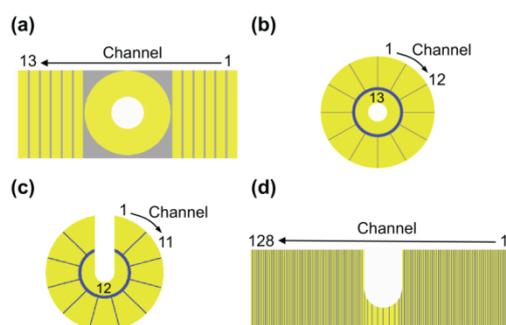
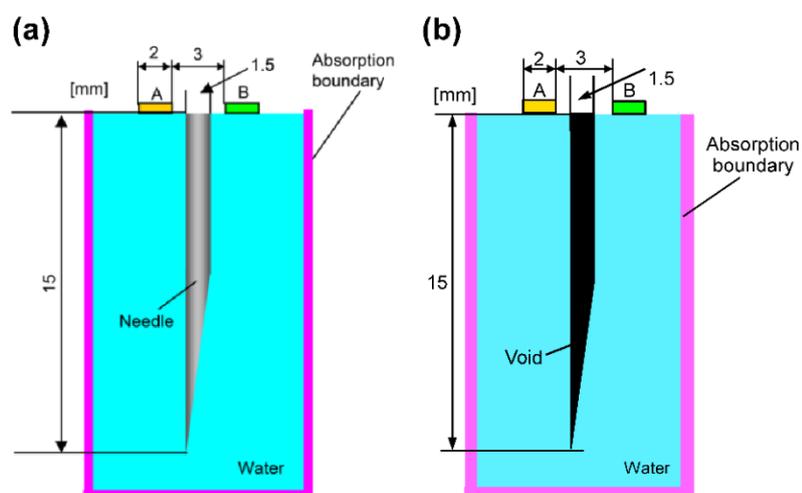


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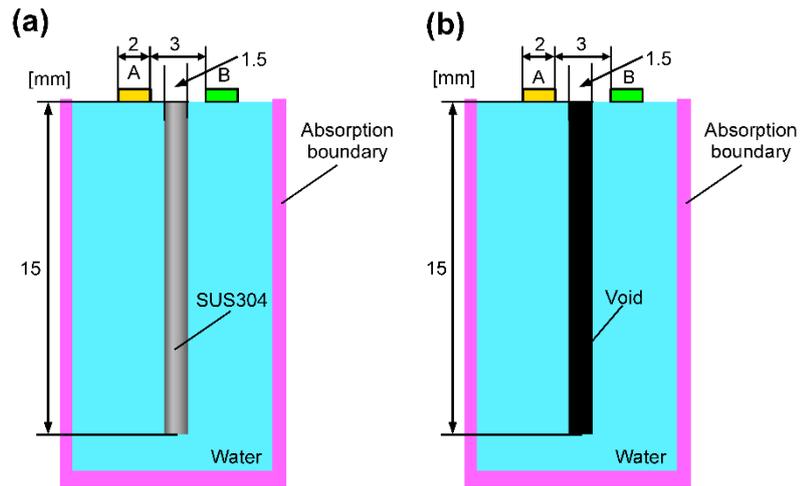
# Needle Tip Detection Using Ultrasound Probe for Vertical Punctures: A Simulation and Experimental Study



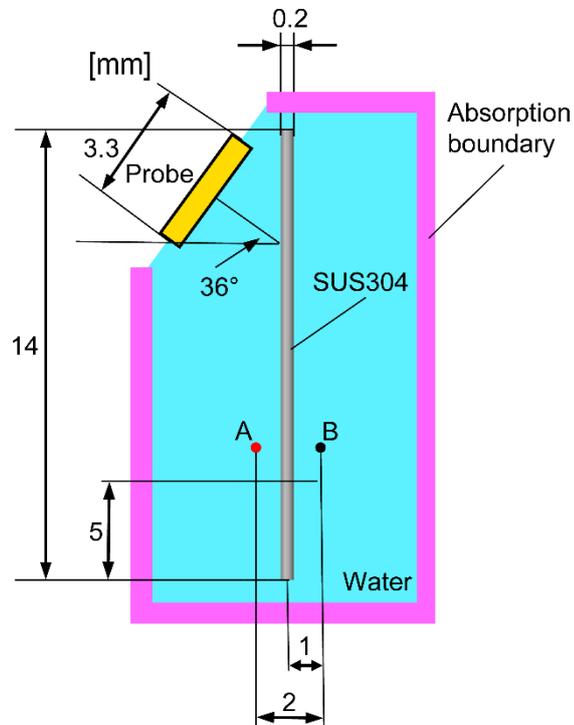
**Figure S1.** Four types of ultrasound array probes for vertical puncture: (a) 13-element linear array ultrasound probe with through-hole in the center (type A) [21]; (b) 13-element ring-type array ultrasound probe (type B) [20]; (c) U-type slit ring-type array ultrasound probe (type C); and (d) 128-element linear array probe (type D) [21]. (a) and (d) are Copyright (2014) The Japan Society of Applied Physics.



