

Fiber alignment in the meniscus during loading

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The use of a custom written algorithm to analyze 3D x-ray images provides new insight into how the collagen fibers are arranged in human meniscus while loaded. The algorithm can identify layers of differently oriented fibers. It can be used for further research to study how damage to the meniscus, due to aging or osteoarthritis, affects the fiber orientations and its response to load.

The knee is the largest joint in the body, and it is the target of large forces daily. An important part of the knee is a pair of c-shaped discs made of collagen, known as the menisci. The c-shape allows the meniscus to alleviate stress on the underlying cartilage by spreading out the force placed on the meniscus along the c-shape. It is known that when the meniscus is damaged the collagen structure is affected, but it is not known exactly how.

Using 3D x-ray images, it could be seen that the orientations of the circumferential fibers are not homogeneous but structured in layers (See Figure 1). To properly investigate how the structure changes, these layers needed to be identified. For this purpose, a specific layer detection algorithm was written, and by analyzing the 3D x-ray images, we could gather a first insight into how the fiber orientations change during loading.

The algorithm consistently found the same collagen layers every time it was applied. The meniscus samples were subjected to vertical forces, and the fiber alignment was investigated within each collagen layer in both the horizontal and vertical plane. The major changes happened in the horizontal plane, as the previously aligned fibers became less aligned with increased pressure.

An interesting behaviour could be seen for the fiber density, as it decreased every time force was applied to the meniscus, to gradually increase back to its original value during relaxation.

The project serves two main purposes. It provides a first insight into dynamic fiber orientation change, a source of information regarding meniscus function and health. It also provides a stepping stone for further developments in developing a method that can be used to identify and extract information from collagen fiber layers.

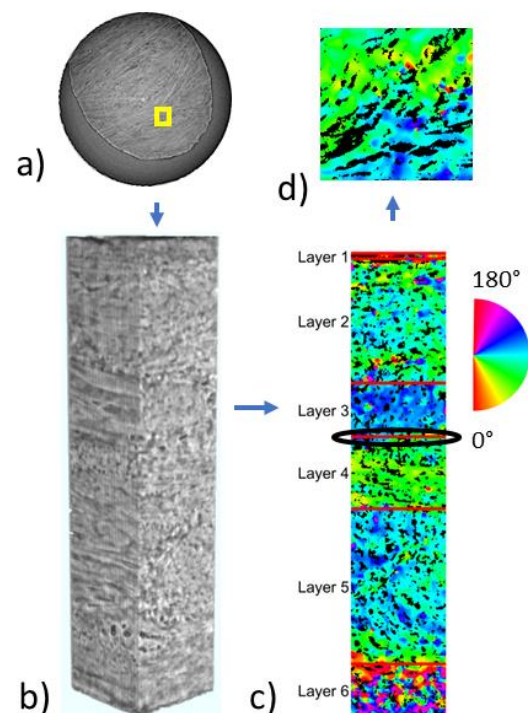


Figure 1. a) Horizontal X-ray image of a meniscus plug. Yellow square marks a section used for analysis. b) A section of the 3D x-ray images. c) Found collagen layers, color coded according to direction in the horizontal plane. d) Slice of colored fibers according to their direction in the horizontal plane. Taken from the region marked by the black ellipse in c).