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Imaging of vertebral surface using ultrasound RF data received at each element of probe for thoracic anesthesia

胸椎麻酔のための各素子での RF 受信データを用いた超音波脊椎描出

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1. Introduction

Epidural anesthesia is a common technique for postoperative analgesia and chronic pain treatment. Since ultrasonography has insufficient performance in depicting the vertebral surface, most examiners perform epidural anesthesia using landmarks on the back without ultrasonography. The pathway to epidural space at thoracic vertebrae is narrower than that of lumber vertebrae, and the epidural anesthesia at thoracic vertebrae is difficult for a beginner. In the present study, we propose a novel ultrasound imaging method to improve the performance by ultrasonography in depicting thoracic vertebral surface.

2. Methods

In this study, we compare the performance of the proposed imaging method with that of conventional ultrasound B-mode imaging method based on delay-and-sum process in depicting thoracic vertebral surface.

2.1 Conventional B-mode imaging method

Figure 1 shows a schema of a B-mode imaging method using a linear probe. Signal intensity $S_i(r)$ of an observation point $R_{i,r}$ at the distance of r in the i-th scan line is given by

$$S_i(r) = \left| \sum_j s_{i,j} \left(\frac{r + \sqrt{r^2 + (x_i - x_j)^2}}{c} \right) \right|^2, \qquad (1)$$

where x_i and x_j are respectively the lateral position of the center axis of transmit beam and that of j-th received element, $s_{i,j}$ is received signal of the j-th received element at the ultrasound transmission to the i-th scan line.

Since the B-mode imaging method assumes that the transmit direction is the same as the receive direction, it is difficult to receive the echo from a inclined specular reflector effectively, resulting in low brightness of a inclined specular target surface.

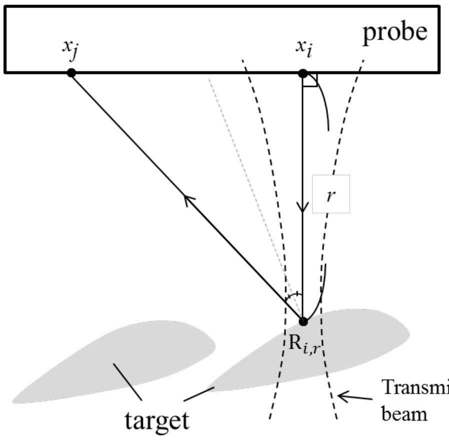

Fig.1 Schema of a conventional B-mode imaging method.

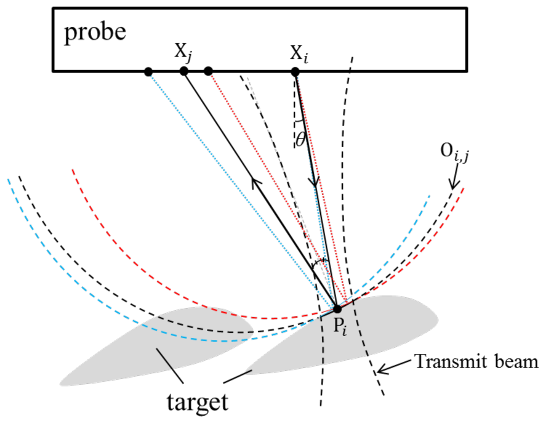

Fig.2 Schema of the proposed method.

2.2 Envelope method using width of transmit beam

The proposed method employs bi-static data acquisition. The conventional envelope method transmits a spherical ultrasound pulse from an element, and it uses received signals separately

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without delay-and-sum process. The sum of a distance of the reflection point P_i from the transmit-position X_i and that from receive-position X_j is equal to the path length. Therefore, the reflection point on a target surface is present on an ellipse where its foci are transmit and receive elements and the length of its long axis is equal to the path length. Therefore, the conventional envelope method depicts plural ellipses, and estimates the target surface using the outer envelope of the ellipses [1].

In the present study, we propose a novel envelope method using width of transmit beam, as shown in Fig. 2. The proposed envelope method also depicts plural ellipses, and it cut out arcs of ellipses within the width of the transmit beam. When echoes are returned from plural targets, an ellipse depicted using the echo from a target sometimes overlaps with another target, as shown in Fig. 2, and the conventional envelope method fails to depict target surfaces correctly. In contrast, the proposed method suppresses this overlap by employing the arc of an ellipse cut out within the width of transmit beam.

