Imaging Capability at Close Range of High Frequency Ultrasound Transducer on the Perforation of Bony Walls Simulating Pedicle Screw Placement

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Research

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Abstract

Background: Ultrasound has been proved to be a promising alternative spine navigation method. High frequency ultrasound transducer has the advantage of high resolution on surface structure, but imaging at close range is difficult, especially in narrow space of the pilot-hole in pedicle.

Methods: Twenty cortical bone chips were made and different size of hole with diameter of 1mm, 2mm, 3mm or 5mm was randomly carved in each bone chip. A tailored 30MHz high frequency transducer scanned bone samples at the distance of 4mm, 3mm, 2mm and 1mm. Successive transmission ringingeffect elimination, Hilbert transform and Gray-scale mapping method were utilized to process and optimize attained original images.

Results: At the distance of 4mm, 3mm, 2mm and 1mm, the holes with diameter of 5mm, 3mm and 2mm could be discerned. At the distance of 1mm, only the holes with 5mm and 3mm could be clearly distinguished and the 2mm hole appeared obscure. The holes with diameter of 1mm could not be detected at any distance. The holes with diameter of 2mm were able to be detected at the distance of 1mm.

Conclusions: This study indicated that the high frequency transducer had limited imaging capability at close range on the bony surface. These results lay a foundation for further developing a novel ultrasound-based spinal pedicle interior imaging and navigation system.

Full Text

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Figures

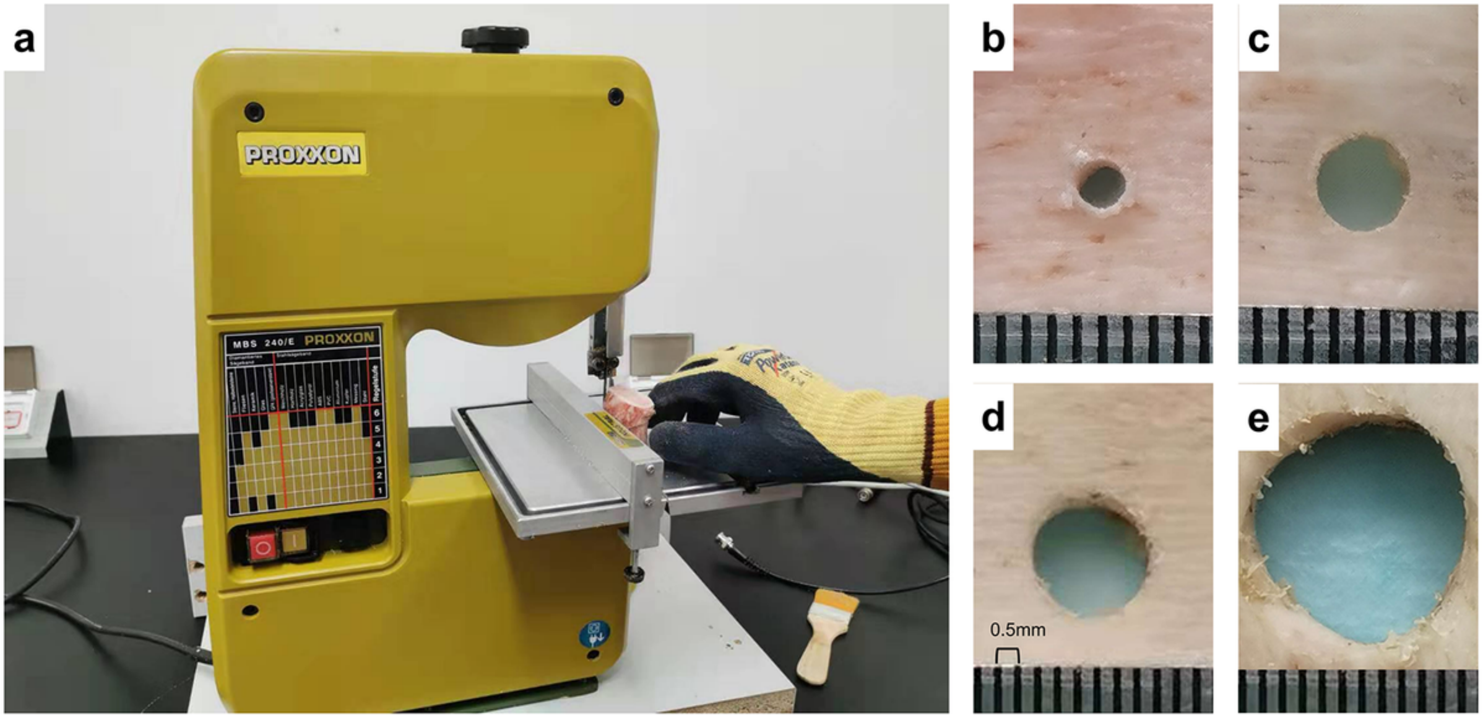

Figure 1

(a) The Chainsaw is used to fabricate the cortical bone chips. (b) The bone chip with diameter of 1mm. (c) Diameter of 2mm. (d) Diameter of 3mm. (e) Diameter of 5mm. The scale of ruler is 0.5mm.

