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Characteristics of the cavitation bubble cloud visualized under micro pulsed light with various exposure time

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1. Introduction

The shock wave therapy device always generates acoustic cavitation when it irradiates ~~a~~ shock pulses to the medium. The shock wave induced acoustic cavitation is known to play an important role in biological effects required for therapy[1,3]. Although the cavitation is important, its characteristics are not well known, yet, because the chaotic nature and fast behavior of cavitation bubbles make it difficult to measure[4]. To observe such ultrafast cavitation behaviors, an optical visualization may be useful under a very short light illumination[5]. Kang et al.[6] reported that the accumulation of high speed snapshot images of shock wave induced cavitation bubbles illuminated by a micro pulsed light successfully reproduce the characteristic distribution of the shock wave (negative pressure) field. In that study, the light exposure time was set to cover the entire lifetime of the bubbles. In this study, however, we attempted to observe cavitation cloud bubbles when altering the exposure time of micro pulsed light.

2. Materials and methods

An experimental setup is shown in Fig 1. A clinical electromagnetic shock wave therapy system (ShineWave-sonic, HnT Medical System, Korea) was employed as a shock wave generator.

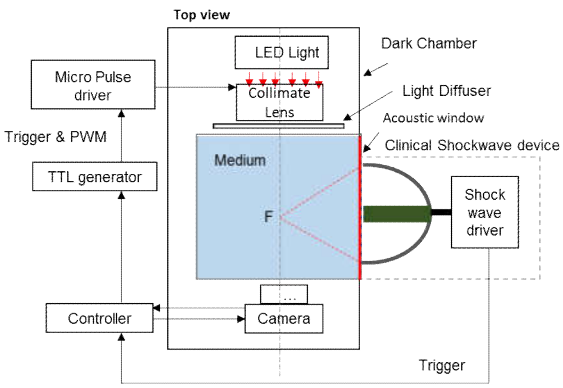

Fig 1. A schematic block diagram of the experimental setup.

The shock wave generator has three identical capacitors connected in parallel that gives a capacitance of 0.15 μF. The capacitors were electrically charged to 17 kV to produce an electrical pulse power which is converted to shock pulses through a cylindrical shock wave transducer. Water tank was filled up with tap water as a propagation medium at a room temperature of 25°C. CCD camera(EOS 5D Mark III, Canon Inc., Japan) and macro lens(EF 100mm F2.8L Macro IS USM, Canon Inc., Japan) were used to focus and observe cavitation cloud. The instantaneous images of cavitation bubbles were taken in the dark chamber under the micro pulse LED light. The light exposure time (T_{ex}) was controlled by micro pulsed driver (MPLL, KIS tech, Korea). The camera shutter remained open for 1 second to acquire the optical image of bubbles for the light exposure. F number was set to 5, and ISO sensitivity was adjusted from 640 to 2,500 to keep the background intensity similar according to the illumination time. A trigger pulse from the shock wave device was used to operate the MPLL controller (MPLL, KIS tech, Korea). The MPLL controller generate pulse width modulation(PWM) signal to adjust the light exposure time at 50 μs after the shock wave was fired. Repeated acquisitions were carried out for 20 times.

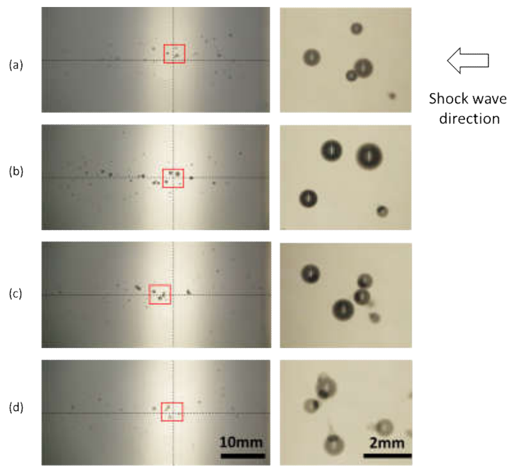

Fig 2. Typical snapshot images of cavitation bubble cloud (left) and magnified bubble images inside the box in the focal zone (right), obtained under the light exposure time of (a) 50 μs, (b) 100 μs, (c) 150 μs, (d) 200 μs. Note that the cross represents the focus)