The following shows the specific depiction procedure of the target surface using the proposed envelope method.

(1) In *i*-th transmit beam, the method selects receive elements that receive signal intensity larger than a quarter the maximum signal intensity among the all received signals in the transmit event.

(2) For each selected element E_j, the method depict an ellipse $O_{i,j}$ where its foci are the transmit beam position X_i and receive element position X_j and the length of its long axis is equal to the path length.

(3) After depicts plural ellipses using all the selected element, it cuts out the arcs of the ellipses within the width of the transmit beam.

(4) The process from (1) to (3) repeats for all transmit beams.

(5) It depicts the outer envelope of the arcs.

3. *In Vivo* Experimental Result

We obtained RF signals of the thoracic vertebra of a 23-years-old healthy male using ultrasound machine (prosound alpha 10, Aloka). We used a linear array probe, which consists of 192 elements, an element pitch of 0.2 mm. We set transmit frequency, sampling frequency, and focal distance as 7.5 MHz, 40 MHz, and 30 mm, respectively.

Figures 3 and 4 show the images of surface of thoracic vertebrae acquired using the B-mode imaging method and the proposed method, respectively. The B-mode image failed to depict the vertebral surface clearly. In contrast, the proposed method clearly depicted the vertebrae surface at a depth of about 23~25 mm as compared to the B-mode image.

4. Conclusion

In this study, we proposed a novel method that depicts the surface of thoracic vertebrae clearly. This result indicates a high potential of the proposed envelope method using width of transmit-beam in depicting the surface of thoracic vertebrae.

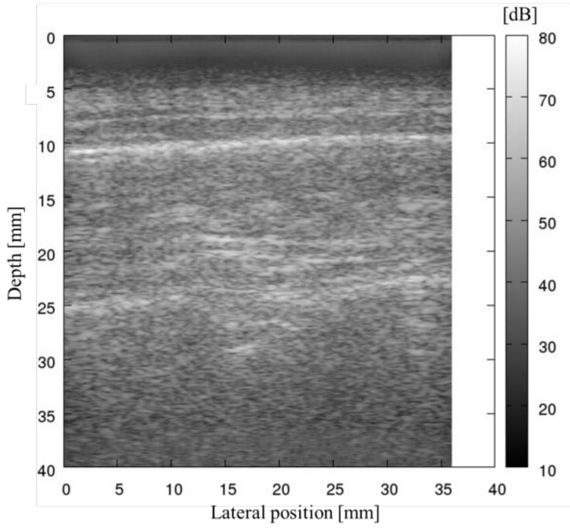

Fig.3 Conventional B-mode image for surface of the thoracic vertebrae.

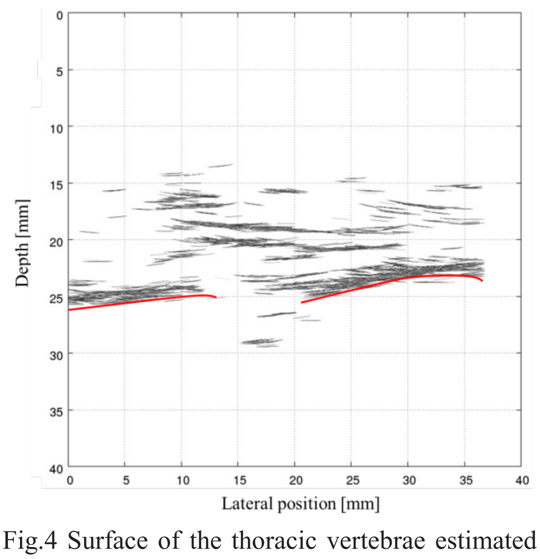

Fig.4 Surface of the thoracic vertebrae estimated by the proposed envelope method using width of transmit beam. Red lines are outer envelope of the ellipse arcs.

References

1. S. Kidera *et al*, IEEE Trans. Geosci. Remote Sensing, 46, 3503– 3513, 2008.