The Alignment Index (AI): A Collagen fibre orientation distribution analysis

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Introduction

Collagen-rich structures of the knee are prone to damage through acute injury or chronic "wear and tear". Damaged tissue has disorganised collagen fibres (fig.1).

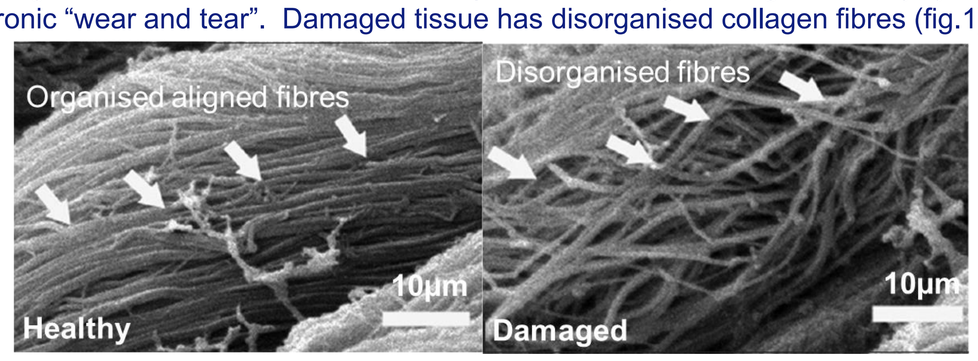
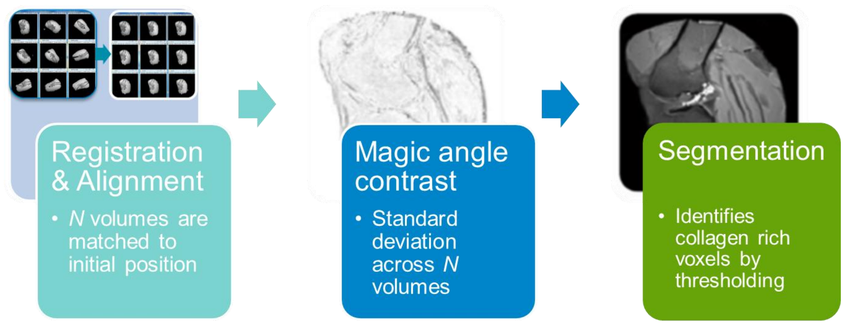


Fig.1 Collagen fibres become more disorganised in damaged tissue[1] – SEM of a healthy and damaged meniscus.

An alignment index (AI) used to analyse orientation distribution of collagen fibres is presented. The AI could be used as a metric of knee health, improving clinical decision making and developing new therapeutic interventions.

Method

A healthy caprine knee was scanned using a Siemens Verio 3T Scanner. The knee was rotated and scanned in nine directions to the main magnetic field B_0[2]. A 3D PD SPACE sequence with isotropic 1x1x1mm voxels (TR1300ms, TE13ms, FOV256mm, BW 434Hz) was optimised to produce the biggest magic angle effect. The image processing steps are shown below.



For each collagen rich voxel the orientation vector is computed using Szeverenyi and Bydder's method[3]. Each orientation vector reflects the net effect of all the fibres contained within a voxel (fig.2).

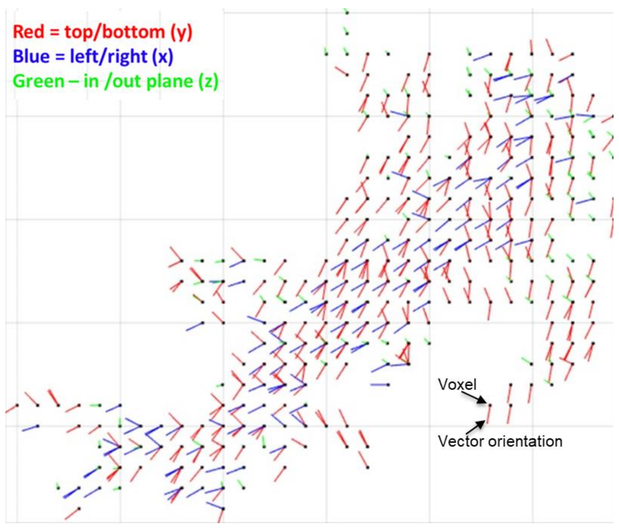


Fig. 2. A fibre orientation map for the anterior cruciate ligament (ACL)

