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INFLUENCE OF THE BIOLOGICAL ORIGIN OF THE LIVER ON THE CONSTITUTIVE AND FAILURE PROPERTIES OF THE HEPATIC PARENCHYMA

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SUMMARY

The aim of this study is to investigate the influence of the biological origin and the preservation method (freezing or not) on the hepatic parenchyma mechanical properties. Uniaxial tensile tests are conducted on human and porcine liver samples to characterize the parenchyma constitutive and failure properties. A statistical analysis revealed that the ultimate true stress is significantly higher on porcine parenchyma; the modulus also seems to be affected. For both origins, the ultimate stress is clearly modified by freezing. Microstructure observations revealed a large difference between porcine and human parenchymas' failure mechanisms, explaining the gap between the ultimate stresses. Using porcine parenchyma to mimic human parenchyma is therefore not satisfactory, especially in terms of failure properties.

INTRODUCTION

Predicting the occurrence of liver injuries is an important matter in the field on transport safety and requires knowledge about the failure properties of the hepatic tissues. In particular, literature provides data about the parenchyma behavior [1,2] but very few about its failure [3]. Potentialities of animal testing lead often to study animal tissues before extrapolation to human tissues, thus most of the available data have been determined on animal livers, especially porcine livers [4]. Moreover, testing soft tissues being complicated leads to the use of freezing in many cases, but the influence of this preservation method is not clear yet [2,3]. This work aims at comparing human and porcine parenchyma in terms of mechanical properties, particularly at failure, and in terms of microstructure. The influence of freezing on the tissue is also investigated.

METHODS

Seven adult pig livers were obtained from the local butchery, within 4 or 5 days after euthanasia. Four livers were removed from post-mortem human subjects (PMHS) from the Department of Anatomy of University of Lyon through the French voluntary corpse donation to science program. In both cases, the whole livers or parts of them were either stored in the freezer until the cutting phase (from 24h to a few days, -18°C), or immediately cut into samples and tested within 5

days after death. Two types of I-shape samples were cut from the livers: parenchyma samples and samples made of parenchyma and capsule ("bimaterial" sample). As described on Figure 2, the failure mechanism of bimaterial samples allowed characterizing both capsule [5] and parenchyma.

The two ends of the sample were clamped; sliding was prevented by using sand-paper stuck on the clamps. Clamps were set up vertically on a Deltalab® EM550 electromechanical testing machine. Samples were loaded until complete failure with a displacement speed of 0.5mm/s, which implied a range of longitudinal strain rate of 10^{-3} to 10^{-2} s⁻¹ depending on the sample initial length, remaining in quasi-static domain. Elongation of the sample on the front and the side faces was recorded with two Visario® 1500 Speed Cam digital video cameras (Figure 1). Clamp-to-clamp displacement and tensile load on the upper clamp were measured by using a cable actuated position sensor and a 3daN-single point load cell.

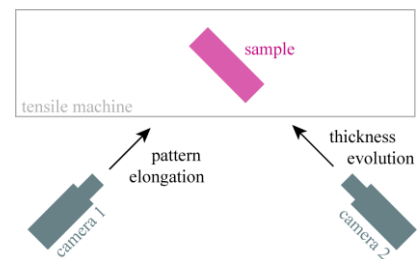


Figure 1: Upper view of the experimental setup.

Constitutive and failure properties of human and porcine parenchymas were compared using a Mann-Whitney test. Significant differences were considered for $p < 0.05$.

For microstructure observation, histological slices of parenchyma were made after testing to observe specifically the failure area (Figure 4).

RESULTS AND DISCUSSION

Figure 2 illustrates the response of bimaterial samples: once the capsule is completely broken, the remaining tissue on the capsule failure area is only parenchyma.