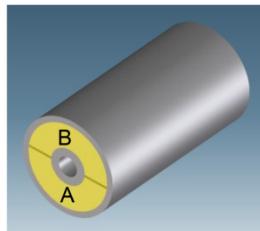
**Figure S2.** Needle simulation model [21]: (a) stainless steel needle and (b) void needle. (a) is Copyright (2014) The Japan Society of Applied Physics.



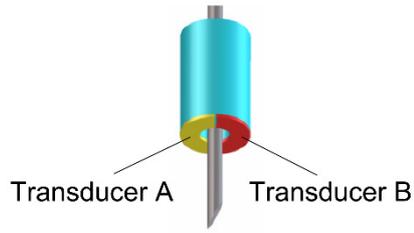
**Figure S3.** Cylinder simulation model: (a) stainless steel cylinder and (b) void cylinder.



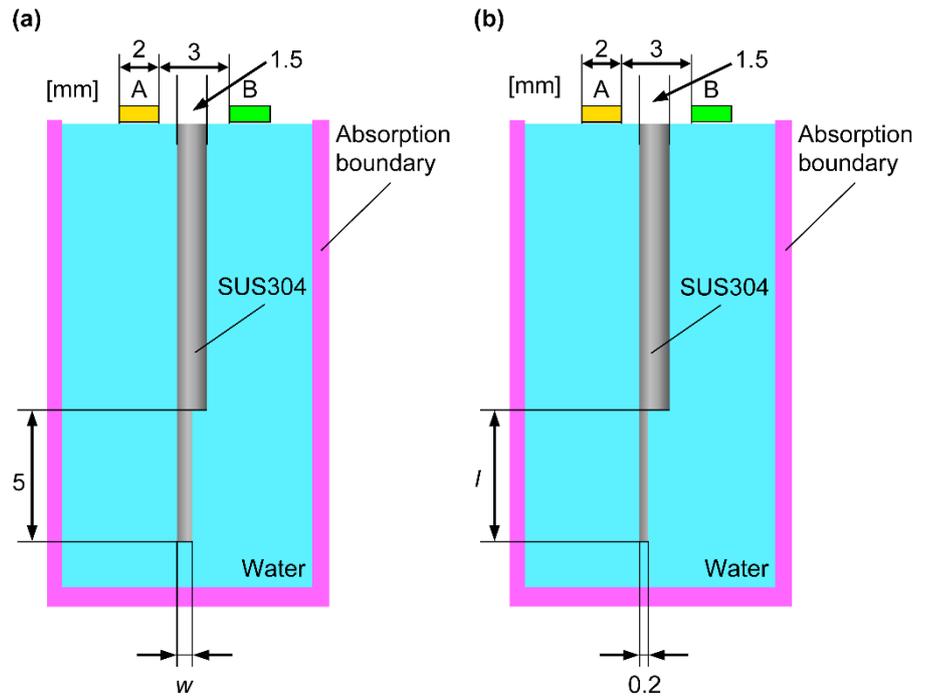
**Figure S4.** Ultrasound-guided wave simulation model.



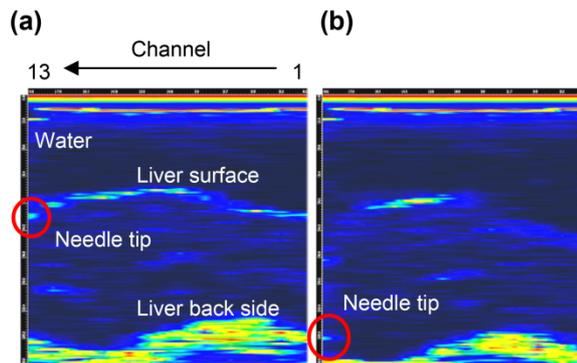
**Figure S5.** Ultrasound probe composed of separated transducers [20].



