Biophotonics Congress: Biomedical Optics 2020 (Translational, Microscopy, OCT, OTS, BRAIN) © OSA 2020

Light Scattering Measurements Enable an Improved Reconstruction of Nerve Fiber Crossings

Miriam Menzel[1,2], Mike Huwer[1], Philipp Schlömer[1], Katrin Amunts[1,2], Markus Axer[1]

[1] *Institute of Neuroscience and Medicine (INM-1), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany*
[2] *C. and O. Vogt Institute for Brain Research, University of Düsseldorf, 40204 Düsseldorf, Germany*
m.menzel@fz-juelich.de

Abstract: We show that light scattering measurements of brain tissue reveal valuable information about the underlying tissue structure such as the crossing angle of the nerve fibers.

OCIS codes: 170.3880; 050.1755; 170.0180

1. Introduction

For current neuroimaging techniques (e. g. diffusion MRI or microscopy techniques), the complex and dense network architecture of the brain poses a major challenge for reconstructing neuronal connections, especially in regions of crossing nerve fibers. Previous simulation studies by Menzel et al. [1] have shown that scattering patterns of light reveal valuable information about the substructure of fibrous tissue samples such as the fiber crossing angle. Here, we show experimentally that light scattering measurements of brain tissue can be used to determine the crossing angle of the nerve fibers within a measured tissue voxel, enabling a much better reconstruction of nerve fibers in the brain.

2. Material and Methods

To study a brain tissue sample with well-defined crossing angle, two optic tracts of a 30 µm thin section of a human optic chiasm were placed on top of each other with a crossing angle of approximately 90° (cf. Fig. 1b). (The optic tracts were selected as they contain mainly parallel fibers with well-defined orientations.) The sample was embedded in a solution of 20 % glycerin, cover-slipped, and measured five months afterwards with the setup shown in Fig. 1a (object-space resolution: 9.22 µm/px). During the measurement, the sample was illuminated under an angle of 36.3° from different directions: a mask with a circular hole (see lower Fig. 1a) was placed on top of a green LED light source (525 nm wavelength) and rotated in steps of 22.5° around the center of the sample in clock-wise direction. For each rotation angle, the light that passed through the sample and fell vertically onto the camera was recorded.

The simulations (Fig. 1c) were performed for an artificial nerve fiber bundle ($30 \times 30 \times 30\,\mu m^3$) with parallel in-plane fibers (i) and two bundles with 90° crossing angle (ii), using a finite-difference time-domain (FDTD) algorithm to compute the propagation of the light wave through the sample (see Menzel et al. [1, 2] for more information). The scattering patterns (second row in Fig. 1c) show the intensity of the scattered light in the hemisphere behind the sample, projected onto the xy-plane (scattering angles range from 0° in the center to 90° at the borders).

3. Results and Discussion

Figure 1b shows the results of the scattering measurement for the crossing optic tracts. In the two nerve fiber bundles (i) and in the crossing area (ii), a region of 10×10 pixels (marked by a little yellow square in the image on top) was selected for evaluation. The colored lines indicate the approximate orientation of the nerve fibers in the investigated regions. (3D-PLI measurements [3] have shown that the tissue of the optic tracts is very homogeneous and that the fibers are mainly oriented along the direction of the tracts.) The graphs below show the average transmitted light intensity for the two regions with parallel fibers (i) and the region with crossing fibers (ii) plotted against the rotation angle of the hole of illumination. The dashed vertical lines (green and magenta) indicate the respective orientation of the nerve fibers as marked in the image on top. The graphs show that the fibers light up when the direction of illumination is oriented perpendicular to the fibers: when being illuminated in the y-direction (rotation angle of 0°), for example, fibers that are oriented along the x-axis (in magenta) light up. Hence, regions with parallel fibers (i) show two distinct peaks that lie 180° apart and the position of the minima indicates the orientation of the fibers (see green and magenta curves). In regions with two crossing fiber bundles (ii), we observe four peaks (peaks that lie 180° apart belong to one fiber bundle). The distance between two neighboring peaks indicates the fiber crossing angle (here: 90°).

Figure 1c shows the scattering patterns obtained from FDTD simulations of parallel fibers (i) and of two fiber bundles with 90° crossing angle (ii). To enable a direct comparison with the measured data, the scattering patterns were evaluated along the circle of illumination (36.3° from the center, see white dashed circle in the scattering patterns). Before evaluation, a Gaussian blur with a diameter of 10° in angular space was applied to the scattering patterns to take the finite size of the hole of illumination into account.

