

Imaging brain morphology with ultrahigh resolution optical coherence tomography

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ABSTRACT

A broadband, Er doped fiber laser source ($\lambda_c = 1350$ nm, $\Delta\lambda = 400$ nm, $P_{out} = 50$ mW) was coupled to a free space OCT system to achieve $2\mu\text{m}$ axial resolution in air ($1.4\mu\text{m}$ in biological tissue). Ex-vivo brain samples from a honeybee and a white New Zealand rabbit were imaged with this system. The high resolution OCT images permitted visualisation of various morphological details.

Keywords: Optical coherence tomography, Ti:Al₂O₃ laser, imaging of biological tissue .

INTRODUCTION AND METHODS

Optical coherence tomography (OCT) is an optical technique that enables non-invasive, high resolution *in vivo* imaging in transparent and non-transparent biological tissue¹⁻³. OCT was previously applied to imaging brain tissue pathology⁴, though here we report, as we believe for the first time, ultrahigh resolution, enhanced penetration images of ex-vivo brain tissue, that enable visualization of fine morphological details.

A state of the art, Er doped fiber-optic laser (MENLO SYSTEMS, $\lambda = 1100$ nm to 1800 nm, $P_{out} = 50$ mW) was coupled into a free space OCT system previously described in reference⁵. Due to a 12 dB step in the laser spectrum at 1550 nm, only the shorter wavelength portion of the emission spectrum was used ($\lambda_c = 1350$ nm, $\Delta\lambda = 400$ nm and $P_{out} = 4.2$ mW) in this project. All optical components were selected to support the propagation of broadband light through the OCT system and to compensate for any polarization and dispersion mismatch between the sample and reference arm of the interferometer. The OCT system was evaluated to provide $2\mu\text{m}$ axial, and $4\mu\text{m}$ lateral resolution in air (corresponding to $1.4\mu\text{m}$ axial and $3\mu\text{m}$ lateral in biological tissue), and sensitivity of 95 dB for 500 μW at the sample surface. Full fringe detection was realized by use of a high speed (10Ms/s), 16 bit A/D converter to digitize the fringe data, thus enabling extraction of functional and spectroscopic information.

The imaged brain tissue samples were prepared by fixing the whole brains of a honeybee and a New Zealand rabbit in a 4% Paraformaldehyde solution.

RESULTS AND DISCUSSION

A structural diagram of the honeybee brain is shown in fig.1. A succession of images were acquired in order to build a 3D view of the bee brain. A representative scan over the α globules of the mushroom body and the visual sensory complex (fig.1 A) reveals the honnecomb like structure of the later, comprised of small compartments ($30\text{-}50\mu\text{m}$ in diameter, see arrow). Another scan (fig.1B) through the β globules of the mushroom body and the optical lobes (LO) reveal limiting membranes in the LO lobe and deeply set morphological features within the β globules. Approximately the same location was imaged with a fiberoptic OCT system at 800 nm central wavelength. Comparison between images B and C on fig.1 demonstrate the enhanced penetration at longer wavelengths.

A transverse OCT scan acquired through the gray and the white matter of a frontal lobe section of the fixed rabbit brain aimed to provide an evaluation of the optical properties of gray and white brain matter. The OCT transverse scan (fig.2 A) demonstrated that the penetration depth in the gray matter is slightly better. In addition,

fine fiber bundles (20-50 μm in diameter) buried in the white matter were also resolved. Fig. 2C shows a longitudinal OCT scan in the rabbit brain frontal lobe. The thin membrane enclosing the blood vessel network is resolved, though the depth penetration is limited only to the gray matter layer ($\sim 3\text{ mm}$ thickness).

