Shaping therapeutical acoustic images using acoustic holograms

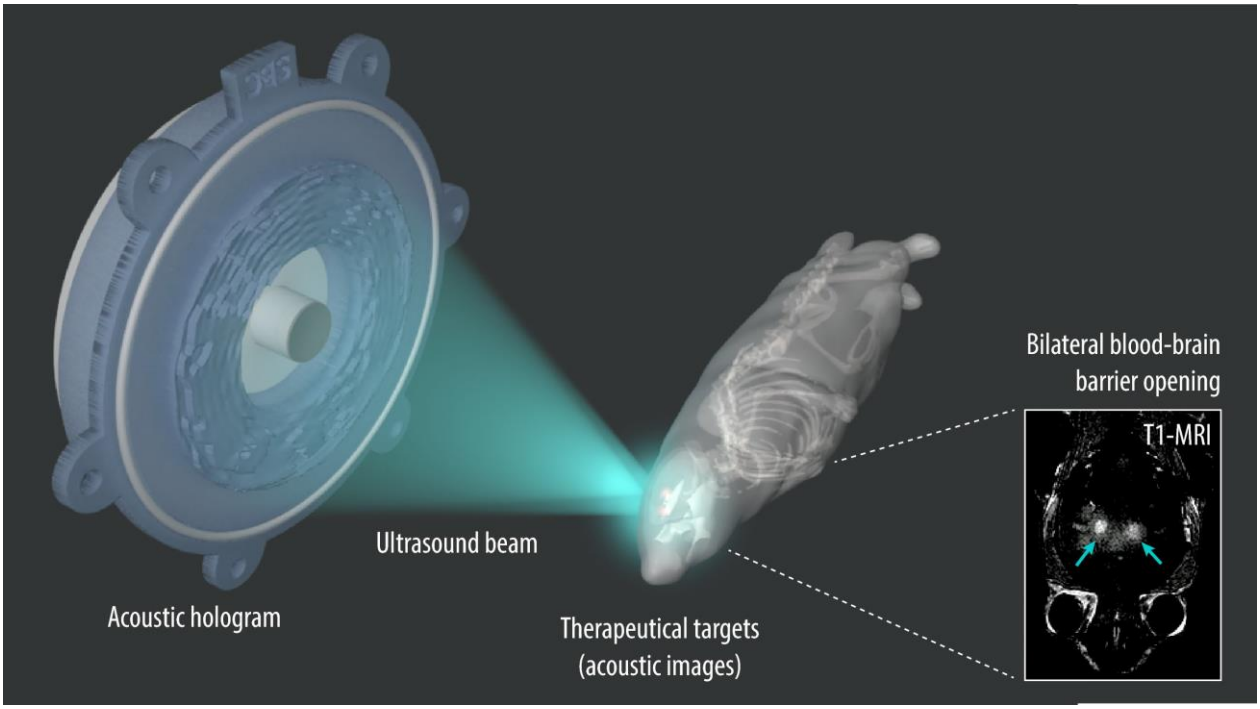
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Optical holograms can modulate light wavefronts to generate visible images [1]. In the same way, acoustic images can also be synthesized by holograms, shaping the areas where mechanical waves present a high amplitude, and areas where the media is at rest. In recent years, acoustic holograms have been exhaustively studied, mainly triggered by the emergence of 3D printing technologies. Artificially structured materials have enabled accurate wavefront engineering for many applications such as particle trapping and manipulation, scattering control and vortex generation, fast 3D-printing, volumetric displays, or 3D imaging [2-4]. Acoustic holograms have found recent application in biomedical applications, in particular in emerging therapeutic applications of focused ultrasound [5-9]. Compared to light, acoustic waves can penetrate deeper into biological tissues. Therefore, acoustic holograms are bursting onto current biomedical applications due to their capability to shape and focus ultrasound fields inside biological media. These engineered materials can encode complex wavefronts to compensate the phase aberrations produced by stiff layers of tissues, such as skull bones in transcranial propagation, enabling the creation of arbitrary therapeutic patterns in the brain or even vortex beams.



In this work, we present the recent advances of acoustic holograms and structured media to engineer the acoustic wavefront and use focused ultrasound beams in biomedical applications. We show how acoustic holograms can shape therapeutical acoustic images for the non-invasive treatment of neurological disorders, to produce cavitation patterns and thermal patterns. When targeting acoustic beams into the brain, accurate focusing is mainly limited due to the strong phase aberrations produced by the refraction and attenuation of the skull. Acoustic holographic lenses can overcome these limitations by synthetizing aberration-free ultrasonic fields of complex spatial distribution inside the skull. Our results show that, using low-cost 3D-printed lenses, ultrasonic beams can be focused not only on a single point, but overlapping at one or various target structures simultaneously, e.g., left and right hippocampi. Other complex fields such as vortex beams for trapping small objects can also be obtained. The technique was tested to perform localized drug-delivery in the brain of a small laboratory animal. A specimen was injected with microbubbles and gadolinium, a magnetic resonance contrast agent. Then, using an acoustic hologram we focused an ultrasound beam at two symmetrical focal spots in the left and right brain hemispheres.

Under the action of ultrasound, microbubbles perform mechanical oscillations that disrupt the blood-brain barrier locally, following a pattern given by the acoustic images. Local gadolinium extravasation was confirmed by magnetic resonance imaging, where two spherical focal spots were observed. In addition, acoustic holograms encode the multiple reflections inside the skull, increasing the angular spectrum of the acoustic image. In this way, acoustic holograms enabled localized drug-delivery in the brain with diffraction-limited beyond the performance of existing approaches.

The technique was also testes to shape thermal patterns in soft tissue to rise the temperature locally. Magnetic resonance imaging (MRI)-compatible holograms were designed by time-reversal simulations and manufactured using 3D-printing for the experiments. Several patterns were tested and validated using magnetic resonance thermometry imaging and thermographic camera in gelatin-milk phantoms and in an ex vivo liver tissue. We observed that holograms can shape heating patterns in arbitrary regions. Using holograms, we were able to shape the focal spot of the ultrasound source to match a therapeutical target. These results open new paths for emerging therapeutic ultrasound applications in neurology, including blood-brain barrier opening for localized drug-delivery or neuromodulation using low-cost systems. On the other hand, increasing the temperature using low-cost and MRI-compatible holographic transducers might be of great interest for many biomedical applications, such as ultrasound hyperthermia, physiotherapy, or high intensity focused ultrasound, where the control of specific thermal patterns is needed.

References

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