Using SRµCT to define water transport capacity in *Picea abies*

Silke Lautner[1], Claudia Lenz[1], Jörg Hammel [2], Julian Moosmann[2], Michael Kühn[1], Michele Caselle[3], Matthias Vogelgesang[3], Andreas Kopmann[3], Felix Beckmann[2]

[1] Eberswalde University for Sustainable Development, Faculty of Wood Engineering, Department Applied Wood Biology, Schicklerstr. 5, 16225 Eberswalde, Germany
[2] Helmholtz-Zentrum Geesthacht, Institute of Materials Research, Max-Planck-Str. 1, 21502 Geesthacht, Germany
[3] Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Hermann-v.-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

INTRODUCTION

Apart from ensuring strength and stability, the woody body of trees also provides the vascular tissue for long distance water transport from roots to shoots. Different to angiosperm trees, having developed a specialized cell type for long distance water transport, axial water transport in gymnosperm trees like spruce (*Picea abies* (L.) Karst.) occurs in tracheids. About 95% of softwood xylem is composed of this cell type, and it is both responsible for stability as well as for axial water transport. Within one growth ring tracheids vary in their appearance: in the early wood region, i.e. xylem cells built from early spring to summer, the main purpose of the tracheids is to ensure water transport pathways into the tree's crown; hence, the tracheid lumina are wide and the cell walls are much thinner than in late wood region (Fig. 1 A). Once the water transport pathway is established, tracheids change their features towards thick cell walls and small lumina. Due to the resulting increase in density, thus formed late wood region, produced between late summer and autumn, enhances strength and stability to the tree. Being a physiological process, wood formation can also be influenced by biotic as well as abiotic impacts, resulting in an altered wood tissue composition or in a change of early wood / late wood characteristics [1, 2, 3].

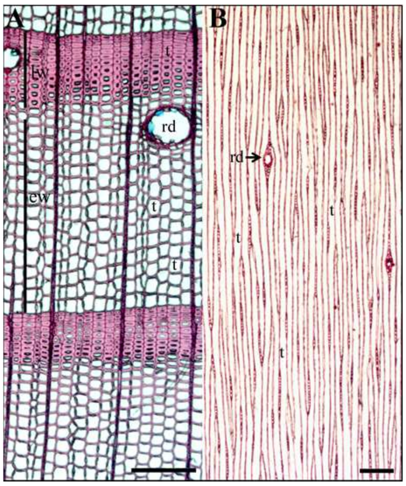

Fig. 1 Light microscopy images of spruce wood. A: cross section; B: tangential section through early wood region. ew-early wood; lw-late wood; rd- resin duct; t-tracheid. Scale bars represent 200 µm

In order to analyze the over-all water transport capacity within one growth ring, time-consuming light microscopy analysis of the woody sample still is the conventional approach for calculating tracheid lumen area (Fig. 1). In our investigations at the Imaging Beamline (IBL) operated by the Helmholtz-Zentrum Geesthacht (HZG) at PETRA III storage ring of the Deutsches Elektronen-Synchrotron DESY, Hamburg, we applied SRµCT on small wood samples of spruce trees in order to visualize and analyze size and formation of xylem elements and their respective lumina (Fig. 3 and 4). The selected high-resolution phase-contrast technique makes full use of the novel 20 MPixel CMOS area detector developed within the cooperation of HZG and the Karlsruhe Institute of Technology.

METHODS

Two reconstruction methods of SRµCT data sets were applied. Comparing reconstructions without (Fig. 2A) and with phase retrieval (Fig. 2B), contrast is enhanced, noise is reduced and 'unphysical' density variations in the reconstruction stemming from propagation effects are removed. In consequence, segmentation process of 3D voxel data sets in the 3D visualization and analysis software AVIZO has a more effective implementation. Furthermore, 3D visualization in terms of images (Fig. 3) or animated videos (please read QR code below) as well as analyzing procedure is less time-consuming.

absorption contrast vs. phase contrast

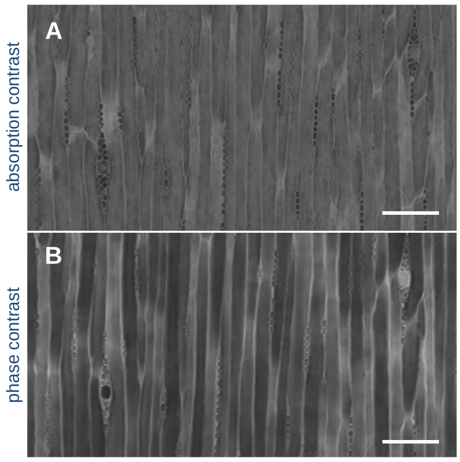

Fig. 2 Horizontal slice through tomographic reconstructions where flat-and-dark field corrected projections (A) or retrieved phase maps (B) served as input. Scale bars represent 200 µm

