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Characterization of the mechanical impulse produced by a clinical ballistic shock wave therapy device.

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1. Introduction

In radial extracorporeal shock wave therapy, the therapeutic outcome results from the interaction of target tissues with mechanical impulses [1], produced by a ballistic shock wave generator. The mechanical impulse is generated by means of a projectile impacting a metallic applicator, named 'shock wave transmitter'. The principle of the mechanical impulse production is the same as that employed in pneumatic jack-hammers [2]. The mechanical impulse is often referred to as 'shock wave', even if its acoustic property is completely different from the conventional shock waves rooted in lithotripsy [3]. The mechanical impulse plays an important role in the therapeutic effects, but the nature of the mechanical impulse used in clinical practice is not clearly disclosed. For instance, the existing measurements carried out by Cleveland et. al. (2007) is considered for 20~25 us [3], even if the pulse length exceeds over several hundred microseconds. The present study reports the physical features observed on the complete range of the mechanical impulse.

2. Materials and methods

Measurements were made on a ballistic shock wave generator employed in a clinical radial extracorporeal shock wave therapy system (Zeus Wave, Wever Instruments, Republic of Korea). The basic structure and the principle of the ballistic source is illustrated in Fig.1.

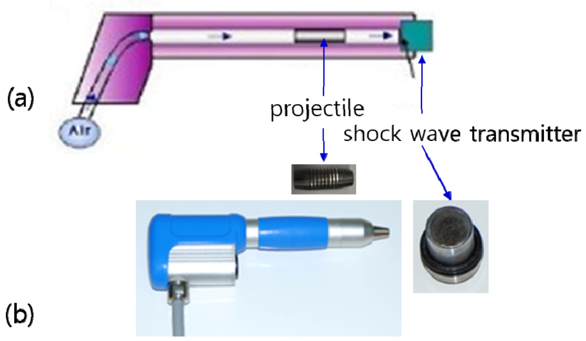

Fig.1. Ballistic shock wave hand-piece: (a) the basic structure, and (b) a commercial product (Zeus Wave, Wever Instruments, Republic of Korea)

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The ballistic hand-piece employs compressed air (up to 7 bars) used to fire a projectile that strikes the back of a shock wave transmitter placed on the skin. The projectile generates stress waves in the shock wave transmitter that propagate as pressure waves into tissue [3].

The shock wave transmitter considered in the present measurement has a circular flat surface tip with a diameter of 15 mm. In this study, the mechanical impulse was recorded by measuring the vibration sensed on the surface of the shock wave transmitter using a laser vibrometer (OFV-5000, Polytec, Germany). The experimental setup is illustrated in Fig.2.

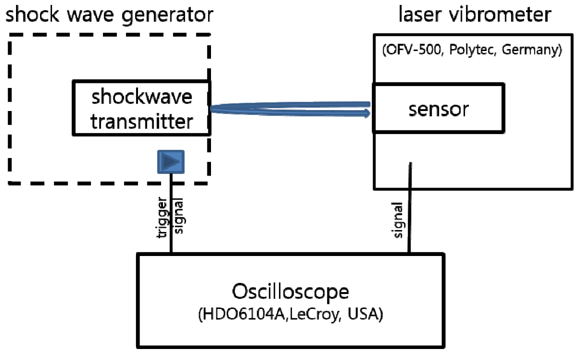

Fig.2. Experimental setup for measuring mechanical impulse radiated from the front surface of the shock wave transmitter.

3. References and Discussion

Fig.3 shows the typical time history of the mechanical vibration measured for over 100 ms on the front surface of the shock wave transmitter at the air pressure setting 1 bar. The projectile fire for shock wave production was triggered at t=0 when the ballistic hand-piece was switched on. The detailed structure of the mechanical impulse (marked by 'A' in Fig.3a) is plotted in the expanded time scales in Fig.3b for 1.2 ms and Fig.3c for 100 us, together with their frequency spectra on their right hand side panels.