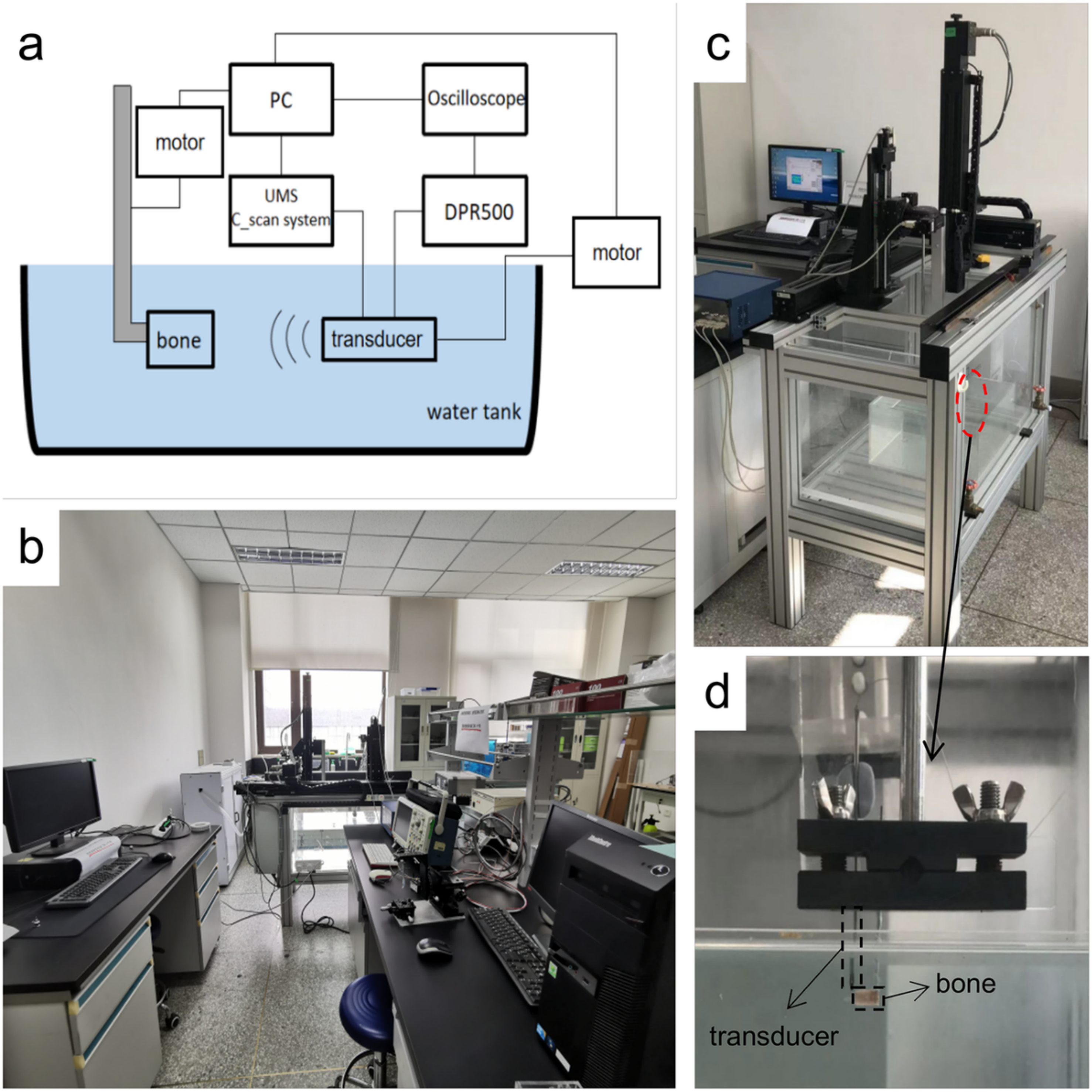

Figure 2

Experiment system used for ultrasonic detecting on cortical bone samples. (a) The schematic diagram. (b) Stereogram. (c) The bone specimen is fixed and measured by USM III. (d) Scanning is performed in the water bath.