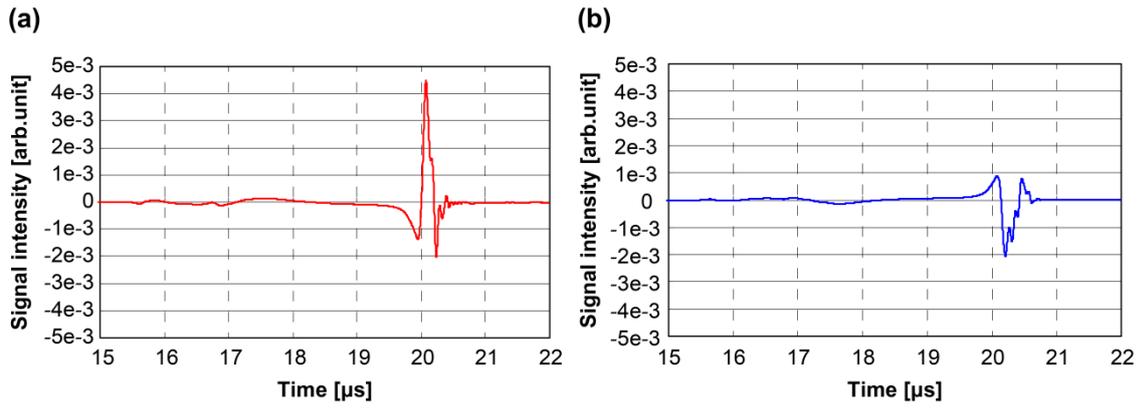
**Figure S6.** Configuration of the needle slope.



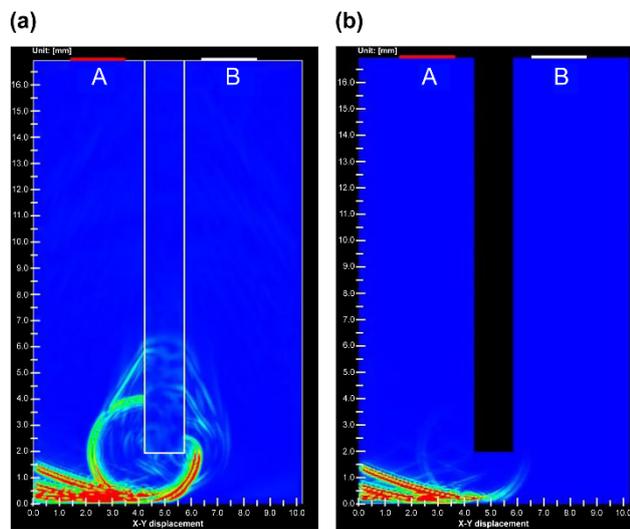
**Figure S7.** Simulation models for needle tip detection: (a) cylinder tip width  $w$  is 0.1–1.0 mm and (b) cylinder tip length  $l$  is 1–10 mm.



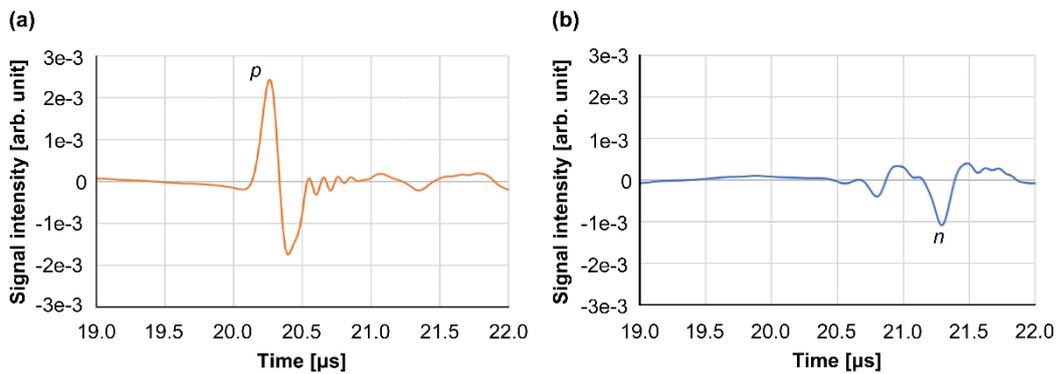
**Figure S8.** B-mode images of the needle tip and porcine liver using a 13-element ring-type array probe (Type B): (a) needle tip near the surface of the liver and (b) needle tip near the back of the liver [20].



