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Effect of Frequency Modulation of Pumping Ultrasonic Wave in Bubble Cavitation

気泡キャビテーションにおけるポンピング超音波の周波数変調の効果

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1. Introduction

Ultrasonic drug delivery system, which uses micro bubbles as drug carriers, has features because drug release at the desired position is controlled by ultrasonic wave which is introduced from outside. Besides, sonoporation, which makes micro pores through cell membrane caused by bubble cavitation, increases the efficiency of drug injection into the target cell.

However, dynamics of micro bubbles under ultrasonic wave irradiation is too complex to control the dynamics precisely. For example, if an ultrasonic wave whose sound pressure is lower than the threshold value of bubble destruction radiates to the micro bubbles, micro bubbles receive acoustic radiation forces from the ultrasonic wave field. Bubble-to-bubble interaction caused by this force makes inherent bubble cloud, in which aggregated bubbles align with almost the same separation. Since the strengths of the acoustic radiation force changes depending on bubble volumetric oscillation, bubble density inside the region of interest and ultrasonic wave irradiation sequence, the resultant bubble cloud dynamics become very complex one. Moreover, flow velocity distribution inside the liquid flow in flow channel makes the bubble-to-bubble interaction complicated one. When an ultrasonic irradiation sequence in the sonoporation is optimized, bubble dynamics under ultrasonic wave irradiation has to be understood and the optimum sequence of ultrasonic wave irradiation is changed depending on the bubble dynamics.

Aiming at preparing bubble condition for bubble cavitation, we proposed a frequency modulation method of pumping ultrasonic wave. When the ultrasonic pumping wave, whose sound pressure is lower than the threshold level of bubble destruction but it is enough to produce the acoustic radiation force to the bubble, is introduced, the bubbles aggregate and they make bubble cloud, in which the aggregated bubbles align with almost the same separation. The separation of each aggregated bubble relates closely to the wavelength of secondary ultrasonic wave radiated from the bubbles, the bubble cloud expands if the frequency of the incident pumping ultrasonic wave decreases. Expansion of the bubble cloud increases the bubble density in the vicinity of the wall in the flow channel. This method is useful when the bubble interacts each other by the secondary Bjerknes force, however, the bubble dynamics inside the flow channel are usually complex one.

In this paper, the dynamics of micro bubbles when the frequency of the pumping ultrasonic wave is modulated is evaluated for different flow velocity and for different bubble density. Relation of the bubble aggregation which is produced by the Bjerknes force and the resultant micro hollows which are produced on the wall of flow channel is evaluated.

2. Experimental Set-up

Fig.1 shows the schematic diagram of the experimental set-up. As a blood vessel phantom, flow channel made by NIPA (N -isopropylacrylamide) gel is adopted. Since the sound speed and the density of NIPA gel are 1539 m/s, and 1.025, respectively, acoustic characteristic of NIPA gel is almost the same with that of the soft tissue. Moreover, NIPA gel is optical transparent, it is easy to observe the micro bubble dynamics inside the flow channel by microscope. The Ultrasonic wave is irradiated by two concave ultrasonic wave transducers with focal length of 30mm. These

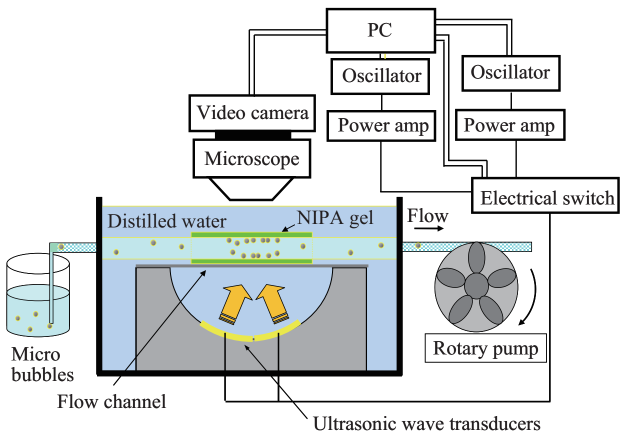

Fig.1 Experimental set-up.

ultrasonic wave transducers are driven by a couple of power amplifies and oscillators via an electrical switch. A set of power amplifier and oscillator is used for producing pumping ultrasonic wave. The pumping ultrasonic wave is used for preparing the micro bubbles for bubble cavitation. The sound pressure of the wave is lower than the threshold level of bubble destruction but it is enough to apply an acoustic radiation force to the oscillating micro bubbles. Other set of power amplifier and oscillator is used for generating high intensity ultrasonic wave for bubble destruction. The oscillators used in the system are controlled by PC and the waveforms of the ultrasonic waves and the sequence of ultrasonic wave irradiation are adjusted in advance. As for micro bubbles, Levovist (GE health care) is adopted.