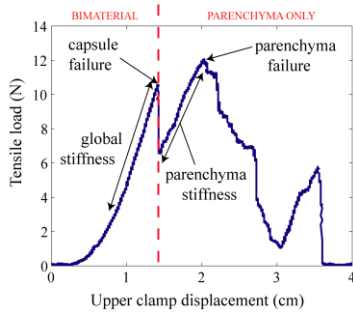


Figure 2: Failure mechanism of the bimaterial samples.

The ratio of load sustained by the parenchyma at the capsule failure is supposed to be the same during all the bimaterial elongation, and the parenchyma geometry during the test is caught by the video cameras. True stress ($\frac{\text{longitudinal force}}{\text{current section}}$) and global strain ($\frac{L-L_0}{L_0}$) can be determined for both types of samples (Figure 3). The stress vs. strain curves exhibit a typical toe-region that can be found in many biological soft tissues. The linear part occurring after this toe-region allows the determination of the modulus, which values are displayed in Table 1. Ultimate Green-Lagrange longitudinal strain and ultimate true stress were also measured.

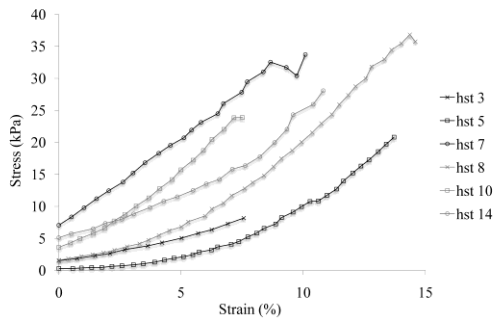


Figure 3: True stress versus global strain for a human liver

Statistical test shows that porcine and human parenchymas are significantly different in terms of ultimate stress. It is also true for the modulus but the smaller amount of samples does not allow drawing a strong conclusion. In addition, for both porcine and human parenchyma, freezing the tissue

Table 1: Mechanical parameters determined on human and porcine parenchyma; values with the same superscript are significantly different with respect to the changing parameter (e.g. ^(a)): porcine fresh parenchyma modulus is significantly higher than human fresh parenchyma modulus).

	Biological origin	Fresh	Number of samples	Frozen	Number of samples
Modulus (kPa)	Human	420 ± 188 ^(a)	16	356 ± 163 ^(b)	15
	Porcine	1384 ± 582 ^(a)	9	1780 ± 732 ^(b)	4
Ultimate strain (%)	Human	16.4 ± 3.9	18	15.3 ± 5.2	16
	Porcine	15.8 ± 3.5	19	18.4 ± 6.0	16
Ultimate stress (kPa)	Human	60 ± 22 ^(c,d)	28	51 ± 37 ^(c,f)	36
	Porcine	82 ± 51 ^(e,d)	40	113 ± 68 ^(e,f)	39

significantly affects its ultimate stress. The difference in term of ultimate stress can be explained by the microstructure (Figure 4): the failure propagates through the connective tissue surrounding the lobules in the porcine parenchyma, while it goes through the lobules in the human parenchyma, so the type of tissues involved in the failure (connective vs. epithelium) is different.

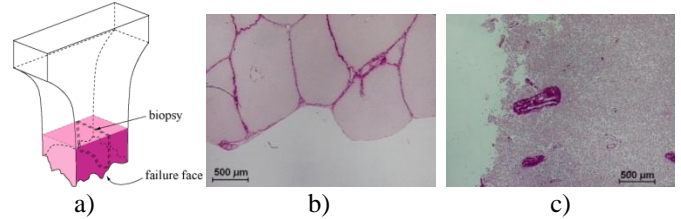


Figure 4: Parenchyma failure mechanism at the microscale: a) Biopsy sampling – b) Porcine parenchyma – c) Human parenchyma

CONCLUSIONS

This work shows that using porcine liver to mimic the mechanical properties of human liver parenchyma is not satisfactory in terms of modulus and ultimate stress, which can be explained by microstructure differences. Freezing the tissue affects significantly the ultimate stress in both human and porcine tissues.

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