It is shown that the typical mechanical vibration on the surface of the shock wave transmitter produced by the collision with the projectile is resonated at a frequency of 90 kHz (f_r)

and modulated with 3.8 kHz (f_d) to a heavily damped sinusoidal pulse. The mechanical impulse of the 90 kHz oscillation lasts more than 2 ms, while the 3.8 kHz damping fluctuation lasts much longer for over 20 ms.

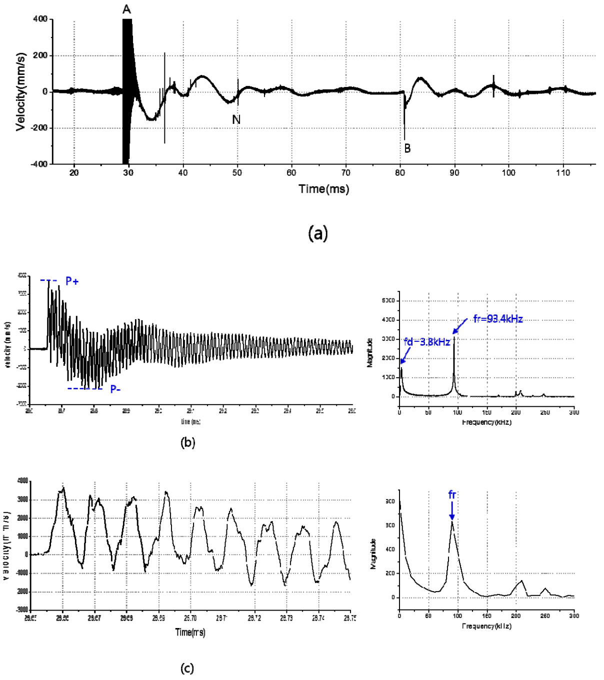

Fig.3. A typical time history of the mechanical vibration measured on the surface of the shock wave transmitter at the air pressure setting 1 bar. The detailed structure of the signal marked by 'A' is illustrated in the expanded time scales in (b) for 1.2 ms and (c) for 100 us. The negative over shot labelled by 'B' represents the collusion by the projectile repelled from the shock wave transmitter back to the loading position, and the 'N' indicates electrical noises sparsely distributed in time.

The noticeable negative over shot at 80 ms (labeled by 'B') represents the secondary collusion that occurs when the projectile repelled from the back of the shock wave transmitter back to the loading position for firing. The over shot has a natural frequency of 133 Hz which is clearly differentiated from electrical noises (labeled by 'N') sparsely distributed in the measured signal.

In the mechanical impulse resonated at 90 kHz, there are two noticeable peak pressures (labelled by P+ and P-) which take place at the different time locations. The time delay between them was observed to be about 150 us. As expected, the magnitudes of the peaks were found to increase as the air pressure setting was raised (the data not shown here).

Multiple mechanical impulses were produced at the high air pressure settings. At the high air pressures, the projectile, after the impact on the shock wave transmitter, repelled back to the loading position and has its kinetic energy even greater than the magnetic force for holding it for reloading. Therefore, the projectile is released from the loading position and moves towards the shock wave transmitter to collide again. This additional collusion takes place repeatedly until the kinetic energy becomes less than the magnetic force to hold the projectile for reloading.

In the shock wave source taken in this study, one mechanical impulse was produced for the air pressure less than 2 bar, two impulses for 2~3 bar and three impulses for the air pressure higher than 4 bar. As expected, at the high air pressures, the magnitude of the multiple mechanical impulses is sequentially reduced with time.

The shock wave transmitter has various shapes and sizes and is selected according to clinical applications. Further studies are suggested to compare the spectral properties of the different shock wave transmitters.

4. Conclusions

This study presents the physical characteristics of the impulsive vibration measured on the surface of a shock wave transmitter in the air. In order to assess the shock waves irradiated to the body emitted from a shock wave transmitter, it is required the hydrophone measurement in a water tank. It is expected that the present results would be of a critical information to interpret the complicated hydrophone measurements.

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