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Enhanced transcranial imaging using longitudinal-shear-longitudinal mode conversion with Barker code excitation

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1. Introduction

The distortion effect of skull bone limits the quality of transcranial ultrasound images. For instance, ultrasonic wavefront direction changes as a result of refraction at the skull-tissue interface, leading to transcranial ultrasound path misestimate. The longitudinal sound speed in skull is faster than its counterpart in tissue, resulting in time delay miscalculation for transkull B-mode imaging. Previous work has predicted the shear acoustic properties in the human skull, and shows better impedence with soft tissue[1,2]. The incoming incident wave will undergo a mode conversion from a longitudinal wave in soft tissue or liquid to shear wave in skull and then back to longitudinal wave in brain tissue, once the incoming wavefront is beyond the critical angle of total reflection of the longitudinal wave.

In this study, we studied the influence of skull on phantom localization in traditional imaging. In contrast, we discussed in details the superiority of the longitudinal-shear-longitudinal conversion method. As shear wave attenuation in the skull is a bit higher than its couterpart of longitudinal wave and slant-set bone will elongate ultraound wave propagation distance in bone, a 13-bit Barker code excitation was utilized for the imaging system for better penetrating ability as well as signal-to-noise ratio (SNR).

2. Material and methods

2.1 Simulation settings

We used the pseudo-spectral time domain method with elastic wave equations to simulate the ultrasound pulse-echo process[3]. The imaging setting of phased array is depicted in **Table.1**. Four simulations were implemented for contrast, with their geometric settings in **Fig.1**. The skull bone was simplified as a homogeneous and isotropic rectangle cuboid, with a longitudinal wave speed $c_l = 3000m/s$ and shear wave speed $c_s = 1500m/s$. The phantom cubic inside the skull was assumed as an elastic cubic with a longitudinal wave speed $c_{lp} = 3000m/s$ and shear wave speed $c_{sp} = 2000m/s$. A center frequency of 1MHz is selected, since the shear wave speed in skull bone is close to ultrasound speed in soft tissue around this frequency.

2.2 Barker code excitation

The 13-bit Barker code excitation [1 1 1 1 1 -1 –1 1 1 -1 1-1 1] is utilized to enhance the transcranial imaging quality. The received signals of the excitation are match filtered and used for imaging process[4].

Table 1 Linear array and B scanning mode settings

Linear phased array probe		Scanning setting	
Element width	1.0×10^{-1}cm	Focus distance	6.0cm
Element number	128	Active elements	16
Elevation number	24	Scanning lines	40
Probe Length	13.1cm	Receive apodization	rectangle
Probe width	16.4×10^{-1}cm	Transmit apodization	hanning

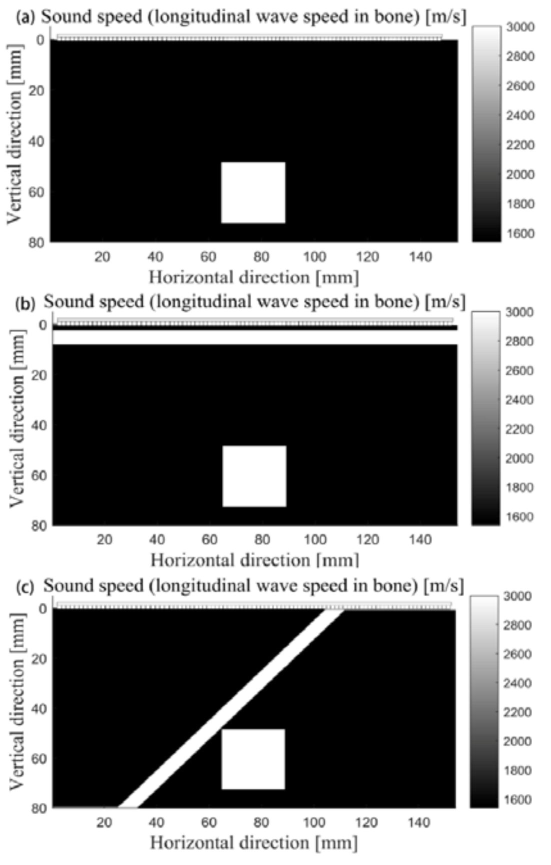

Figure.1 the geometric settings (a) without skull bone (b) horizontally arranged (c) with an angle of $\pi/4$