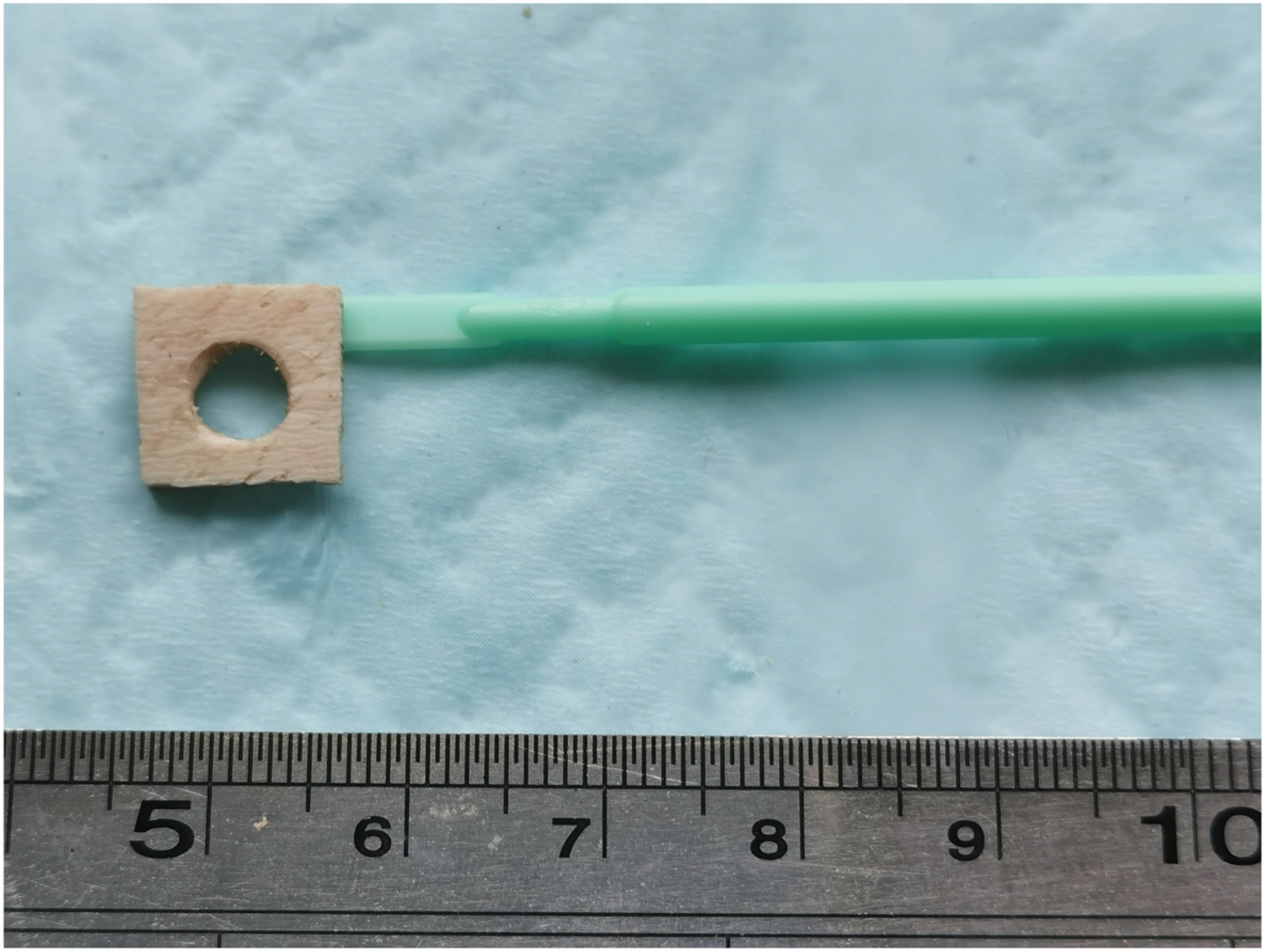

Figure 3

The ABS rod serving as a weak ultrasonic reflector is used to fix the bone sample.

