriented fibres network (Pancheri et al. 2014) which is responsible of its anisotropic and non-linear mechanical response. Mechanical tests on fascia lata samples are mainly performed in tension along either longitudinal or transversal direction based on an anisotropic description of fibres' families (Pancheri et al. 2014). Recently, Sednieva et al. (2020) showed the presence of shear mechanism on the ilio-tibial band (i.e. part of fascia lata) during knee flexion-extension movement. In this study, we can also notice the lack of adequation between the directions of the principal strains relatively to the orientations of visible fibres' families on the ilio-tibial band. To the best of our knowledge the only shear test analysis made on fascia lata samples was performed by Ruiz-Alejos et al. (2016). They performed pure shear tests consisting in uniaxial tests on a large strip of tissue. The present preliminary study proposes similar shear tests performed on fascia lata, and a preliminary analysis of fibres kinematics during such loading.

### 2. Methods

#### 2.1. Material

An entire fascia lata was collected from the thigh of a Post Mortem Human Subjects (female, 90 yo) involved in a previous analysis (Sednieva et al. 2020). The tissue was kept frozen before testing. When

thawed, one sample was cut as a rectangle strip such as the width is bigger than the length,  $70 \times 30$ mm here. The thickness of the sample, measured with a calliper, was 0.4mm. Care was also taken so that the tensile direction of the sample was the bisector of the angle between the two fibres' families seen at the macroscopic scale.

#### 2.2. Loading methods

Shear tests (or large band tests, LB) were performed using an INSTRON 8802 (High Wycombe, England) machine with a 250N load cell (accuracy of 0.1%). In order to prevent any slippage, the sample was clamped with emery cloth which changes the area of interest size to  $70 \times 14.55$ mm. For this test, 10 loading-unloading cycles were applied along the y direction (Figure 2a and b). For each cycle, a global tensile strain of 10% was applied at a maximum strain rate of  $0.11 \text{ s}^{-1}$ , as already performed by Ruiz-Alejos et al. (2016). The nominal stress was computed from the initial load and the measured initial section.

#### 2.3. Fibres' kinematics analyses

First, the kinematics of the fibres' families, which were visible on the fascia lata was observed during tension. The sample was imaged with a Photron SA3 camera. The light was adjusted to optimize image quality and to enhance the fibres' contrast. The images of the fibres network were analysed with the software OrientationJ, National Institute of Health at 0% strain and at 10% strain of each cycle.

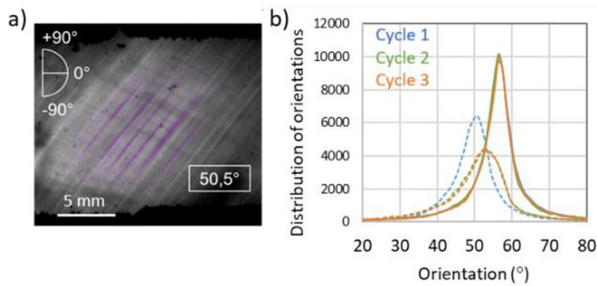
#### 2.4. Strain field measurement

Then, the surface strain measurement was performed by Digital Image Correlation (DIC). The sample was speckled with black paint and filmed with two Photron SA3 cameras. DIC was performed with the software Vic3D 8, Correlated Solution ® to analyse mainly major and minor principal strains distribution on the entire sample and in its central area (noted R0).

### 3. Results and discussion

#### 3.1. Fibres kinematics

As fascia presents two visible directions of fibres, it was expected to identify two main fibres distributions, corresponding to two peaks. However, only one main direction could be highlighted which corresponds to the dense fibres' family. The other fibres were partly detected (Figure 1a and b). The orientation of the detected fibres is changing with the global



**Figure 1.** Analysis of the fibres orientation: a) image of the sample and the detected fibres (purple) for a 0% strain state; b) Distribution of fibres orientation at different deformation state and for different cycles: dotted line, 0% strain; continuous line, 10% strain.

deformation (Figure 1b). The higher the deformation was, the bigger the distribution of one preferred orientation was, which illustrates that fibres tend to align in one direction when the tissue is towed in that direction as already observed in other studies (Jayyosi et al. 2016).

