Microstructural analysis of human bridging veins

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I. INTRODUCTION

Bridging veins (BV) drain the blood from the cerebral cortex into dural sinuses by puncturing through the dura mater. Relative movement between these two structures can cause these veins to rupture, producing acute subdural haematoma (ASDH), a head injury with a mortality rate between 30% and 90% [1]. Ruptures most often occur in BV draining into the superior sagittal sinus (SSS). Despite the importance of the BV in the aetiology of ASDH [2], little is known about their histological, morphological and mechanical properties [3].

Most of the finite element (FE) head models include a mechanical representation of BVs. The KTH FE head model has discrete beam elements with a stiffness of 1.9N, while the SIMon, the UCDBTM and the WSUBIM model also have similar BV representations[3]. In every case the BV material used is linear elastic, which does not show the anisotropic nature of the tissue, and also the vein geometry is oversimplified. Accounting for collagen fibre orientation in BV by using a fibre reinforced material model on a realistic geometry will increase the biofidelity of such models. The first study that investigated the microstructural characteristics of human BV was that of Yamashima *et al*. [4]. They reported that more than half of the collagen fibre distribution was oriented in a circumferential manner. Pang *et al*. [5] used unstained fresh porcine BV and showed that the principal direction of collagen fibres was longitudinal. Vignes *et al*. [6] used human BV to demonstrate a helical orientation of the collagen fibres at the SSS-BV junction, in contrast to the linear orientation elsewhere. Nierenberger *et al*. [7] stated that in the SSS of human BV the collagen fibres are mostly circumferentially oriented, with a homogenous structure of wavy collagen bundles.

We hypothesized that collagen fibres tend to develop and form differently throughout BV length due to a difference in reinforcement and loading conditions between the SSS and the brain. The goal of this study is to objectively assess the fibre distribution and the mean angle of collagen fibres throughout the BV length in order to better understand the BV collagen microstructure and use this knowledge for material modelling in the future.

II. METHODS

Bridging veins from one human head, collected from the Anatomy Department of KU Leuven, were harvested and kept frozen at -80°C. Each sample was left to thaw in a fridge at 4°C for 30 minutes prior to the experiment. From a total of 17 samples obtained, 12 were scanned. A dissection microscope and surgical tools were used to cut along the length of the BV in order to open the tubular structure into a flat tissue.

The samples were then mounted on an in-house-built uniaxial tension device compatible with a Zeiss LSM780 microscope. Two dots were placed on the sides of each BV with Indian ink, in order to measure the width change after stretching. The motivation behind the setup design was to initially self-align the specimen about to be scanned without applying strain. Then 50% strain was applied on the specimen to investigate the recruitment of the collagen fibres. This setup applied displacement manually through a microscrew. No force data were collected, though, because the objective of this setup was to align the tissue in a way that gave a known coordinate system to the data captured by the microscope. The vessel's two ends were glued using acrylic glue on stainless steel blocks and were then mounted on the setup. The lumen of the sample was facing the setup's coverglass. The tissue was kept hydrated inside a bath with 0.9% NaCl solution for the duration of the scan. Each scan lasted for approximately 1 hour and 30 minutes. Imaging was performed on a Zeiss LSM780 with an objective 25x coupled to a MaiTai DS pulsed laser (@ 850 nm) to generate second harmonics from collagen and elicit auto-fluorescence. Signals were captured in forward and backward direction on BIG detectors and stored as four colour Z-stacks. For each sample, a large area of several mm^2 was scanned, starting from the SSS connection point. The Z-stacks were stitched together using a Zeiss stitching module. Prior to the calculation of the local orientations, acquired Z-stacks were denoised and enhanced to highlight fibrillar structures from the background. Then, for

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each Z-plane of the stack, the ImageJ plugin OrientationJ [8] was used to extract the local 2D orientations of the fibres based on structure tensors. A mixture of von Mises distributions was fit to each of the histograms to acquire μ, which is the mean angle, and κ, which is a measure of concentration, of each component along with the component's percentage. The von Mises distribution is commonly used as a model for many circular data problems and is the n-periodic equivalent of a Gaussian distribution for directional statistics [9]. To fit the von Mises distribution mixture, the mvmdist Matlab package was used [10-11] .