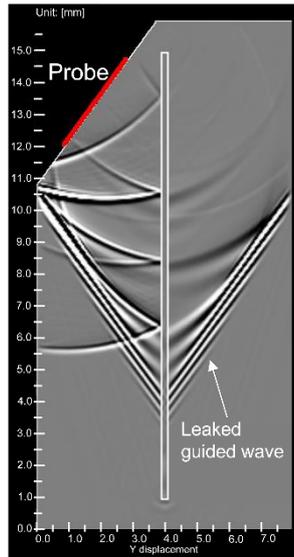
**Figure S9.** Waveforms from the needle tip in the simulation: (a) at A-side receiver and (b) at B-side receiver.



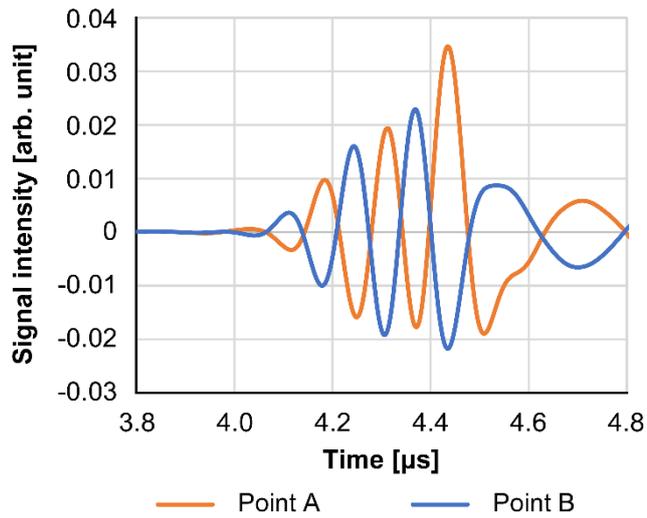
**Figure S10.** Simulation image of ultrasound propagation at the tip of the cylinders: (a) stainless steel cylinder and (b) void cylinder.



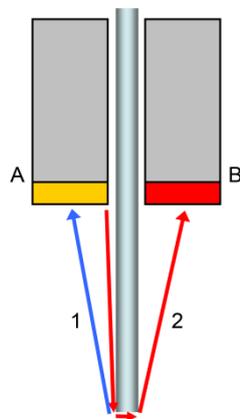
**Figure S11.** Waveforms from the stainless cylinder in the simulation: (a) A-side receiver and (b) B-side receiver.



**Figure S12.** Ultrasound propagation of guided wave: frequency is 7 MHz, and white indicated positive amplitude, whereas black indicated negative amplitude.



**Figure S13.** Waveform of leaked ultrasound-guided wave at points A and B in Figure S4.



**Figure S14.** Propagation paths for the cylinder [26]. Red and blue arrows indicate inverse phases.

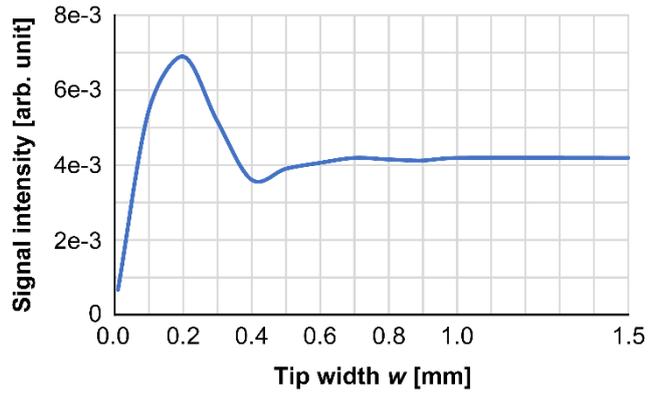


Figure S15. Relationship between tip width and signal intensity.