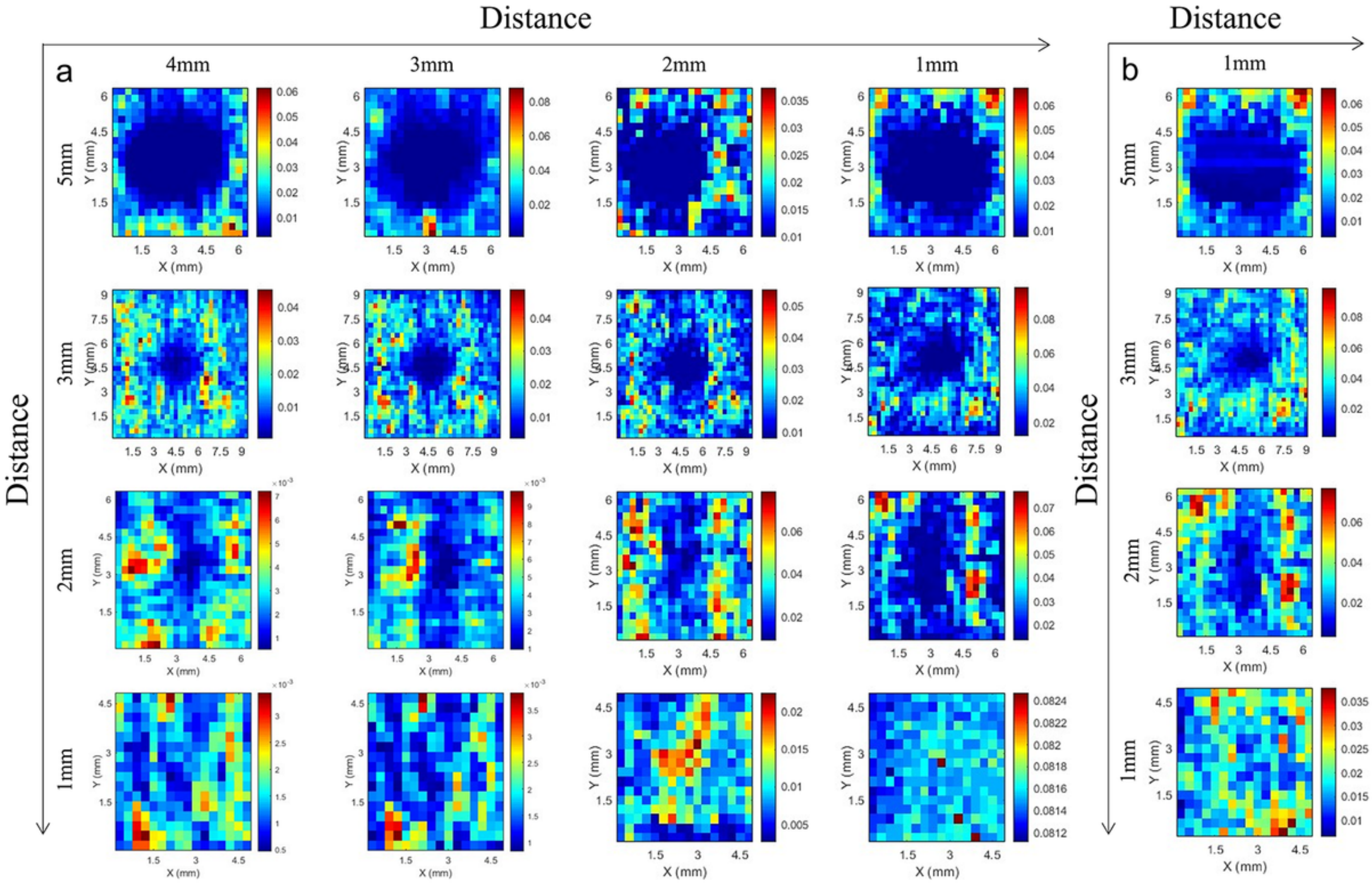

Figure 4

Original sound field images attained by 30MHz ultrasound transducer (a) The holes with diameter of 5mm, 3mm and 2mm can be discerned at the distance of 4mm,3mm,2mm and 1mm from the transducer to the bone surface. The hole with diameter of 1mm cannot be detected at any distance. (b) Further processed by the transmission ringingeffect elimination method, the hole with diameter of 1mm still could not be discerned. (Each pixel of the generated image represents a 0.3mm× 0.3 mm square, from which we can simply estimate the dimension of the ultrasound image to be measured).