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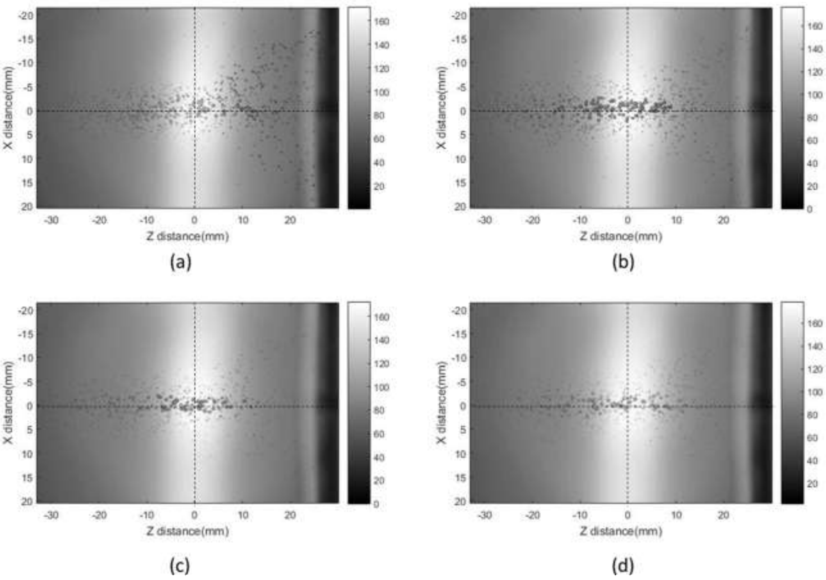

Fig 3. The images resulting from the accumulation of the 20 snapshot images of cavitation bubbles visualized under the light exposure time of (a) 50 μs, (b) 100 μs, (c) 150 μs, (d) 200 μs.

3. Results and Discussion

Fig. 2 depicts the typical acquired instantaneous snapshot images of cavitation bubble cloud taken at a time delay of 50 μs after shock wave generator triggered. Light exposure time were chosen to set to (a) 50, (b) 100, (c) 150, and (d) 200 μs for which the dynamic behavior of cavitation bubble was projected onto a single image. It was observed that the bubbles appeared sparsely and were spherical shape for the light exposure time from 50 to 150 μs (Fig. 2(a) and (b)). The number and size of bubbles decreased slightly in Fig. 2(c) compare to Fig. 2(b). A dark area appears at the edges of bubbles and moves toward adjacent bubbles(Fig. 2(c) right hand side). The bubbles that had relatively long lifetime remain in the focal area and were observed to form jets during their inertial collapses as seen in Fig. 2(d).

The spatial distribution of cavitation bubbles are projected to the accumulated images of the 20 snapshot images of cavitation bubbles (Fig. 3)[6]. Small bubbles that were generated by the shock wave are illustrated in the accumulation of the images acquired for the initial 50 μs light illumination (Fig. 3(a)). In contrast, large bubbles were observed in the accumulation of the images obtained with 100 μs light exposure condition (Fig.3(b)). It was shown that the small bubbles are distributed outside the focus area, and become blurred and disappeared as the illumination time increases (Fig. 3(c) and 3(d)).

4. Conclusion

The trajectory of the dynamic response of the cavitation bubbles to shock wave visualized under the illumination of a micro pulsed light is projected for the light exposure time onto an image. It was found that, if the exposure time covers the entire bubble lifetime, the bubble collapse and jet formation can be projected on the image. An appropriate control of the timing and length of the light exposure may enable one to selectively view the desired features of the cavitation bubble activities in the shock wave field.

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