Focusing through multimode optical fibres in biological tissue

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Controlling light field propagation through step-index multimode optical fibres (MMF) is challenging due to the unpredictable phase delays and coupling occurring between modes but has several important applications. These applications include biological imaging for which the small diameter (<100 μm) of the fibres offers an avenue for minimally invasive access to deep (cm) locations in living animals. The ability to form a diffraction-limited focus at the MMF distal end (away from the light source) is of particular relevance to optical microscopy as such focus is necessary to achieve a spatial resolution and a signal-to-background ratio sufficient for visualising subcellular structures.

Advanced software and wavefront shaping strategies have been implemented such that deep-brain imaging with one-photon point-scanning fluorescence microscopy can be achieved in living animals using MMF[1-3]. These implementations relied on a calibration procedure providing the full complex field propagation in the MMF and therefore the different shaped wavefronts required for every point in the image. Here, we report on how distal aberrations must be considered during the calibration process. Specifically, we compared the performance of our MMF imaging system for visualising beads and neurons when the calibration is done in air or in a 22% glucose solution. We found that the lateral extent and peak intensity of the excitation volume as well as the spatial resolution and signal-to-background ratio for fluorescence imaging were all significantly improved for brain imaging when the calibration was performed in a milieu with a matching refractive index (22% glucose solution, n=1.37), instead of using the standard approach (air, n=1)[1-3]. Taking into account tissue optical properties is essential for achieving diffraction-limited focusing using an MMF and thus obtaining optimal imaging quality in biological tissue.

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