EXPERIMENTAL MEASUREMENTS DRIVING MODELING OF VIIP SYNDROME

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INTRODUCTION

Visual Impairment and Intracranial Pressure (VIIP) syndrome is a concern for long-duration space flight. Current thinking suggests that the ocular changes observed in VIIP syndrome are related to cephalad fluid shifts resulting in altered ocular, cardiovascular, lymphatic and cerebrospinal fluid (CSF) pressures. In particular, it is hypothesized that increased CSF pressure drives connective tissue remodeling of the posterior eye and optic nerve sheath. As part of ongoing modeling studies to elucidate the pathophysiology of VIIP, we require data on the biomechanical properties of the meninges forming the optic nerve sheath, specifically fluid permeation across the meninges and the stiffness of this tissue. We describe here preliminary experimental measurements of these quantities.

METHODS

Porcine eyes were obtained immediately after death from a local abattoir. The optic nerve meninges (primarily the dura mater) were gently refracted to reveal the optic nerve proper, which was carefully removed. The sheath was returned to its original configuration to leave a “hollow” cylindrical meninges attached to the posterior globe. The distal end was cannulated, sealed, and attached to a system that allowed the pressure within the meninges (simulating CSF pressure) to be controlled. The anterior chamber of eye was also cannulated and attached to an independent pressure control system. The diameter of the sheath was recorded using a CCD camera as the CSF pressure was cycled between 7-50 mm Hg at different IOPs. In a second set of experiments, the rate at which fluid leaked through the meninges was recorded by observing the slow drainage of an elevated fluid reservoir.

RESULTS

Cyclic pressure-diameter curves showed a preconditioning effect, with repeatable behavior after 4-6 cycles. (Figure 2) The meninges showed marked nonlinear stiffening, particularly at CSF pressures >15 mmHg. The tangent moduli extracted from this data were 318, 745, and 1273 kPa at CSF pressures of 7, 15 and 30 mmHg, respectively. Permeability experiments showed that the flow rate through the intact meninges was on the order of 2 ml/hr at a driving pressure of 30mmHg, corresponding to a permeability of 7.34×10^{-5} ml/min/cm^2/mmHg.

Figure 1: Photograph of a porcine eye being prepared for testing. The meninges (optic nerve sheath) and the eye itself have both been cannulated, using the silver fitting (middle of the photo) and the blue needle (entering anterior chamber), respectively.

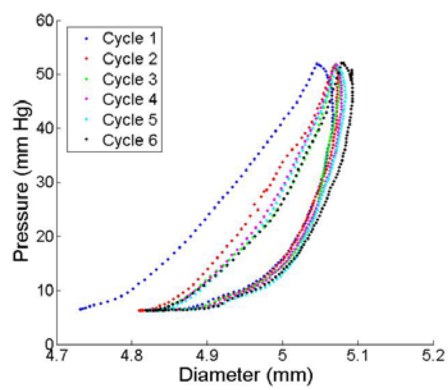

Figure 2: Pressure-diameter curves for a single porcine meninges, tested over six 7-50 mmHg pressure cycles. This information, together with the geometry of the meninges, allows determination of the tangent modulus (stiffness).

CONCLUSIONS

The meninges demonstrate biomechanical properties typical of other soft tissues, with non-linear stiffening and appreciable hysteresis on pressure cycling. This tissue has a surprisingly large permeability, suggesting that there could be important CSF drainage through the sheath into the periorbital fat. These experimental measurements, extended to post mortem human eyes, will be critical in driving computational models of the VIIP syndrome.