1P5-1

Transmission of shock waves by a focused carbon nano tube coated transducer through human skull cadaver

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1. Introduction

Focused ultrasound (FUS) generates heat to make necrosis of the target tissue. It has been used as a non-invasive tool for removing tumor and target tissues. [1], [2] One of the applications is brain therapy, where the sonic energy is focused to generate heat on the target brain tissues, even if the most energy is lost at the skull. Transcranial FUS (trFUS) is now clinically used as an effective technique for treating cerebrovascular diseases such as essential tremor, Parkinson's disease, and Alzheimer's disease. [3] However, there are disadvantages in the FUS thermal ablation due to unwanted thermal damages on the surrounding tissues during the treatment. [2] Laser-generated FUS is suggested to an alternative for resolving the problems because the single shock pulse with large amplitudes for lasting a few micro-seconds hardly produces heat.

The purpose of this study is to test the feasibility of transcranial transmission of the shock wave generated by a CNT/ PDMS (Carbon Nano Tube / Polydimethylsiloxane) transducer. [4]

2. Material

Three skull cadavers obtained from the Anatomy Laboratory in Jeju National University were used in the present study. They were numbered as No.96, No.99, and No. 100.

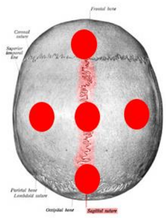

Fig. 1 A human skull cadaver and the measurement sites.

The thickness of frontal lobe, left and right temporal lobes, occipital lobe, and central position of the skull were measured, together with the speed of sound, at the measurement sites marked on **Fig. 1**. The measured values were averaged at each measurement site and the results are presented in **Table 1**.

Table. 1 Average thickness and sound speed of three human skull cadavers

	No.96	No.99	No.100
Thickness(mm) (n=25)	6.39±0.5	5.31±0.5	5.71±0.5
Sound speed of the skull (m/s) (n=5)	2729±200	2733±263	2668±173

3. Experimental set up

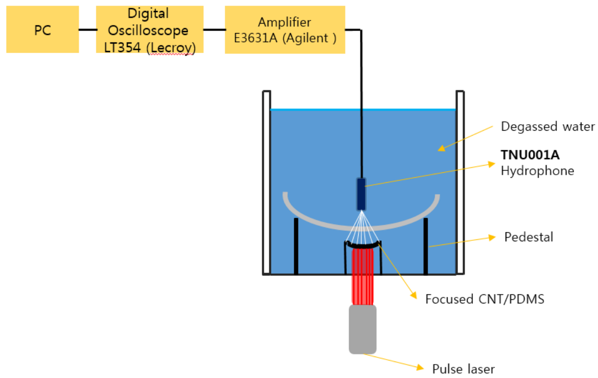

Fig. 2 CNT/PDMS transducer and hydrophone measurement system

When the laser is applied to the focused CNT/PDMS (F# = 1, Focal length = 5cm) immersed in the water, the CNT absorbs heat and the subsequent process of contraction and expansion in CNT/PDMS composite layer results in a shock pulse. Experimental setup to measure the attenuation of the shock pulse through the skull is shown in Fig. 2. A pulse laser system (Tribeam, Jeisys, Medical Inc, Seoul, Korea) with a wavelength of 532 nm, energy of 175mJ, and pulse repetition frequency of 2 Hz was used to generate the shock pulse, and a needle hydrophone (TNU001A, Onda, Sunnyvale, CA, USA) was used to measure the shock pulse transmitted through the skull. The hydrophone with a 30 dB preamplifier (HPA30, Onda, Sunnyvale, CA, USA) powered by to a 40V power supply (E3631A, Agilent, Santa Clara, CA, USA). The signal was monitored with an oscilloscope (LT354, Lecroy, New York, USA), and was analyzed using MATLAB as a post-processing.

4. Experimental result

In this study, time window was set within ± 1.5 μs from the maximum amplitude of the measured data for frequency analysis, and the results are shown in **Table 2**. **Fig. 3** (a) shows the measured reference signal of the shock pulse when the skull is absent, together with its frequency spectrum. The transmitted signals through the cadaver skulls are shown in **Fig. 4** (a), (b), and (c). The waveforms are similar each other for the 2 skulls of No. 96 & 99, as seen in Fig. 4 (a) and (b). However, the ultrasonic frequency of transmitted through the other skull (No. 100) was much 26% higher and the maximum pressure amplitude was about 30 times larger.

