A NUMERICAL APPROACH OF EYE LUMPED PARAMETER MODELING FOR VIIP SYNDROME

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INTRODUCTION

Cephalad fluid shift due to microgravity exposure is hypothesized to be a major contributor to the risk of Visual Impairment and Intracranial Pressure (VIIP) which has affected a large number of astronauts who have participated in long-duration missions. VIIP syndrome, driven by the loss of the body's hydrostatic pressure gradient, triggers a wide range of ophthalmic changes including choroidal folds, posterior globe flattening, and permanent changes in visual function. To this end, the overall slow onset of changes and similarity to that of elevated intracranial pressure (ICP) suggests that not only interdependent biomechanical and biochemical changes play a role, but also connective tissue remodeling. Thus, chronic biomechanical responses to microgravity will be the focus of this work to understand the quasi-homeostatic state that evolves over weeks to months in space. Towards this end, a set of linked whole-body lumped parameter sub-models are being developed to predict fluid transport within and among the eye, cardiovascular system (CVS), and central nervous system (CNS). In this work, a preliminary version of the eye lumped parameter modeling will be derived to investigate the hydrodynamic pathways of the eye and how they directly affect intraocular pressure (IOP).

METHODS

Fluid shifts and varying IOP in the eye are critical contributors of VIIP. Three main effects drive vascular pressure changes: aqueous humor drainage, blood volume of the eye, and mean arterial pressure, which affects the aqueous humor production rate. In conjunction with other whole-body lumped parameter models (shown in Figure 1) proposed, the eye lumped parameter model aims to investigate the hydrodynamic pathways of the eye and how these volumetric changes may affect IOP. The tissue modeling for this task must supply the eye lumped parameter model with any relevant tissue properties, primarily compliance and resistance. In the model, the eye is treated as a distensible compartment inside of which exists a second distensible compartment representing the intraocular vasculature.

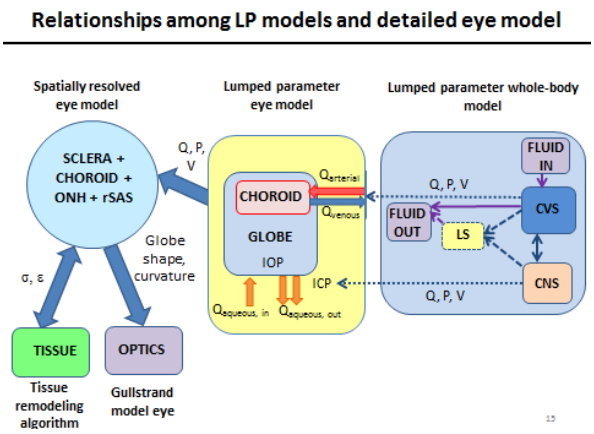

Figure 1. Schematic of lumped parameter eye and whole-body models, where information is used to develop a future finite-element of the eye. CNS – central nervous system; CVS: cardiovascular system; LS: lymphatic system; ON: optic nerve; ONH: optic nerve head; P: pressure; Q: flow rate; RS-SAS: retrobulbar sub-arachnoid space

Kiel et al. [1] have developed a model of ocular blood flow, ocular mass transport and aqueous humor dynamics which represents the state of the art in lumped parameter modeling of the eye. However, this model includes a large number of parameters that cannot be measured under microgravity conditions because it is based off a rabbit eye. Because it incorporates many features that are not relevant to VIIP, we are re-constructing the model to contain the appropriate fidelity necessary for VIIP investigations, using Kiel et al. as a valuable starting point.

Based on equations outlined by Kiel et al., an abbreviated governing equation set has been derived for the ciliary blood flow and aqueous humor production and for the structural response of the globe to applied flows and surrounding pressures. The equation set is solved in MATLAB via a stiff variable-order differential equation solver, based on the numerical differentiation formulas (NDFs). Future work includes assembling all of the relevant data in a format that can be cleanly interfaced with future external modules, including a cardiovascular and cerebrovascular lumped parameter model, tissue models, and a finely discretized computational model of the globe and retrobulbar space. We will use VV&C practices outlined in NASA-STD-7009 to ensure the model can be used with sufficient confidence to answer VIIP research questions.

[1] Kiel, J.W.; Hollingsworth, M.; Rao, R.; Chen, M.; Reitsamer, H.A. (2011) *Prog Retin Eye Res* 30, 1-17.