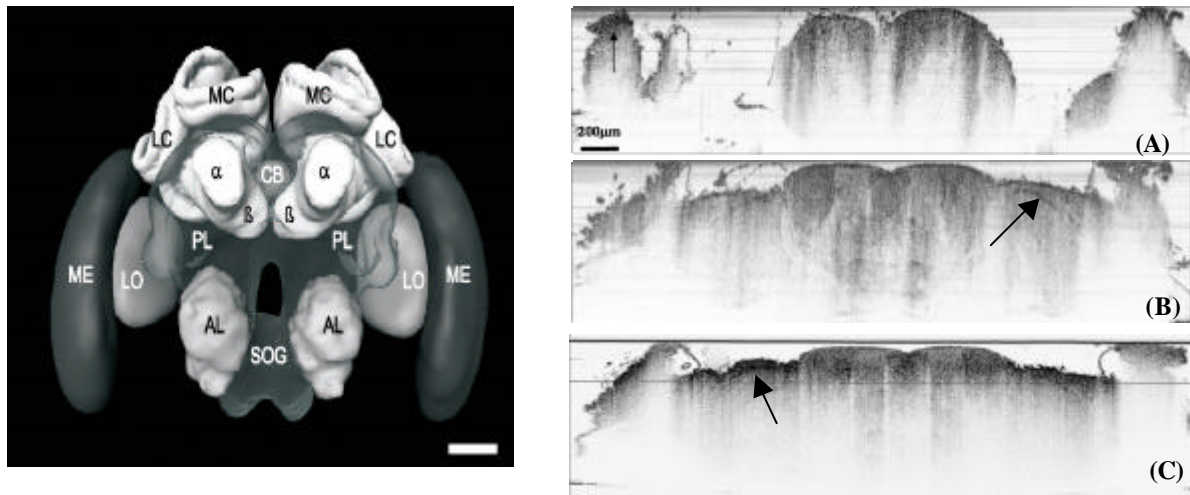


Fig.1 Structural diagram of the honeybee brain (left); OCT images (right): (A) through the ME visual sensory complex and the α globules of the mushroom body; (B) through the β globules, the optical lobes, LO, and the ME complex (B); (C) same location as in (B) but acquired at $\lambda = 800\text{ nm}$. The arrows indicate limiting membranes in the β globules and cell structures in the visual sensory complex. Scalebar is 200 μm .

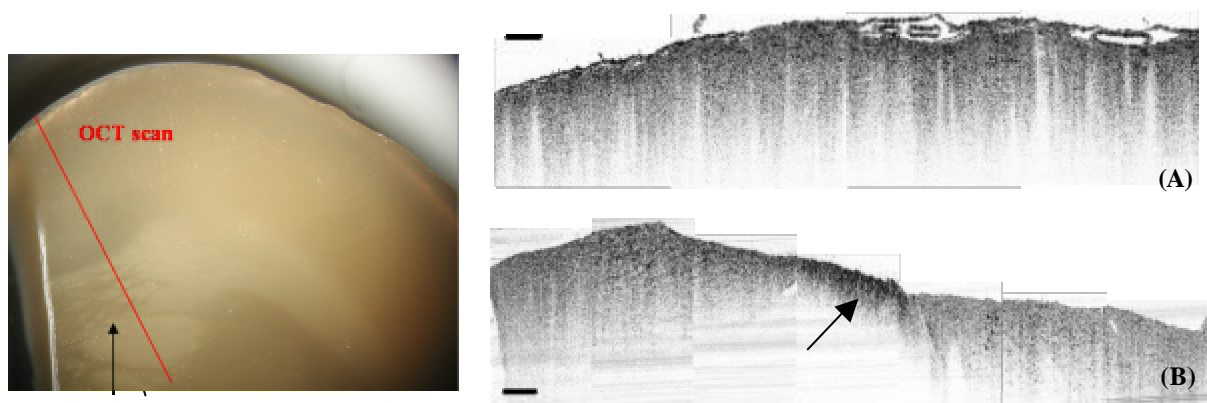


Fig.2 A digital photograph of a transversal section of the rabbit brain. The red line indicates an OCT transversal scan and the arrow points to a group of fiber bundles in the white matter (left). A transverse OCT scan (A) – the arrow indicates the resolved fiber bundles. A longitudinal OCT scan demonstrating the penetration depth in the rabbit brain tissue (B). Scalebar is 200 μm .

CONCLUSION

We have demonstrated that ultrahigh resolution OCT in the 1300 nm wavelength region permits visualization of fine morphological details at superficial depths ($\sim 1\text{ mm}$) in fixed animal brain tissues. This method may find potential applications as a tool in brain physiology research and as a clinical diagnostics method.

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