The assembly of all unit vectors represents the fibre orientation map. Voxel are shown as · and the orientation vectors are either a **red**, **blue** or **green** line dependent on the position of actual direction of the dipolar interaction for that particular voxel.

Alignment Index (AI)

The AI in any direction is defined as a ratio of the fraction of orientations within a 20° cone (solid angle) centred in that direction to the same fraction in a random (flat) case[4,5] (fig.3).

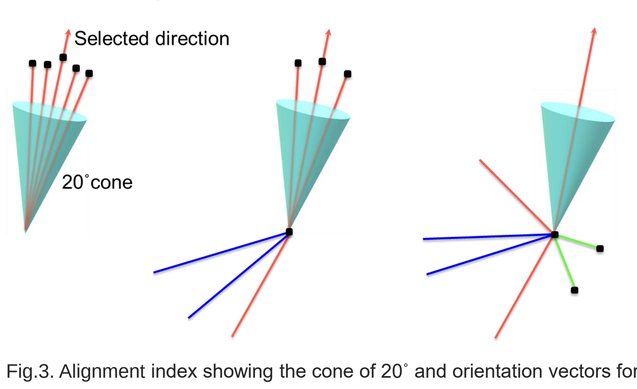


Fig.3. Alignment index showing the cone of 20˚ and orientation vectors for anisotropic and isotropic alignment..

The AI is normalised. Increasing AI values indicate increasingly aligned structures.

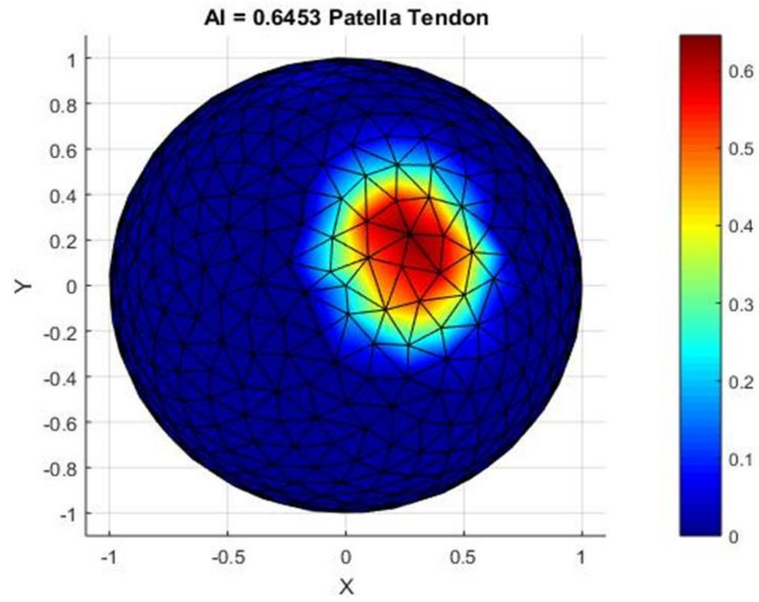
AI=1 indicates that all collagen fibres are orientated within the cone of 20° centred at the selected direction.

AI=0 indicates isotropic collagen fibre alignment.

