Quantitative description of vessel geometry from microscopic MR skin imaging

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Introduction

Inflammatory skin diseases such as vasculitis usually manifest first in cutaneous vessels before affecting other organs with potentially lethal consequences. Treatment and outcome depend strongly on an accurate diagnosis of the type of vasculitis. The gold standard is deep biopsy and histological examination with the drawback that multiple biopsies have to be taken frequently, inter alia due to discontinuous involvement of vessels. Furthermore, the technique is invasive and treatment monitoring in longitudinal studies is not possible for the same anatomical location. Finally, shrinking artifacts arising during the fixation process of the specimen might obstruct the in vivo geometry of the vessel tree.

Magnetic resonance microscopy can be employed to obtain in vivo images of the human skin and three-dimensional models of skin vasculature [1, 2]. High magnetic field and/or very sensitive surface coils can be used to achieve the required sensitivity. In this work we present a method to derive a graph representation of the segmented vascular tree and calculate quantitative descriptive parameters using graph theory methods. These geometrical properties of the cutaneous vessel tree assessed in vivo might provide the basis for a more reliable classification of the underlying vascular pathology.

Materials and Methods

Nine healthy volunteers (3 f/6 m, age = 29 ± 5 years) were included in the study after giving written informed consent in agreement with the local ethics regulation. Acquisitions were performed on a 3 T Bruker MedSpec S300 (Bruker BioSpin, Ettlingen, Germany) using a whole-body gradient system (B-GA55) and a 15 mm transceive surface coil (Rapid Biomedical, Würzburg, Germany). Measurements consisted of three consecutive 3D GE sequences with TR = 32.5 ms, TE = 10 ms, FOV = $(17 \times 17 \times 11)$ mm^3 and an isotropic spatial resolution of 100 µm in a total scan time of 10:07 min for each scan. The area of skin investigated was located on the anterior part of the thigh, approximately 15 cm above the knee.

Fig. 1: Example of a cutaneous vessel tree segmented from human in vivo data with 100 µm isotropic resolution.

Matlab 7.8 (The Mathworks, Palo Alto, CA, U.S.A.) was used for image post-processing. The data sets were zero-filled to 75 µm isotropic resolution and averaged after rigid-body realignment with SPM8b (The Wellcome Trust Centre for Neuroimaging, UCL, U.K.); vessel trees were manually segmented (see Fig. 1). From the segmented data, the relative blood volume was calculated as the fraction of vessel voxels vs. the total number of skin voxels.

A 3D thinning algorithm based on [3] was implemented to obtain the medial lines of the vessels, i.e. the skeleton. Fig. 2A shows the skeleton of an exemplary part of a vessel tree. Vessel diameters were calculated using the distance transform function, evaluated at the position of the skeleton voxels. In order to produce a graph, all voxels in the skeleton were interpreted as nodes of a graph. Neighboring voxels were connected by edges in the graph. The nodes were assigned to one of the categories end point (■), junction (◆) or line point (○) (Fig. 2B). Redundant nodes were eliminated following the guidelines in [4] (Fig. 2C). The resulting graphs were reduced, i.e. normal line points were eliminated and the distances along the path between either two junctions or a junction and an end point were summed to calculate the length of the branches (Fig. 2D).

Results

The relative blood volume was 6.2 ± 1.7 µl/cm^3 or 0.62 ± 0.17 vol%. The number of vessel branches found was 31 ± 12 over the study population. The upper table shows the distribution of vessel diameters, and the bottom table gives the distribution of branch lengths (mean ± SD).

Vessel diameter	< 200 µm	200 – 400 µm	400 – 1200 µm	> 1.2 mm
% of total vessel length	73 ± 8 %	20 ± 6 %	6 ± 2 %	1 ± 2 %

Branch length	0 – 2 mm	2 – 4 mm	4 – 6 mm	6 – 8 mm
Relative frequency	15 ± 4 %	6 ± 2 %	75 ± 6 %	4 ± 4 %

Fig. 2: From skeleton to graph.

Discussion and Conclusion

A technique to obtain quantitative parameters from in vivo microscopic MR data of cutaneous vasculature has been developed and its feasibility shown. The value found for the relative blood volume is comparable to literature data derived from optical methods [5]. Within a group of nine healthy volunteers, consistent results were observed for diameter and branch length distributions. With a larger cohort of subjects, parameters for healthy vasculature could be confirmed and a distinction from pathological skin vessels could be realized. Also, the comparison of vascular parameters at the same anatomical location in the course of treatment might be monitored.

References

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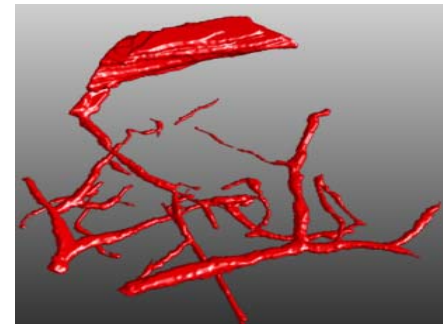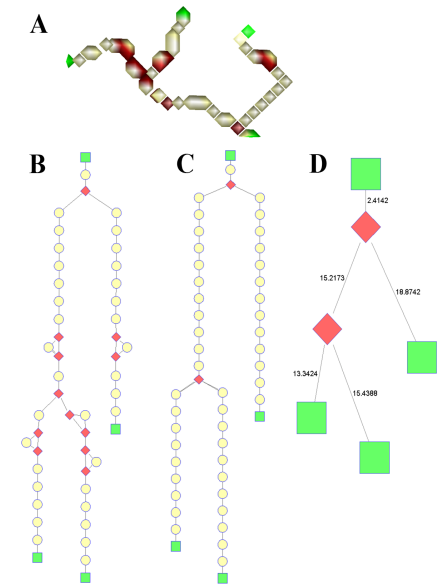[5] VÄLISUO et al., *Skin Research and Technology*, **16**(4):390–396, 2010