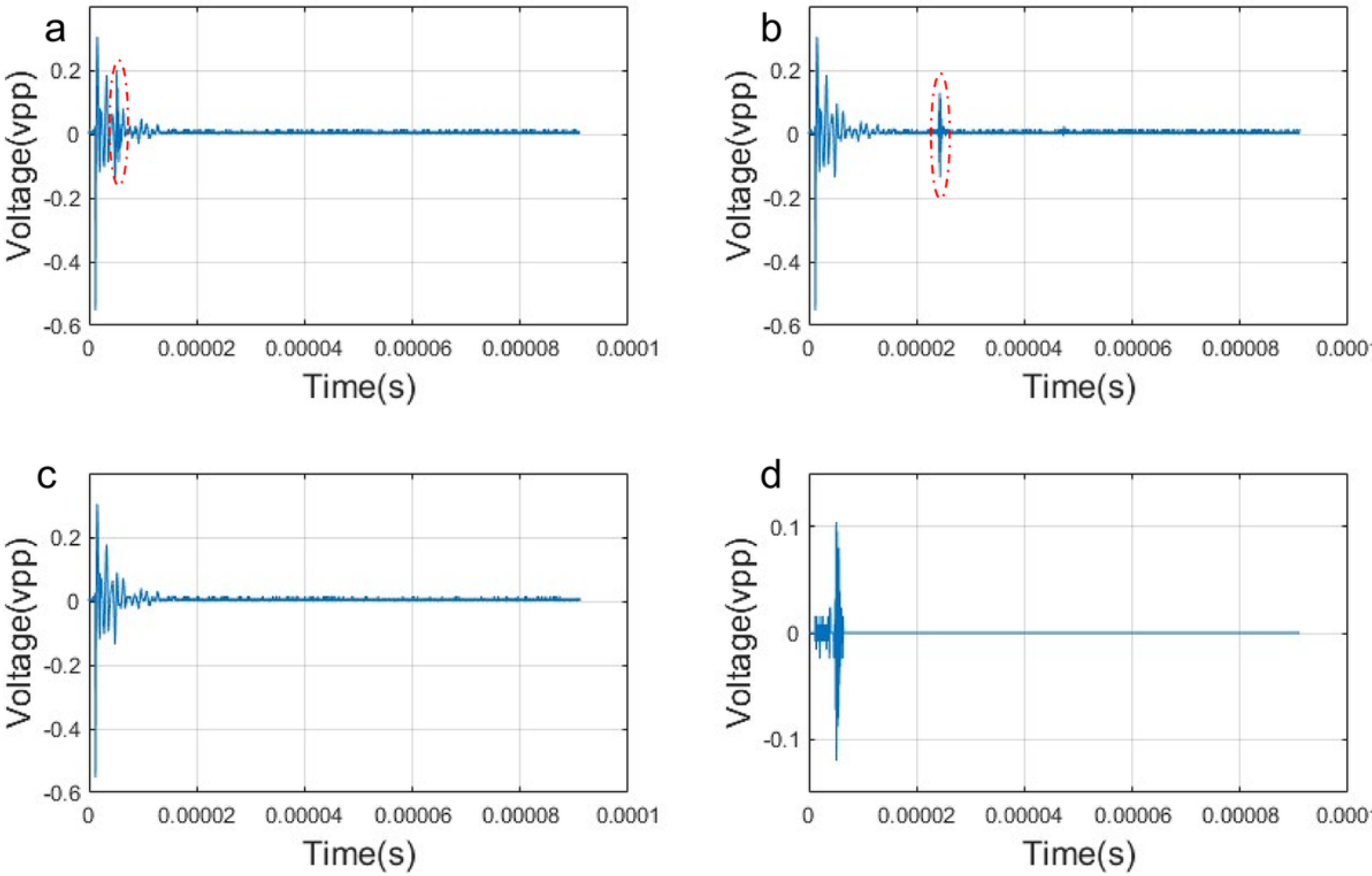

Figure 5

(a) The echo-signal is submerged in transmission ringingeffect signal (The pulse curve circled in red is the echo signal). (b) The echo-signal is outside of the transmission ringingeffect signal (The pulse curve circled in red is the echo signal). (c) Transmission ringingeffect signal. (d) The pure echo signal in Fig. 5(a) obtained by eliminating the transmission ringingeffect signal.

