Focusing light in deep tissue with time-reversed ultrasound microbubble encoded light
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ABSTRACT

Optical scattering of biological tissue limits the penetration depth of conventional optical techniques, which rely on the detection of ballistic photons. Recent developed optical phase conjugation (OPC) technique breaks through this depth limit by shaping an optical wavefront that can “undo” the optical scattering. Assisted with an ultrasound focus, this technique enables optical focusing inside biological tissue in a freely addressable fashion. However, ultrasound modulation efficiency is low and the focusing resolution is limited by the ultrasound. Here we present a new technique, time-reversed ultrasound microbubble encoded (TRUME) optical focusing, which is able to provide high focusing efficiency and sub-ultrasound resolution. This technique achieves the wavefront solution by taking the difference of the optical fields captured outside the sample before and after ultrasound-driven microbubble destruction. A conjugated wavefront was then reconstructed and sent back to the sample to form a focus at the site of microbubble destruction. We experimentally demonstrate that a focus with ~2 um size was formed through a 2-mm thick biological tissue using this method. While the size the microbubble sets the resolution of an individual focus, the scale of the ultrasound focus limits the focusing addressability of this technique. Importantly, by utilizing the nonlinear destruction of microbubbles, the TRUME technique breaks the addressable focus resolution barrier imposed by the ultrasound focus. We experimentally demonstrate a 2-fold improvement in addressability using this effect. Since microbubbles are widely used as ultrasound contrast agents in human, this technique provides a promising solution for focusing light deep inside biological tissue.

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