Collagen Macrostructure And Corneal Shape: Lessons From Different Species

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Collagen fibrils provide both strength and shape to tissues and organs of the vertebrate body through their biomechanical properties including high axial tensile strength and low lateral stiffness. In the vertebrate eye, collagen forms a continuous outer tunic comprised of an anterior transparent cornea and a posterior opaque sclera that together protects the inner ocular structures while passing light back to the retina. In terrestrial vertebrates, the cornea has also evolved into a refractive element whose curvature and shape provides over 60% of the refractive power of the eye. Although visual disorders such as astigmatism, myopia, hyperopia and ectasia in humans are thought to involve defects in corneal biomechanics and collagen organization, little is known regarding how collagen organization controls corneal biomechanics and hence corneal shape.

Our laboratory has been interested in identifying the mechanisms controlling corneal structure by understanding how the collagen fiber patterns are associated with different corneal shapes and functions. For these studies, we have used non-invasive, non-linear optical (NLO) imaging of second harmonic generated signals (SHG) from collagen to track the 3-dimensional collagen fiber organization of the cornea from various species. In fish (Salmo, Acipenser, Coryphaena, Carcharodon, Rhizoprionodon), stromal collagen is organized into uninterrupted layers extending across the cornea, similar to plywood. Adjacent plies have an orthogonal arrangement, rotated <90°, leading to an angular displacement in the plies of >180° when moving from the anterior to the posterior cornea. Interactions between plies are minimal with occasional axially oriented fiber bundles extending from one ply to the adjacent parallel ply, except for sharks and sturgeons, which have sutural fibers and 'corkscrew' collagen fiber bundles, respectively. In birds (Gallus, Buteo, Phasianus), a similar rotating orthogonal ply arrangement is observed with individual plies broken down into smaller fibers bundles showing a highly interwoven organization with fiber branching and anastomosing leading to a 'chicken wire' appearance. In mammals (Homo, Oryctolagus, Canis, Mus, Felis, Zalophus), the collagen fibers are randomly oriented and highly interwoven and intertwined, decreasing with corneal depth. Mechanical testing thus far suggests that collagen fiber interweaving and intertwining is associated with increased mechanical stiffness. While additional vertebrate classes need to be evaluated, development of a refractive cornea and control of corneal shape appears to be associated with the appearance of a more complex interwoven and intertwined collagen fiber structure. What mechanisms control the development of this complexity remains to be identified.