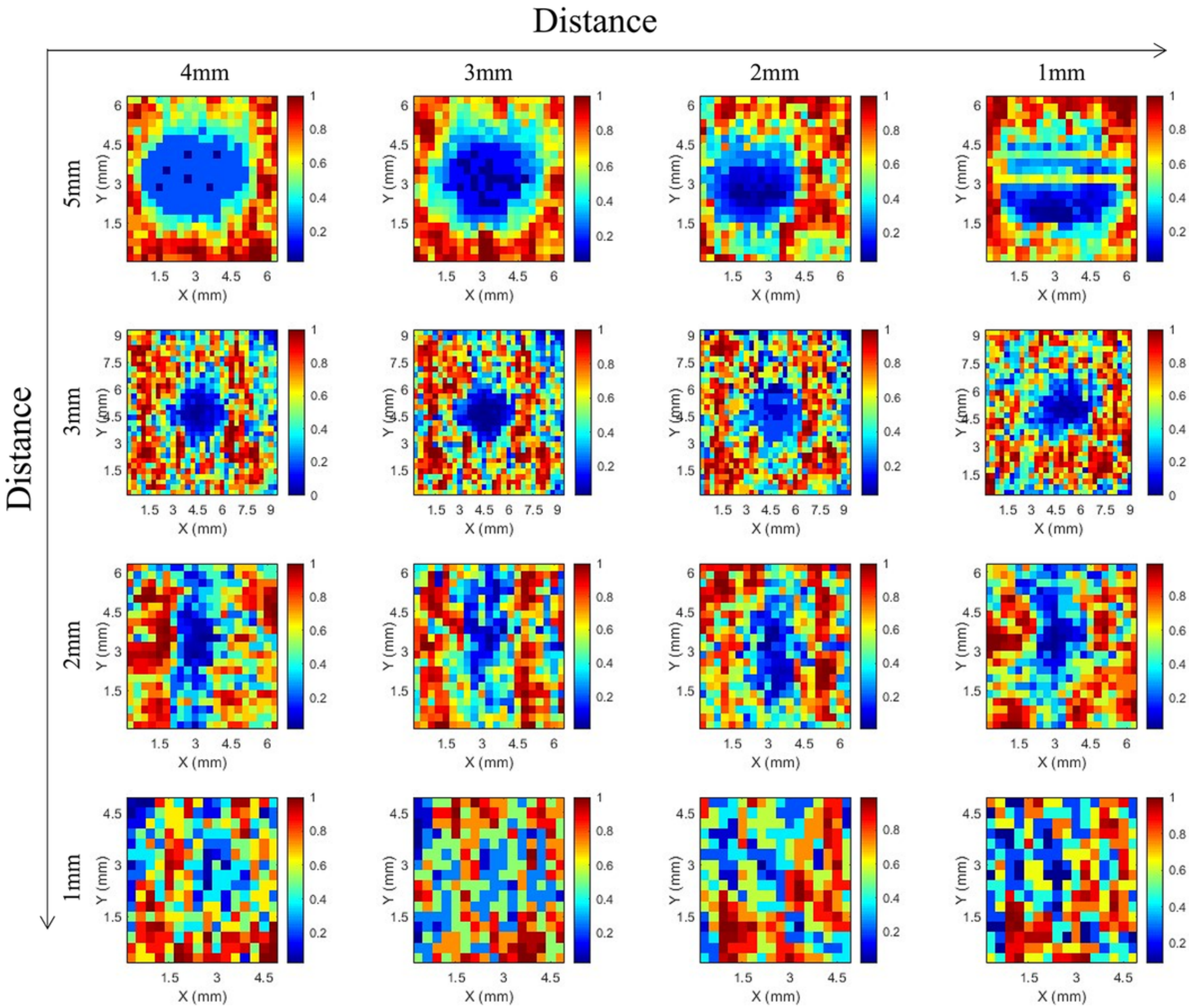

Figure 6

Hilbert transform and logarithmic function based gray-scale mapping method are sequentially utilized to achieve B-mode images. The images of the holes with diameter of 5mm, 3mm and 2mm are clearer than before, and the hole with diameter of 1mm still cannot be detected at any distance.