3. Experimental Results

Fig.2 shows the comparison between micro bubble trapping pattern and the micro hollows, which are produced by bubble cavitation. In the experiment, first the pumping ultrasonic wave is irradiated for preparing the bubble condition. The frequency modulation method is adopted. Frequency modulation range is from 2.5 MHz to 1.75 MHz and the frequency modulation repetition frequency of 4 Hz. Sound pressure of the pumping ultrasonic wave is set to 50 kPa. After repeating the frequency modulation during 2 sec., high intensity ultrasonic wave is introduced. Figures 2(a-1) and (b-1) are the aggregated micro bubbles which are adhered to the internal wall of the flow channel. Figures 2(a-2) and (b-2) show the micro hollows, which are produced after bubble cavitation, for the flow phantoms shown in figs. 2 (a-1) and (b-1). Black dots shown in figs. 2 (a-2) and (b-2) are the micro follows. In order to compare the micro bubble aggregation pattern and the micro hollows pattern, the micro hollows pattern is overlapped on the micro bubble aggregation pattern in figs. 2 (a-2) and (b-2). From the results, it is found that a lot of small hollows are formed on the same area of the bubble cloud is produced, however, the size of micro hollows is much smaller than the size of bubble aggregation.

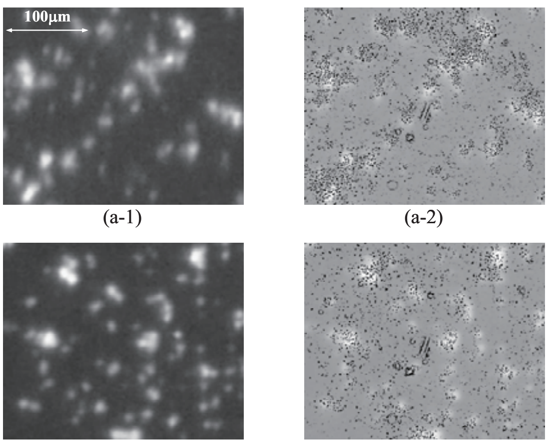

Fig.2 Comparison between bubble cloud pattern ((a-1), (b-2)) and micro hollow pattern produced after bubble cavitation ((a-2), (b-2)) for the same phantom.

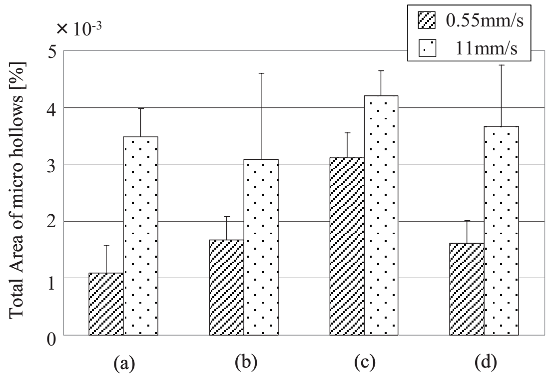

Fig.3 Effect of frequency modulation sequence. (a): fixed frequency case. (b), (c) and (d) are the sweep repetition frequency of 2 Hz, 4 Hz and 8 Hz, respectively.

Total area of micro hollows is evaluated for different frequency modulation sequence. **Fig.3** shows the result. Fig. 3(a) is the result for the case where pumping ultrasonic wave frequency is fixed (2.5 MHz) Figs. 3(b), (c) and (d) are the frequency sweep repetition frequency of 2 Hz, 4 Hz and 8 Hz, respectively. Results obtained for the flow velocity of 0.55 mm/s. and 11 mm/s. are shown in the figure. From the results, it is found that an optimum frequency modulation sequence exists for the flow velocity of 0.55 mm/s., however, almost the same results are obtained for the flow velocity of 11 mm/s. This result implies that the micro bubble dynamics is different for the different flow velocity.

4. Conclusion

It is important to prepare the micro bubble condition immediately before bubble cavitation, however, micro bubble dynamics is affected by many parameters, such as ultrasonic waves, surrounding liquid flow, bubble characteristics and bubble density. In this paper, micro hollows produced bubble cavitation are evaluated for pumping ultrasonic wave irradiation sequence.

References

1. Y.Yamakoshi, T. Miwa, etl.al: Jpn. J. Appl. Phys. **49** (2010) 07HF17.
2. Y.Yamakoshi,and T. Miwa: Jpn. J. Appl. Phys. **48** (2009) 07GK02.