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Numerical modelling of Ocular Biomechanical Behaviour Based on Fibril Density and Orientation Data for the Whole Eye Globe

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Introduction: Microstructure, and in particular the distribution of collagen fibrils, has a direct effect on the biomechanical behaviour of ocular tissue, with higher fibril content indicative of higher mechanical stiffness and preferential orientation causing anisotropic stiffness [1]. This study is the result of extensive amount of research and data collection over several years on human ocular biomechanics and microstructure. The findings of this study will enable the development of multi-scale numerical models that can be used in ophthalmology for disease management, medical device development and optimisation of surgical procedures.

Methods: Seven ex-vivo healthy human eyes (age between 60 and 80 years) were received from the Fondazione Banca degli Occhi del Veneto Onlus Eye Bank, Italy. After measuring the thickness across the whole surface, the eyes had their microstructure characterised by wide-angle X-ray scattering (WAXS) at the Diamond Light Source Synchrotron research facility [2]

Results: Analysis of the microstructure data illustrated the preferential orthogonal arrangement of fibrils in the central cornea. In the central cornea 31±3% of total fibrils were in the temporal-nasal direction and 31±2% in the superior-inferior direction. This changed to preferential circumferential orientation of fibrils at and around the limbus (37±2%), which then decreased to (22±1%) around the equator. Beyond the equator, circumferential fibril content increased again to 27±2%, and remained at this level until reaching the posterior pole. The proportion of meridional fibrils were at its minimum level (19±2%) at the limbus, before increasing to a maximum value (32±2%) at the equator - at approximately the location of the extraocular muscle attachment. Beyond the equator, and up until the posterior pole, meridional fibril content was close to 25%, indicating no preferential orientation. Fibril density at the central cornea exhibited the lowest value and increased significantly ($p<0.001$) to almost twice the central values at the limbus. After a sudden drop in density from the limbus to the equator, the fibril density experienced a gradual increase to a maximum value around the posterior pole, which was significantly higher than at the limbus ($P<0.001$). A predominantly circumferential distribution was found within a 4mm from the centre of the optic nerve head. In this area, the proportion of the circumferential fibrils increased from 26±2% at the centre of optic nerve head to 35±2% at 1.75mm radius and then decreased back to 26±1% when approaching a 4mm radius.

Discussion: This study analysed the largest set of X-ray scattering data from healthy human eyes. It enabled a better understanding of fibril distribution and density across the full eye. These findings are used in the development of material constitutive models describing the biomechanical behaviour of ocular tissue.

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