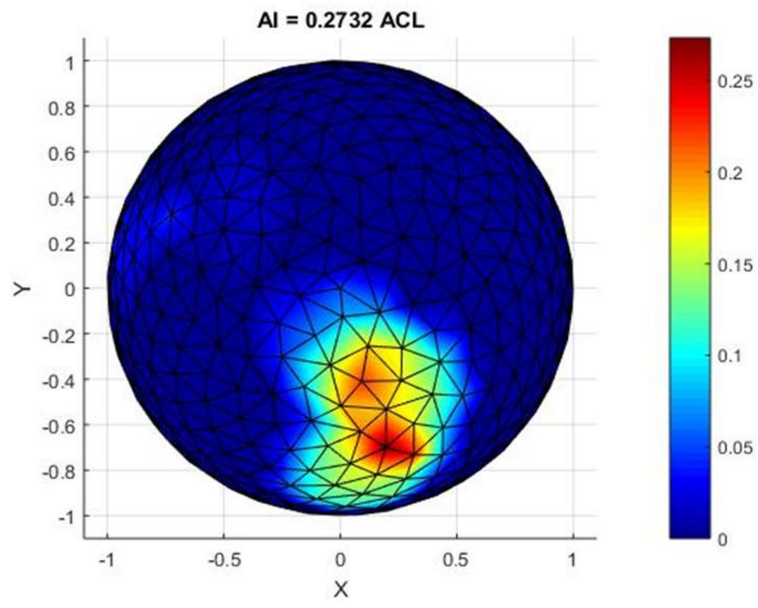
By computing AI for a regular gridded orientation space we are able to visualise AI on a hemisphere, facilitating better understanding of the collagen fibre orientation in different structures.

Results

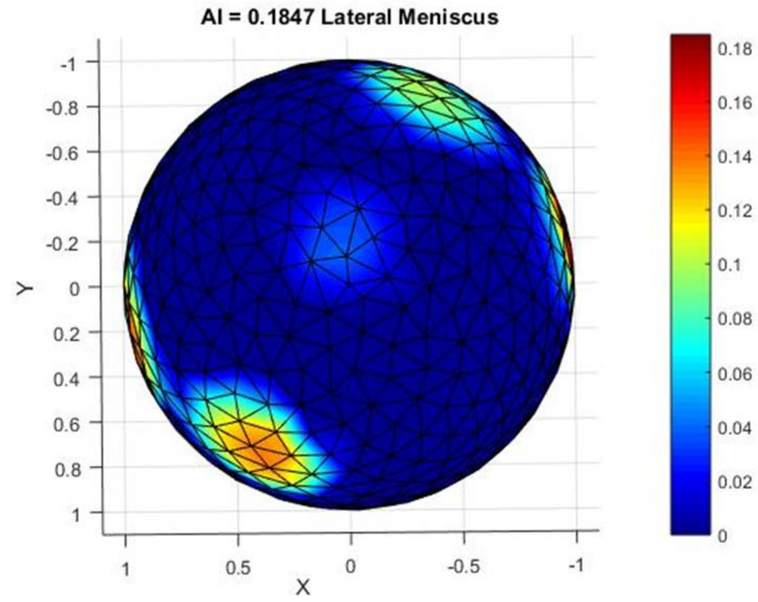
The patella tendon has a single predominant fibre alignment and an AI=0.6453.



The anterior cruciate ligament (ACL) has two fibre bundles anterior medial and posterior lateral and an AI=0.2732.



The meniscus has three fibre groups (vertical, radial and circumferential) and an AI=0.1847.



Discussion

The most aligned knee structure is the patella tendon where the collagen fibres align with the skeleton to transmit forces through bones and muscles. This structure had the AI closest to 1. The ACL had the second highest AI and is composed of two fibre bundles aligned diagonally across the knee. The meniscus acts as a shock absorber and is made up of vertical, radial and circumferential fibres which disperse forces more equally. The complexity of the meniscal structure resulted in the lowest AI. To date, this technique has only been performed with healthy tissue; the AI may become closer to zero if there is damage disrupting the collagen fibre alignment.

Conclusion

The AI can further our understanding of collagen orientation distribution and could be used as a quantitative, non-invasive measure of structural health.

Contact

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References

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