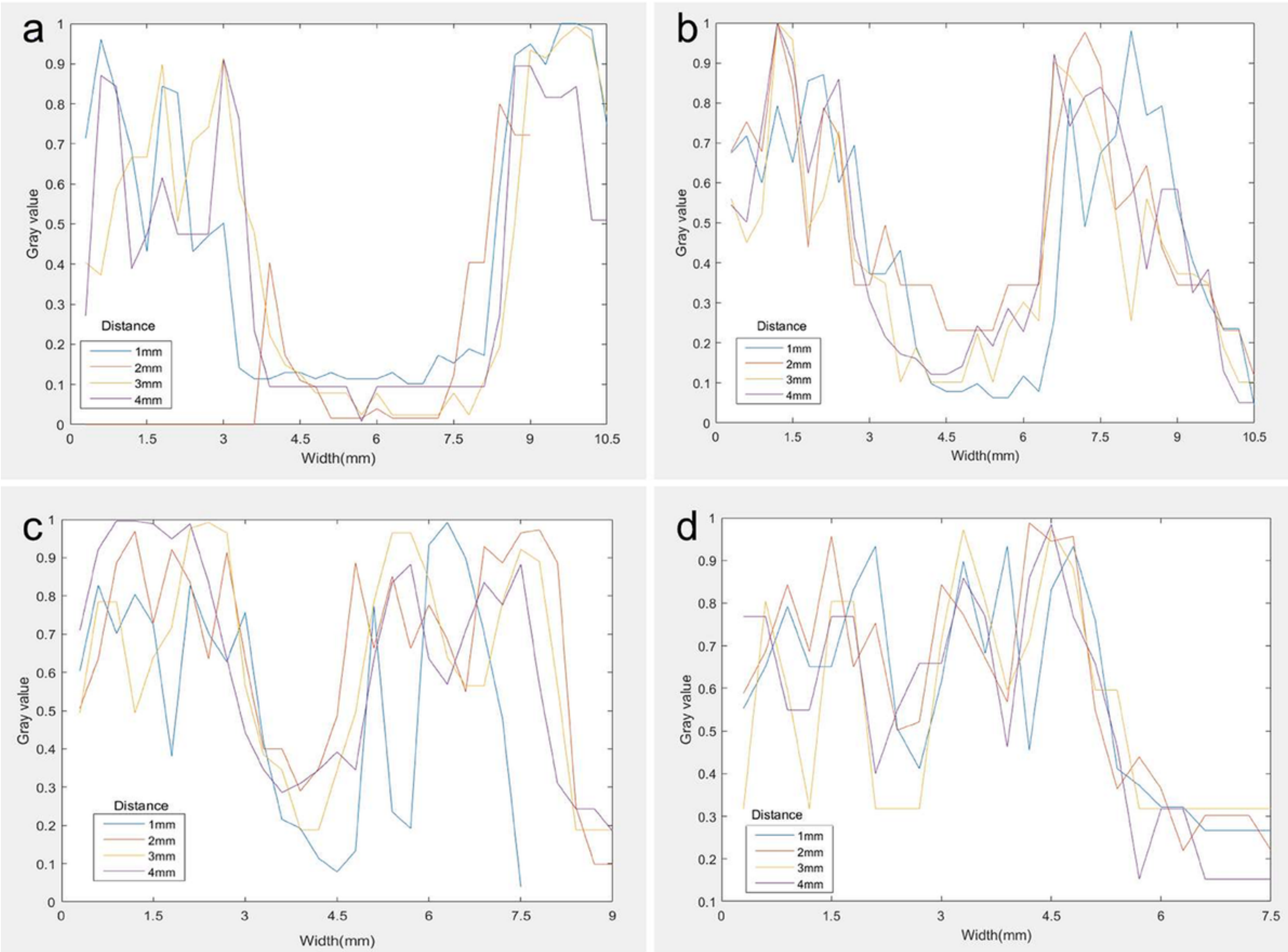

Figure 7

The four sizes of holes are successively detected at the distance of 4mm, 3mm, 2mm and 1mm. (a) The hole with diameter of 5mm. (b) The hole with diameter of 3mm. (c) The hole with diameter of 2mm. (d) The hole with diameter of 1mm.

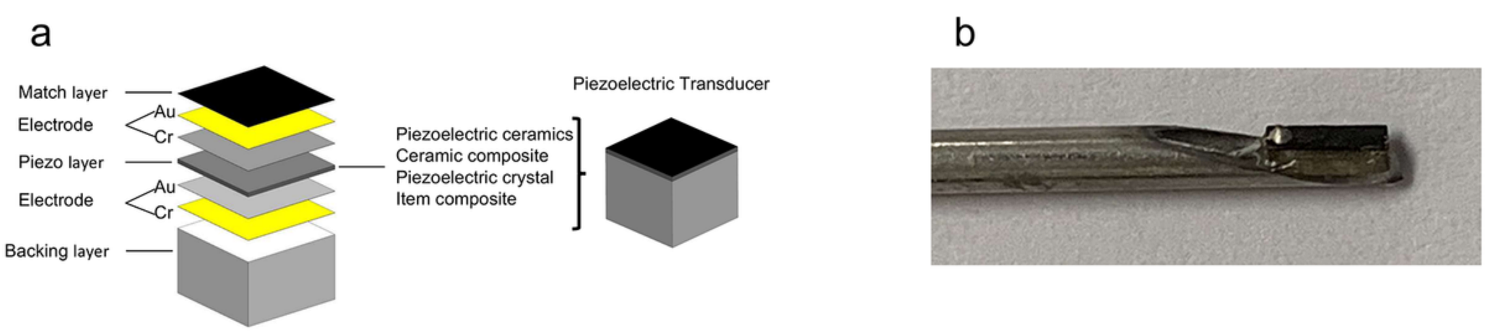

Figure 8

The schematic diagram of 30MHz fabricated transducer (a) The three-tiered structure. (b) Single-element ultrasonic transducer of 30MHz.