It was found that the skull allowed the shock pulse to transmit the most at the frequencies of 285 Hz and 359 kHz, while the higher frequencies were mostly attenuated through the skull. The attenuation coefficients were measured to 4.7, 5.0, and 4.1 np/cm at 1 MHz as shown in Table 2.

Table. 2 Average maximum voltages and pressures at the center frequencies and attenuation coefficients measured at 1 MHz through human skull cadaver. (n=5)

	Ref	No.96	No.99	No.100
Max Voltage(V)	1.22	0.084	0.092	0.26
Acoustic Pressure(MPa) (1MHz sensitivity = 3.14$\mu V/Pa$)	0.4	0.027	0.029	0.084
Center freq (kHz).	686	285	285	359
Max dB at the center freq	-53.90	-65.25	-62.47	-58.69
Attenuation Coeff (np/cm at 1MHz)	-	4.72	5.04	4.05

5. Discussion

The shock wave generated by a CNT/PDMS transducer was measured after transmission through three human skull cadavers. Each human skull varies in thickness, sound speed and attenuation. The cadaver skull No. 100 transmitted the sound energy efficiently. This would be attributed to the geometrical differences and skull density ratio. Further investigation is required for higher pressure at the transmission frequency band through the skull. It also needs to minimize the laser output variation in the future studies.

6. Conclusions

In this study, we investigated the shock wave transmission through human skull cadavers which was generated from the CNT/PDMS transducer. Three skull cadavers were used to measure the transmitted pressure and center frequency, attenuation coefficient, and sound speed. The average transmitted sound waves have maximum pressure between 27 kPa and 84 kPa at center frequencies of 285 Hz and 359 kHz. Future research will attempt to increase the transmitted power for effective non-invasive treatment of the brain tissue by opening of blood brain barrier, sonoporation, neuromodulation or cavitation effect of the shock wave generated by CNT-PDMS through the skull. To achieve the goal, the optimization of the CNT design and fabrication with appropriate #F is required.

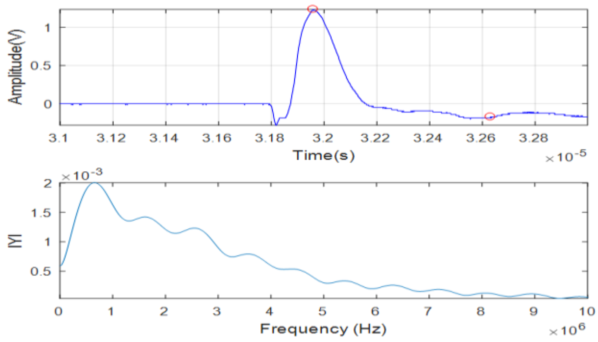

Fig. 3 Reference signals of shock wave generated by a CNT/PDMS transducer in water in time domain (a) and in frequency domain (b)

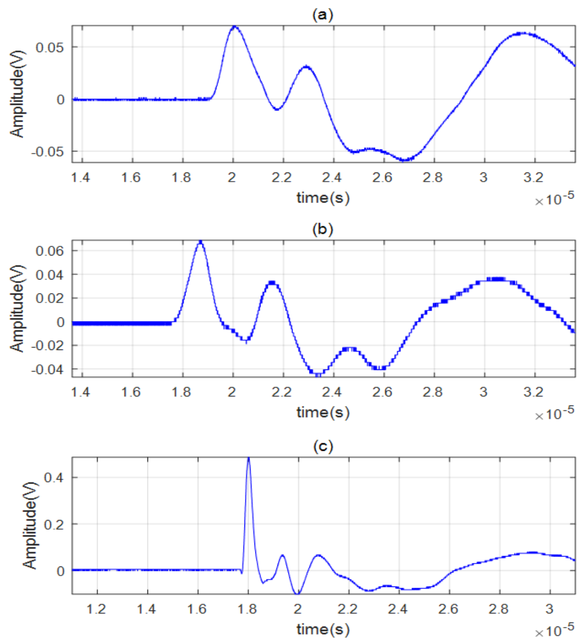

Fig. 4 Transcranial signals at central positions of three human skull cadavers, (a) No. 96, (b) No. 99, (c) No. 100

References

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