Longitudinal and circumferential mechanical behavior of human cerebral artery

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LONGITUDINAL AND CIRCUMFERENTIAL MECHANICAL BEHAVIOR OF HUMAN CEREBRAL ARTERY

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Introduction

The prevalence of unruptured intracranial aneurysms in the general population, as reported by a recent review [Wardlaw, 2000], ranges between 3% and 6.6%. However, the incidence of ruptured aneurysms is low, with approximately 0.5% per year, suggesting that very few aneurysms rupture. Clearly, new patient-specific indexes predicting aneurysm risk of rupture should be proposed, in order to guide therapeutic decision for unruptured aneurysm.

Previously, we showed that aneurismal pulsatility might be a relevant patient-specific predictor of aneurysm risk of rupture [Sanchez, 2013], as the pulsability showed to provide information on the degradation of the mechanical properties of ruptured aneurism tissue. However, the biomechanical properties of healthy arteries of circle of Willis are poorly reported. In this study, we attempted to identify the biomechanical behavior of healthy intracranial artery taken from autopsied subjects.

Materials and methods

Five circle of Willis were taken from 5 autopsied subjects who died from an extra-cranial cause. Their ages ranges from 30 to 80 years. This research study protocol was approved by the local ethic committee. From all circle of Willis, 16 segment of artery was used in this study.

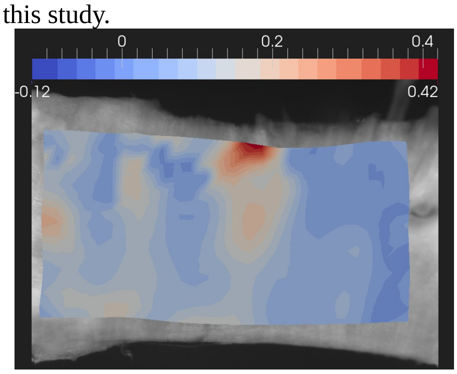

Figure 1: Green Lagrange strain from DIC.

Under microscopy, the aneurysmal wall samples were dissected in a longitudinal direction and circumferential direction to obtain two regular rectangular pieces (Fig.1). A uniaxial stretch test was carried out on the sample within the warmed (40°C) physiological liquid in order to simulate the in vivo conditions. This testing device was composed of a Texture Analyzer with a 50 N load cell and two digital video camera to compute a DIC analysis (Fig.1).

To obtain the strain/stress relation, we proceed to a mathematical matching to determine the corresponding hyperelastic model and its coefficients. In our cases, the best match was obtained with a 2 parameters Yeoh model (eq. 1) :

$$W(I_1)=C_1(I_1-3)+C_2(I_1-3)^2 \qquad (1)$$

Results and discussion

The mechanical behaviors in the longitudinal and circumferential directions are significantly different (Tab. 1) for healthy arteries, indicating a fibrous, structured soft tissue. Indeed, the mechanical behavior is stiffer in the longitudinal direction than in the circumferential direction, in agreement with other studies [Hu, 2007].

We also compared the mean stiffness's of the healthy arteries to the stiffness's of the aneurysmal tissue. We found a significant difference (p=0.01), with a mean reduction factor of 2.8 on parameter C_2 between healthy artery and aneurysmal tissue, suggesting a more linear behavior in the aneurysmal tissue.

Table 1: C_1 and C_2 coefficients from human cerebral artery with interval confidence (95%).

Direction	C_1 [Mpa]	C_2 [Mpa]
Longitudinal	0.2 ± 0.11	12.3 ± 7.35
Circumferential	0.1 ± 0.06	4.4 ± 3.21
p value	0.1152	0.0365 *

Conclusion

Variations of the biomechanical properties was found between aneuvrysmal tissue and healthy artery tissue. First, a significant reduction of the stiffness was found, in particular concerning the C_2 parameter in the Yeoh model used between healhty and degradated tissue, suggesting that the aneurysm has a more linear behavior then healthy tissue. Second, the mechanical behavior of degrated tissue is close to the mechanical behavior of circumferential direction of healthy arteries.

References

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