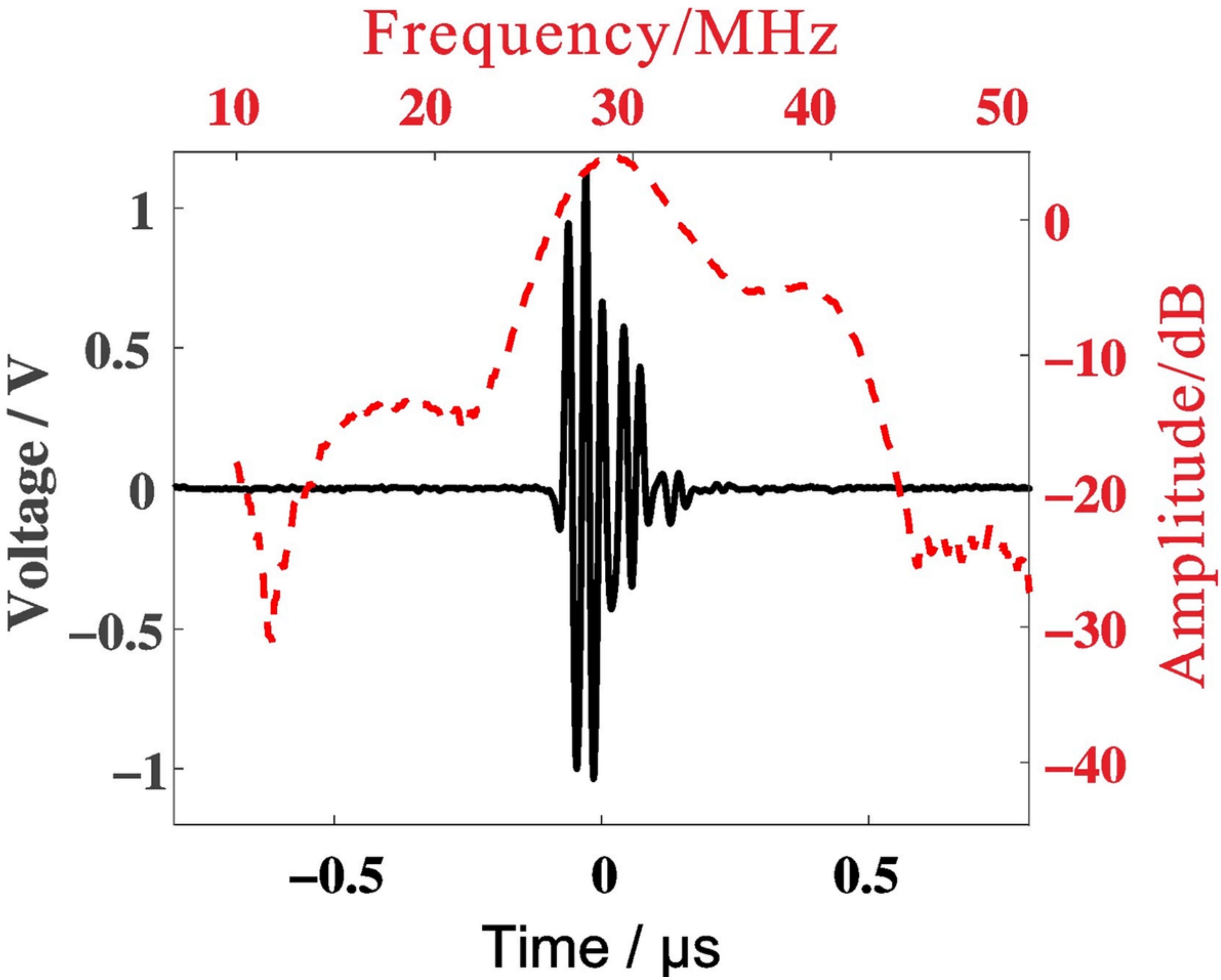

Figure 9

The pulse-echo curves of the transducer. The radio frequency (RF) curve is shown in the black line and the envelope curve is shown in the red line.