

MULTIAXIAL RESPONSE OF HUMAN CEREBRAL ARTERIES

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INTRODUCTION

Head trauma frequently involves damage to the cerebral blood vessels (Graham, 1996), and even when the vessels are not damaged, evidence from recent studies suggests that they contribute to the overall response of the brain as a vital piece of its composite structure (Zhang et al, 2002; Parnaik et al, 2004). Thus, characterization of cerebral vessel mechanical response is a necessary step in the development of more accurate models of traumatic brain injury (TBI). Though it was limited to tests in the axial direction, a recent study of these vessels found that the arteries are significantly stiffer than the veins, and that they fail at a lower level of stretch (Monson et al, 2003). On the subject of TBI, then, the arteries are believed to be the more important vessel to characterize – outside of the critical role of the bridging veins in the production of subdural hematoma – and are the focus of this study.

Previous investigations of the mechanical behavior of human cerebral arteries are few and generally focus on a single direction of loading, usually consistent with the particular problem motivating the study, rather than on multi-axial response. While it is believed that axial stretch is the primary mode of vessel deformation in TBI, it is important to define how stretch is influenced by internal pressurization. Data reported here define this effect and pave the way for the development of constitutive relations appropriate for study of TBI as well as other problems involving the cerebral vasculature.

METHODS

Five arteries were obtained from the surface of the temporal lobe in patients undergoing temporal lobectomy for the treatment of epilepsy. Accompanying tissue was carefully dissected away under a microscope, and vessel branches were occluded by tying with suture. Microspheres were positioned along the length of each specimen to allow tracking of deformation through video. The ends of each vessel were then cannulated with needles and attached to a custom device capable of controlling both axial stretch and internal pressure and were subjected to various load combinations within the physiological range. All experiments were conducted at quasi-static rates.

Axial force and internal pressure data, along with cross-sectional information and video measurements of axial motion and diameter, were used to calculate mean stretch and Cauchy stress values in the axial and circumferential directions. The radially-cut, zero-stress section was used as the reference configuration, and incompressibility was assumed. Stiffness values – defined as $\Delta(\text{stress}) / \Delta(\text{stretch})$ – around in situ loading conditions were calculated and compared for the two directions of loading.

RESULTS AND DISCUSSION

Data from experiments consisting of tests both where axial stretch was held constant at various levels while internal pressure was increased and where internal pressure was

held approximately constant while axial stretch was increased demonstrate an interdependence between the axial and circumferential behaviors (**Figure 1**), with increased constant stretch in one direction

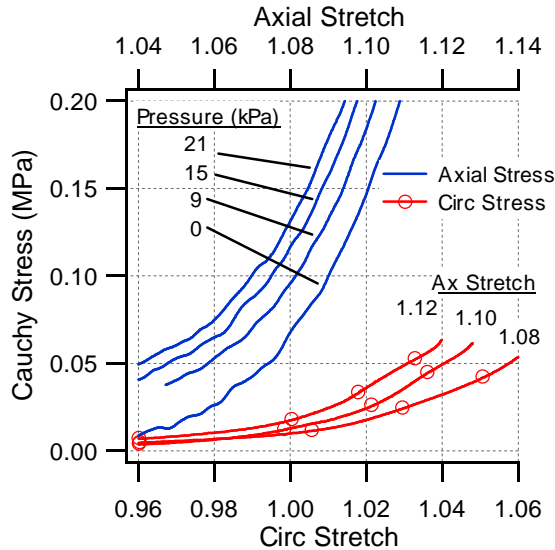


Figure 1 Cauchy stress-stretch response in the axial and circumferential directions for various combinations of physiological loading conditions

resulting in a shift upward and/or to the left for the direction of increasing stretch.

Because the figure is scaled so as to allow direct comparison of response for the two directions, it is also clear that when these vessels are deformed from in situ conditions, they are more resistant to increases in length than diameter. As Table 1 demonstrates, axial stiffness was higher than circumferential stiffness for all five specimens, though there is significant variation in the degree to which this is true.

Table 1 Individual and mean in situ circumferential and axial stiffness values, and their ratio.

Specimen	Stiffness Circ, E_c (MPa)	Stiffness Axial, E_z (MPa)	E_z / E_c
1	0.72	2.22	3.08
2	0.82	8.62	10.51
3	0.95	3.35	3.53
4	0.60	3.81	6.35
5	0.92	2.71	2.95
Mean	0.80	4.14	5.28

While stiffness variations and interdependence between directions of loading are both expected findings for vasculature in general (Humphrey, 2002), the relative magnitudes of these characteristics have not been previously reported for human cerebral arteries. These multi-axial response data are vital for the construction of constitutive equations for use in models investigating a variety of problems involving the cerebral arteries.

SUMMARY/CONCLUSIONS

The reported multi-axial data for human cerebral arteries confirm the interdependence of loading directions and reveal that, under in situ loading conditions, the vessels are stiffer in response to extension than to circumferential stretch.

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