Full-Wave Joint Inversion in Transcranial Photoacoustic Computed Tomography
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Photoacoustic computed tomography (PACT) is an emerging computed imaging modality that exploits optical contrast and ultrasonic detection principles to form images of the absorbed optical energy density within tissue. In PACT, the biological tissue of interest is irradiated with a short laser pulse. Under the condition of thermal confinement, the absorption of the optical energy results in the generation of pressure waves via the photoacoustic effect. These pressure waves are subsequently detected using broadband ultrasound transducers. The PACT reconstruction problem corresponds to a time-domain inverse source problem, where the initial pressure distribution is recovered from the measurements recorded on an aperture outside the support of the source.

Transcranial PACT holds great promise for human brain imaging. However, a major challenge in transcranial PACT brain imaging is to compensate for aberrations in the measured acoustic data due to the propagation of the photoacoustic wave fields through the skull. To properly account for these effects, a wave equation-based inversion method should be employed that can model the heterogeneous elastic properties of the medium. Previously, iterative image reconstruction methods for 3D transcranial PACT have been developed based on the elastic wave equation. To accomplish this, a forward model based on a finite-difference time-domain discretization of the elastic wave equation has established. Subsequently, gradient-based methods were employed for computing penalized least squares estimates of the initial pressure distribution that produced the measured photoacoustic data. The results in Fig. 1 show the need for compensating for skull-induced acoustic distortions and the ability of wave-equation-based iterative reconstruction algorithms to compensate for them.

In the wave equation-based iterative reconstruction algorithm, accurately compensating for the distortions induced by the skull requires prior knowledge of the spatial distributions of the acoustic parameters within the skull. However, such information may be difficult to obtain in practice. To circumvent this, a joint reconstruction (JR) method for transcranial PACT is reported in this work. In the JR method, the spatial distribution of the skull’s acoustic parameters is reconstructed concurrently with the sought-after initial pressure distribution. This approach represents a paradigm shift in the way that images are reconstructed in transcranial PACT imaging systems. Because the spatial distribution of the skull acoustic parameters will automatically be accounted for in the joint-reconstruction procedure, the proposed method holds great promise for and maximizing image quality in transcranial PACT.

Fig. 1. Reconstructed maximum amplitude projection (MAP) images corresponding to the cases: (a) reference image with skull absent; (b) image reconstructed by a backprojection algorithm that ignored the skull; and (c) image reconstructed by an iterative algorithm that compensates for the skull.