Supplementary Information

Axial evolution of the waveform

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To investigate how this propagation behaviour depends on the prescribed focal distance, we generated single-point phase holograms with focal positions $F(0, 0, z_f)$ for z_f = 2.5, 5.0, 7.5, 10.0, 14.0, and 20.0 mm. Figure 1 shows the corresponding measured and simulated pressure waveforms along the acoustic axis. For Z = 2.5, 5.0, and 7.5 mm, the pressure amplitude initially increases and reaches a maximum near the prescribed focal position before decreasing with propagation distance. At larger distances, the waveform changes only weakly and approaches that generated by the non-focusing hologram.

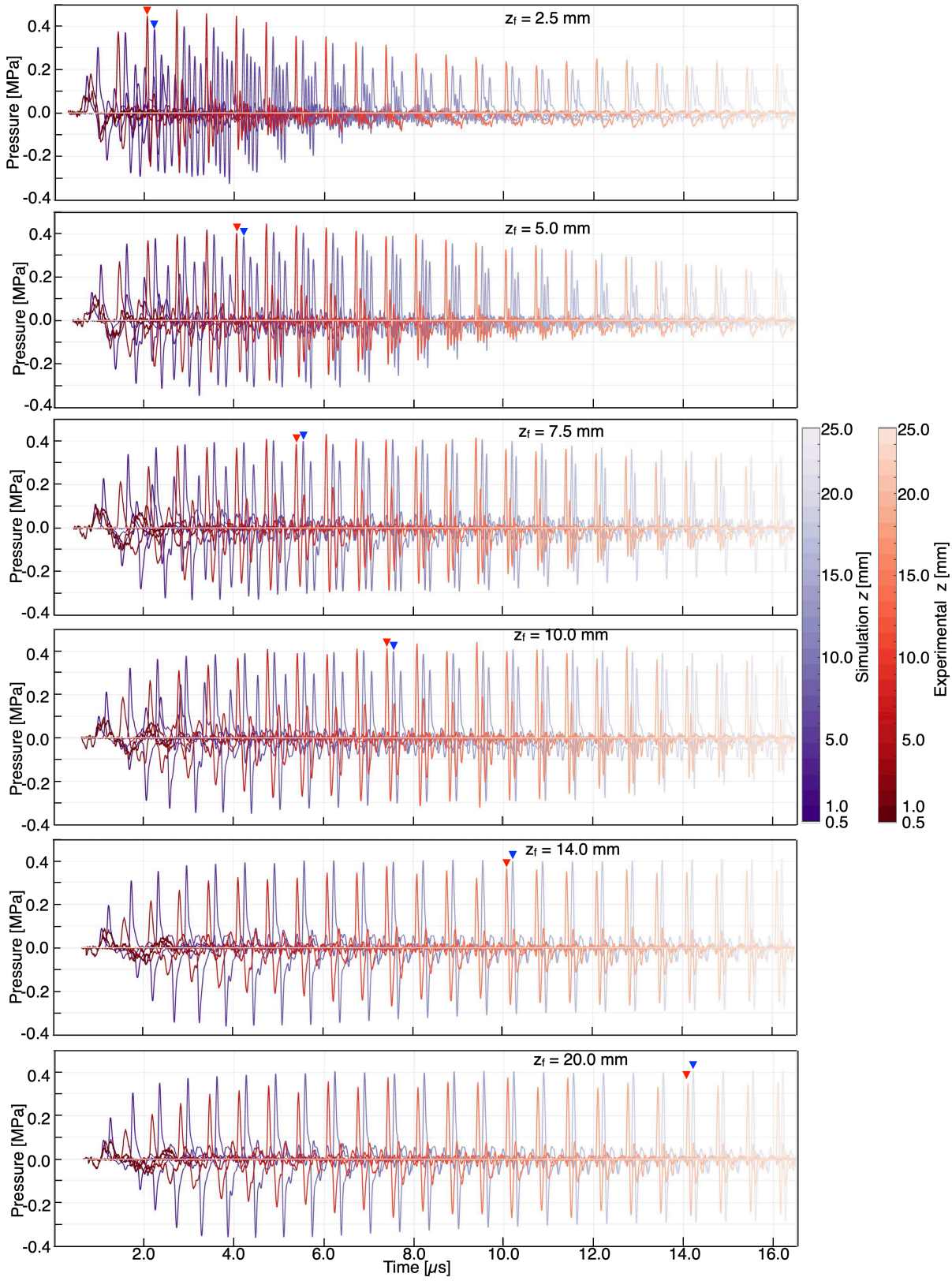
For larger focal distances, the axial evolution changes qualitatively. For z_f = 10.0 mm, the pressure amplitude increases up to approximately z = 10 mm and decreases gradually beyond $z \approx 14$ mm. For z_f = 14.0 and 20.0 mm, the pressure amplitude increases progressively towards the prescribed focal position and varies only weakly beyond it. These differences arise from the interplay between holographic focusing and near-field diffraction from the finite photoacoustic source.

To estimate the extent of the acoustic near field, we consider a circular aperture of radius a, for which the position of the outermost axial interference maximum is approximately

$$z_p = \frac{a^2}{\lambda}, \tag{1}$$

where λ is the acoustic wavelength. The non-focusing hologram exhibits prominent spectral maxima at 1.79 and 3.42 MHz (Fig. **??**D), corresponding to wavelengths of approximately 837 and 439 μm in water, respectively. Taking the effective source diameter $2a$ as the short axis of the projected optical field, $2a$ = 5.6 mm, yields $z_p \approx 9.4$ and 18.3 mm for these two frequencies.

The focal positions z_f = 2.5–7.5 mm therefore lie within the near-field regions associated with both spectral maxima, whereas z_f = 14.0 and 20.0 mm extend beyond the near-field distance associated with at least one of them. The distinct axial pressure evolution observed for different focal positions thus reflects the superposition of the prescribed holographic focusing with the frequency-dependent diffraction pattern of the finite photoacoustic source.



Supplementary Fig. 1. Dependence of the axial pressure evolution on the prescribed focal distance z_f. Single-point phase holograms were designed to focus at $F(0, 0, z_f)$. Red curves show hydrophone measurements and blue curves the corresponding numerical simulations. Waveforms were obtained at z = 0.5 mm and subsequently at 1-mm intervals up to z = 25 mm. Triangles indicate representative axial positions at z_f = 2.0, 5.0, 7.0, 10.0, 14.0, and 20.0 mm.