The graphs obtained from the simulations (Fig. 1c) correspond very well to the graphs obtained from the measurement (Fig. 1b). This shows that our simulations make accurate predictions and that we can use light scattering measurements to predict the substructure of brain tissue such as the crossing angle of the nerve fibers. In the case of fibers with small crossing angles or multiple crossings, the sample should be illuminated with smaller angle distances to resolve more details in the scattering pattern. Future studies should address an automated evaluation and interpretation of the scattering measurements.

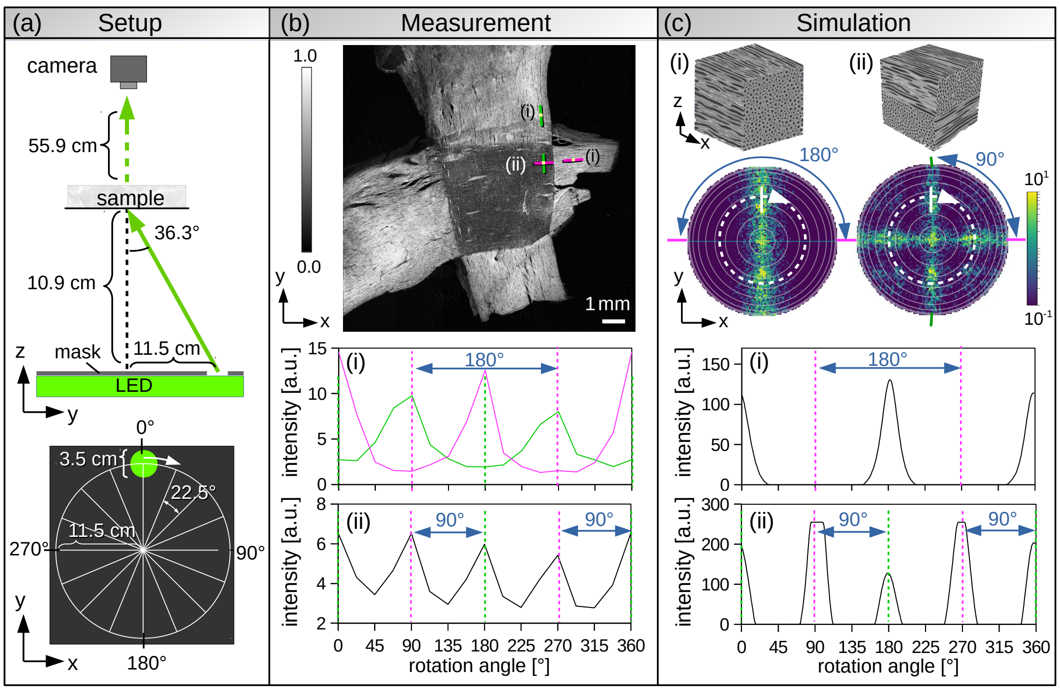

Fig. 1. **(a)** Measurement setup (side view and top view of the mask). **(b)** Measurement results of two crossing nerve fiber bundles (optic tracts): The upper image shows the strength of the birefringence signal obtained from a 3D-PLI measurement with 1.33 µm/px [3]. The graphs below show the average transmitted light intensity obtained from the scattering measurement in the evaluated regions (two regions with parallel fibers in green and magenta (i) and one region with crossing fibers (ii)) plotted against the rotation angle of the hole of illumination. **(c)** Scattering patterns obtained from FDTD simulations of (i) parallel fibers and (ii) two fiber bundles with 90° crossing angle (upper images). The graphs below show the intensity of the corresponding scattering pattern, evaluated along the dashed white circle in clock-wise direction.

References

1. M. Menzel *et al.* "Finite-Difference Time-Domain simulations of transmission microscopy enable a better interpretation of 3D nerve fiber architectures in the brain," *arXiv*:1806.07157.
2. M. Menzel *et al.* "Finite-Difference Time-Domain Simulation for Three-Dimensional Polarized Light Imaging," *Lecture Notes in Computer Science*, K. Amunts, L. Grandinetti, T. Lippert, and N. Petkov, eds., Vol. 10087 (Springer, 2016), pp. 73–85.
3. M. Axer *et al.* "A novel approach to the human connectome: Ultra-high resolution mapping of fiber tracts in the brain," NeuroImage **54**(2), 1091–1101 (2011).