III. INITIAL FINDINGS

Two types of collagen architectures can be seen in our samples. The most common of the two, seen in 8 of 12 scanned samples, is single-layered and organised in evenly distributed bundles, with a mean bundle diameter of 2.92 μm and a standard deviation of 1.51 μm. The average diameter of these samples was 2.2 mm and the average wall thickness was 134 μm. On the other hand, in 4 of the 12 samples bigger bundles were seen, with a double-layered vessel wall and a mean width size of 48.58 μm and a standard deviation of 22.50 μm. These samples had an average diameter of 3.7 mm and a wall thickness of 155 μm.

When the von Mises model was fitted simultaneously on all measurements from all samples in order to obtain average measurements, it resulted in 3 fibre families at a mean angle μ_1=-20°, μ_2=12° and, μ_3=-1° with a concentration of κ_1=16.4, κ_2=7.3 and κ_3=104.2. In every sample the collagen fibre orientation analysis showed that there is one axially oriented fibre family in BV, but there can be more than one fibre families in angles ranging from 60° to -60°.

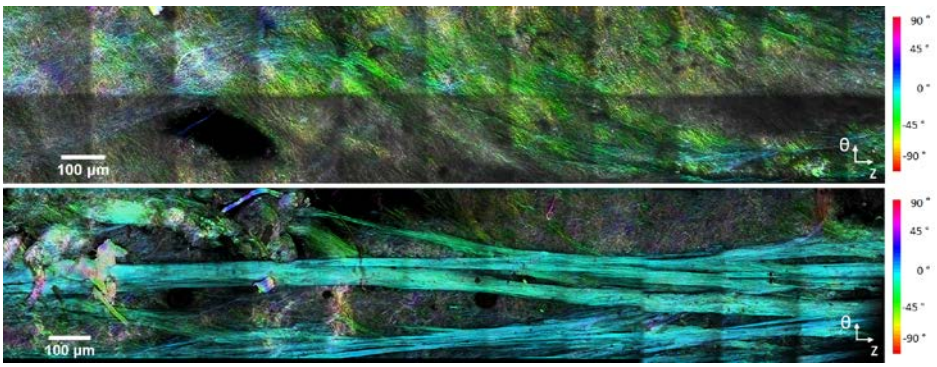

Fig. 1. Colour-coded fiber orientation scans of BV with different collagen architecture types.

IV. DISCUSSION

Even though BV are a major cause of ASDH, head models still lack the information needed to model these vessels with biofidelity. In this study, a method has been developed to obtain information in an objective way. A clear limitation is that all the vessels were taken from a single human head. In addition, the veins were cut open to improve image quality and that could affect the collagen orientation, although all scans were taken in areas as far away as possible from the longitudinal cut. Having information with high biofidelity along with the full range of possible values is paramount for finite element modelling to bring new insights to our understanding of the mechanism behind head impact traumas.

V. REFERENCES

[1] Depreitere, B., *et al*., *J. Neurosurg*, 2006.
[2] Zhou, Z., *et al*., *J Neurotrauma*, 2018.
[3] Famaey, N., *et al.*, *J Mech Behav Biomed Mater*, 2015.
[4] Yamashima, T., *et al*., *J Neurology, Neurosurgery and Psychiatry*, 1984.
[5] Pang, Q., *et al*., *J Vasc Res*, 2001.
[6] Vignes, J. R., *et al*., *J Neurosurg*, 2007.
[7] Nierenberger, M., *et al.*, *Surg Radiol Anat*, 2013.
[8] Püspöki, Z., *et al*., *Adv Anat Embryol Cell Biol*, 2016.
[9] Ni Annaidh, A., *et al.*, *Ann Biomed Eng*, 2012.
[10] Bentley, J., Simon Frazer Univ., 2006.
[11] Dhillon, I., *et al*., *Comput Sci Univ Texas*, 2003.