3. Results

The corresponding imaging results of different geometric settings in Fig.1 are exhibited respectively in **Fig.2**. Obviously, the image of upper surface of the elastic cubic is located at 48mm in Fig.2(a) when there is no skull between elastic and probe. When the skull bone is horizontally arranged, the image of cubic upper surface is located at 45mm, about 2mm higher than its real location, which is the result of wave speed distinction and wave path deflection of skull and soft tissue. When the skull is arranged with an angle of $\pi/4$, the effect of phased distortion reduces and the upper surface of cubic in image is about 48mm as shown in Fig.2(c). With this angle, the incident angle of all active elements exceed the critical angle of $\pi/6$, ensuring the shear wave mode dominance in the bone. The weak white line in Fig.2(a) comes from the bottom line of the cubic. It is notable that the Artifacts in Fig.2(b) and Fig.2(c) are caused by multiple reflections in the skull bone The upper surfaces of images are marked with red line for better comparison.

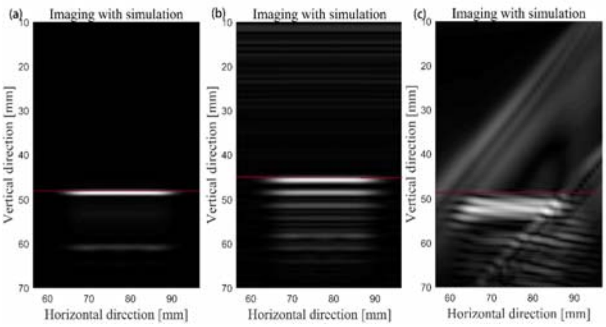

Figure.2 the images (a) without skull bone (b) horizontally arranged (c) with an angle of $\pi/4$

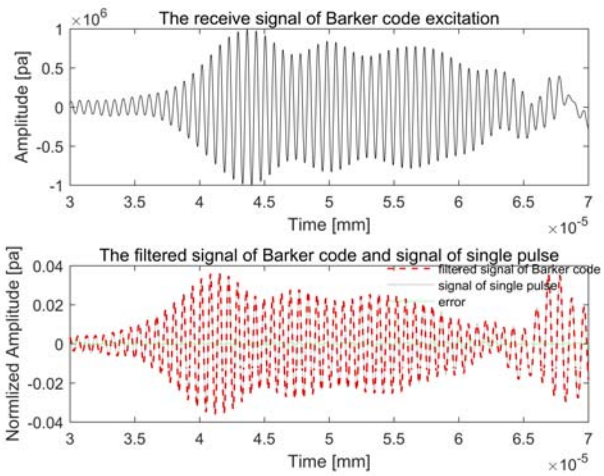

Figure.3 (a) acquisition of Barker code excitation (b) contrast of filtered signal of Barker code, signal of single pulse and the error in certain time intercept interval

The normalized match filtered signal of 13-bit Barker excitation, the received signal of single pulse and the error are exhibited in **Fig.3**. It indicates a 97.3% precision using Barker code excitation without considering noise. The imaging quality of code excitation and single pulse are depicted in **Fig.4**, and the SNR was improved from 5.4db to 16.9db with white noise, which will help phantom cubic imaging to be more obvious.

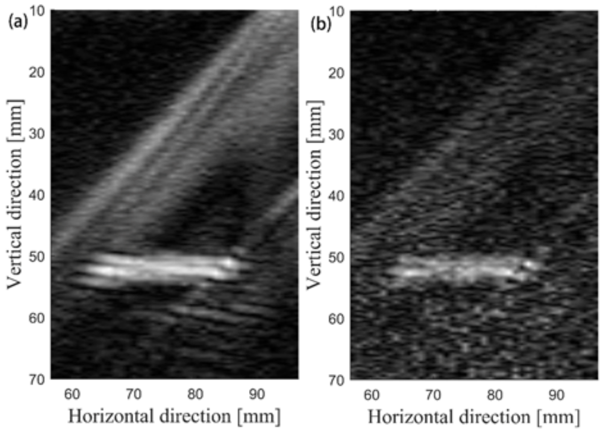

Figure.4 (a) the image of Barker code excitation (b) the image of single pulse excitation

4: Conclusion

The idea of enhanced transcranial imaging using longitudinal-shear-longitudinal mode conversion which shows better phantom localization accuracy is presented. The Barker code excitation is an efficient method for better signal-to-noise ratio, which can be used to enhance the transcranial ultrasound wave propagation and imaging. This ideal may be a supplement for the transcranial imaging system.

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