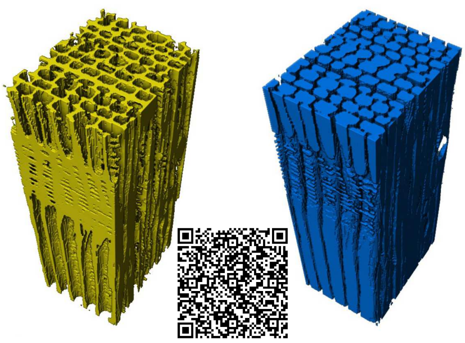

Fig. 3 Visualization of cell wall (yellow, left) and lumina (blue, right) volumes of representative 3D areas of spruce's early wood region. ROI: 0.13 mm³. For 3D animation please follow QR code.

RESULTS

Light microscopy analysis on tracheids revealed an average lumen volume of 0.005 mm³ per early wood tracheid, compared to 0.0005 mm³ in late wood tracheids. The ten times higher lumina volume in early wood tracheids is reflecting the importance of this tissue for axial water transport capacity. Both, results of light microscopy analysis and SRµCT analysis on the identical spruce wood sample revealed a very similar volume ratio of early wood : late wood tracheid lumina (Fig. 4). These results corroborate our microscopic analysis presenting a substantialy higher lumina volume in early wood tracheids. Likewise, increase of cell wall volume in late wood regions of a growth ring points towards the enhancement of strength and stability for the woody body in this part of the growth ring.

light microscopy & SRµCT

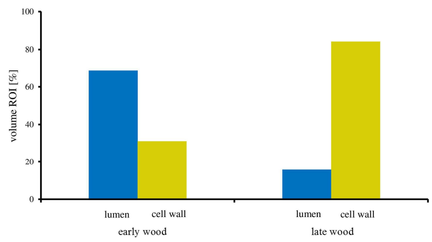

Fig. 4 Calculated ratio of spruce wood tracheid's lumina and cell wall of a chosen region of interest of synchrotron radiation-based microtomography. Early wood tracheid lumen clearly exceeds late wood lumen, emphasizing its importance for axial water transport. ROI: 0.13 mm³

CONCLUSIONS

SRµCT is a promising method for non-destructive 3d analysis of xylem [4,5].

The novel 20 MPixel CMOS camera in combination with propagation phase contrast allows for high throughput scan showing high dynamics within the tomogram.

Even though spatial resolution in SRµCT is still below that of light microscopy, volume calculation of selected wood tissues gained by SRµCT correspond well with traditional light microscopic analysis methods.

REFERENCES

1. Lautner, S., *Wood formation under drought stress and salinity. In: Cellular Aspects of Wood Formation*, Springer Verlag, Berlin & Heidelberg, 187-202, (2013).
2. Janz, D., Lautner, S., Wildhagen, D., Behnke, K., Schnitzler, J.-P., Rennenberg, H., Fromm, J. and Polle, A., *Salt stress induces the formation of a novel type of ‚pressure wood' in two Populus species*, New Phytologist 194: 129-141 (2012).
3. Fromm, J. and Lautner, S., *Abiotic Stresses on Secondary Xylem Formation. In: Secondary Xylem Biology: Origins, Functions, and Applications*, Elsevier Academic Press, 59-71, Amsterdam & London (2016).
4. Lautner, S. and Beckmann, F., *Analysis of wood microstructure by synchrotron radiation- based X-ray microtomography (SRµCT)*, Proc. SPIE Vol. 8506 85060F-1
5. Trtik, P., Dual, J., Keunecke, D., Mannes, D., Niemz, P., Stähli, P., Kaestner, A., Groso, A. and Stampanoni, M., *3D imaging of microstructure of spruce wood*, J. Struct. Biol. 159, 46-55 (2007).

Financially supported by the German Federal Office for Agriculture and Food
Project ID: 28W-B-4-083-01

For further information, please contact: silke.lautner@hnee.de

For further 3D animations of spruce wood, please read QR code