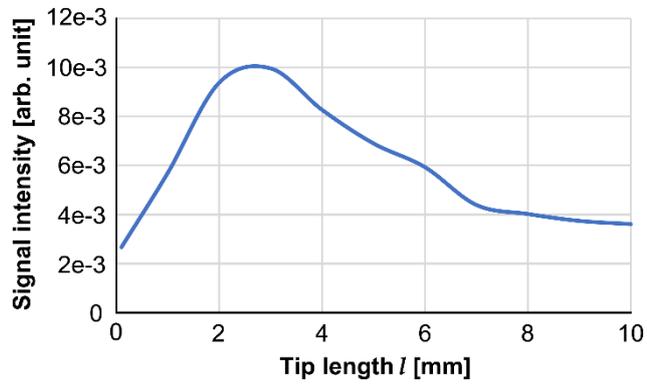


Figure S16. Relationship between tip length and signal intensity.

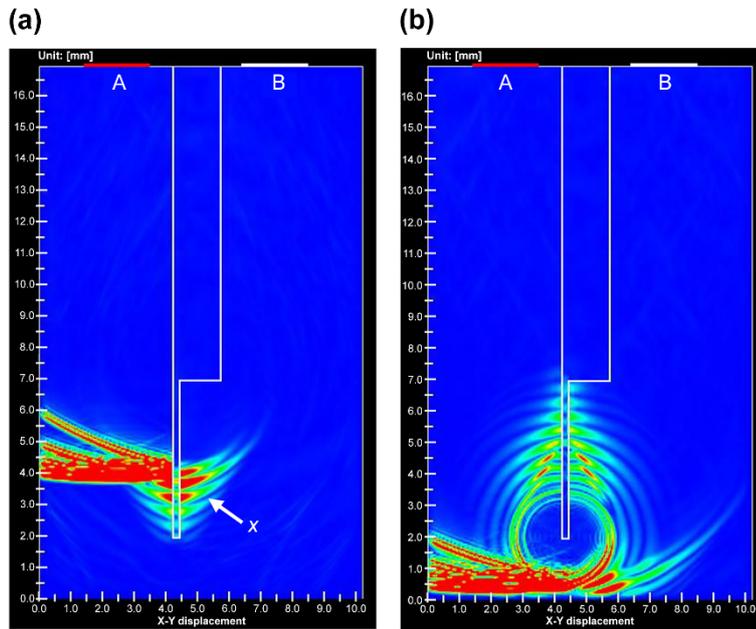
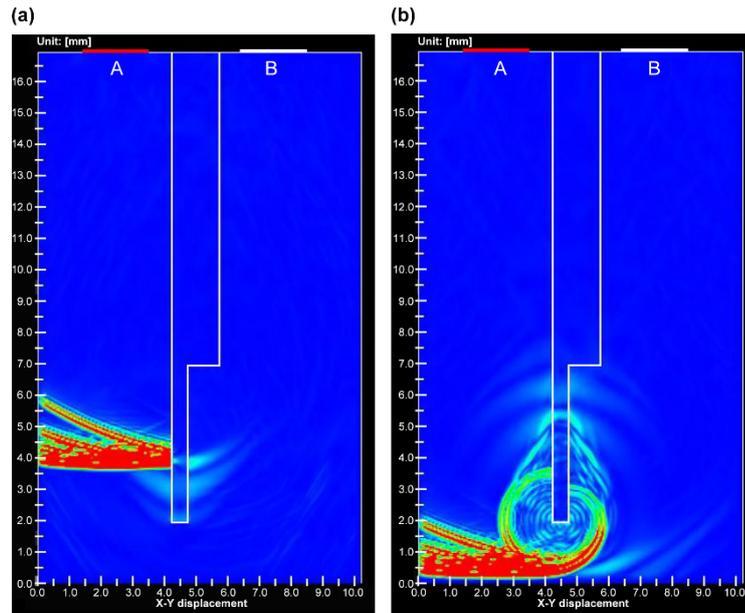


Figure S17. Ultrasound propagation at a 0.2-mm tip width: (a) before reflecting at the tip and (b) after reflecting at the tip.



**Figure S18.** Ultrasound propagation at a 0.5-mm tip width: (a) before reflecting at the tip and (b) after reflecting at the tip.