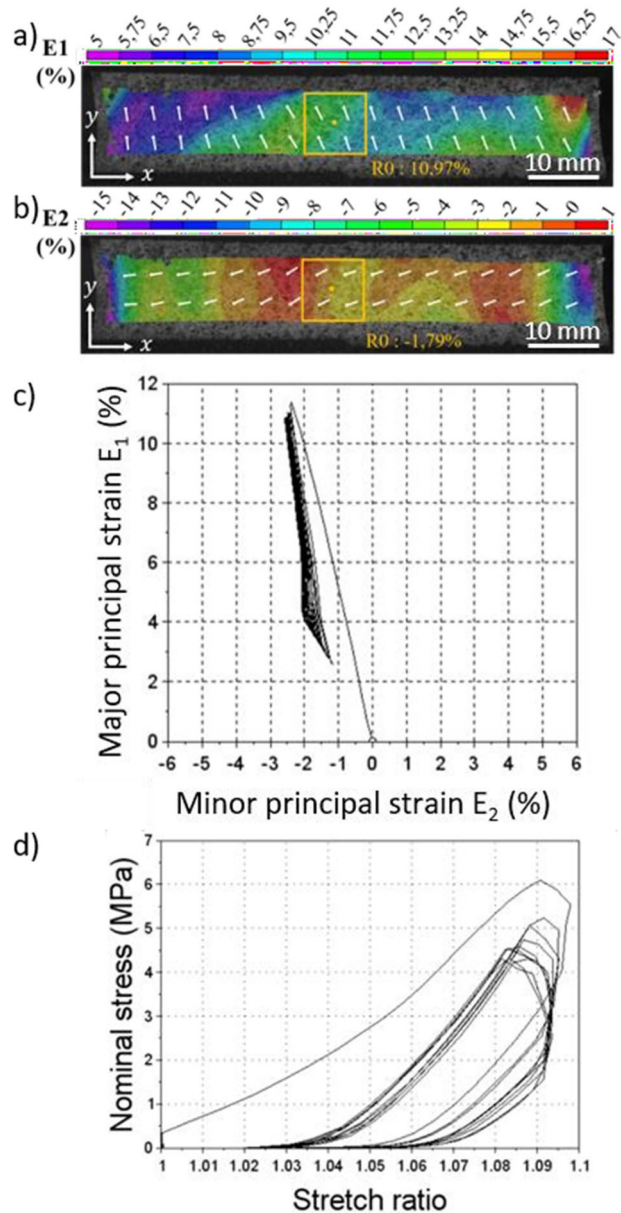
It can also be highlighted (Figure 1b) that the first cycle was different from the others. The main orientation angle was  $50.5^\circ$  at the beginning of the first cycle while it was in average  $53.3^\circ$  for the other cycles. At the maximum strain of the ten cycles, it was always  $56.5^\circ$ .

Finally, the difficulty of tracking the two fibres' families may be caused by shadows on the sample where fat was not entirely detached from the fascia. The quality of the fibres network imaging and analysis is currently being improved with ongoing test.

### 3.2. Strain fields and stress-strain curve

Strain field analysis is shown in Figure 2a and b. On Figure 2c, it can be seen that the amplitude of the principal minor deformation  $E_2$  is small compared to the major one  $E_1$ . After the first cycle, the sample does not recover its initial strain state with a remaining  $E_1$  close to 3% and  $E_2$  close to -1%, suggesting an irreversible damage or structural effect in the tissue. The relationship between these residual strains observed with DIC and fibres orientation could be therefore interesting to investigate.

We applied a global stretch ratio of 1.10 along the bisector of the two visible fibres' families (Figure 2d). For 1.06 stretch ratio, the nominal stress was 1.5 MPa (corresponding to a force of 42N) while it was 0.9 MPa in Ruiz-Alejos et al. (2016). Therefore, the apparent stiffness that we observed along the bisector direction is higher than the one they obtained in the longitudinal direction of their sample, which corresponds to the more dense fibre family.



**Figure 2.** Green-Lagrange strain fields for a 10% global tensile strain: a) Major principal strain  $E_1$ ; b) Minor principal strain  $E_2$ , (white arrows give strain directions, the sample central area is noted  $R_0$ ); c)  $E_1$  versus  $E_2$  curve, d) Stress-stretch curve obtained for the central area.

## 4. Conclusions

This preliminary study is a first step towards the analysis of the deep fascia behaviour under shear loading. It allowed a first comparison with results from Ruiz-Alejos et al. (2016) and proposed a first analysis of fibre kinematics at the macroscopic level.

Such a shear test does not mimic what has been observed in situ by Sednieva et al. (2020) during knee flexion-extension. The kinematics of the fibres also confirmed the fact that the network tends to align in one direction as the deformation increases. Other studies are

currently being conducted to perform series of other shear tests such as Bias Extension tests. The images analysis is also being improved in order to visualize both orientations of the fibres.

### Disclosure statement

No potential conflict of interest was reported by the authors.

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**KEYWORDS** Fascia; ex-vivo experiments; shear tests; digital image correlation; fibre kinematics

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