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Reduction of cavitation generation region outside focal region of high-intensity focused ultrasound by split-aperture transmission for standing wave suppression

定在波抑制のための開口分割 HIFU 照射による焦点領域外キャビテーション生成領域の低減

Yui Tanaka [1†], Daisaku Mashiko [1], Shin-ichiro Umemura [1], and Shin Yoshizawa [2]
([1] Grad. School of Biomed. Eng., Tohoku Univ.; [2] Grad. School of Eng., Tohoku Univ.)
田中結衣 [1†]，益子大作 [1]，梅村晋一郎 [1]，吉澤晋 [2]（[1]東北大院 医工，[2]東北大院 工）

1. Introduction

HIFU (high-intensity focused ultrasound) is a noninvasive treatment method to coagulate a tissue without incision. In HIFU treatment, ultrasound generated outside the body is focused onto the target tissue. Cavitation bubbles can be generated by negative pressure in the HIFU field. It is known that the ultrasonic tissue heating can be accelerated by using cavitation bubbles[1)]. To efficiently utilize this effect, a “trigger HIFU” sequence, consisting of “trigger pulses” and “heating bursts”, has been proposed[2)]. The trigger pulse is a high-intensity pulse for generating acoustic cavitation bubbles, and the heating burst is a low- to moderate-intensity burst to heat tissue. It is important to generate and use cavitation bubbles selectively in the focal region of HIFU. However, it is known that cavitation bubbles can be generated by standing waves even at low intensity[3)]. If cavitation bubbles are generated outside the focal region, it may cause side effects such as skin burns. To reduce the possibility of generating cavitation bubbles outside the focal region, a split-aperture transmission was previously proposed to suppress standing waves[4)]. In the previous study, it was found that the temperature rise at the surface of a gel phantom was less by split-aperture transmission than by full-aperture transmission. In this study, a cavitation area during the trigger HIFU exposure is investigated by high-speed photography. The results by several types of split-aperture transmission and full-aperture transmission are compared.

2. Material and Method

2.1 Experimental Setup

Fig. 1 shows the experimental setup. A 2D array transducer (Japan Probe) with a diameter of 147 mm and a focal length of 120 mm was driven at 1 MHz. The experiment was conducted in a degassed water (dissolved oxygen concentration of 20 to 30%), and a sapphire glass of 5 mm thick was placed 7 mm toward the transducer from the HIFU focal point as an acoustic reflector to generate standing waves. Cavitation bubbles generated on the sapphire glass were observed with a high-speed camera (Shimadzu HPV-2A) at 250 kfps using a pulsed laser with a pulse length of 20 ns and a wavelength of 640 nm (Cavitar CAVILUX Smart). The high-speed photographs were binarized to calculate cavitation generation areas. The calculated areas were averaged for 25 consecutive frames in 0.1 ms and then averaged over three tests of each HIFU exposure sequence.

2.2 HIFU Transmission Method

Fig. 2 shows three transmission methods. The 128 elements of the 2D array transducer were divided into two groups of 64 elements. They are referred to element 1 and element 2, respectively. Fig. 2 also shows an example for dividing the aperture into six sectors. Adjacent two sectors belonged to different elements groups. In the continuous transmission sequence, the heating burst was continuously transmitted from elements 1 and 2 simultaneously. In the intermittent transmission sequence, the heating burst from elements 1 and 2 is paused for 0.05 ms every 0.1 ms. In the split-aperture sequence, the heating burst was transmitted alternately from the elements 1 and 2 once every 0.05 ms. In the previous study[4)], the number of sectors was six as shown in Fig. 2. In this research, the split-aperture sequences by 2, 4, or 10 sectors were also tested for the comparison. The trigger pulse was transmitted simultaneously from elements 1 and 2 at a total acoustic power (TAP) of 930 W, and the heating burst was at a TAP of 110 W for 75 ms in all sequences. The ultrasonic frequency of 1 MHz, the total acoustic energy, and the exposure time were the same in all sequences.

yui.tanaka.p3@dc.tohoku.ac.jp

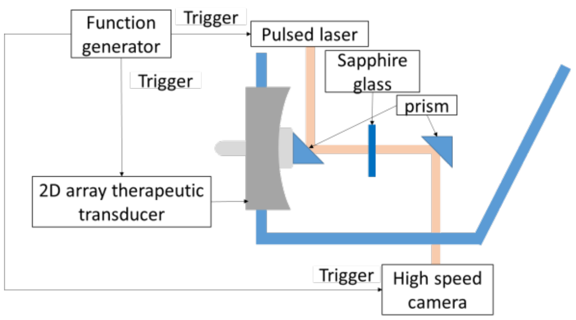


Fig. 1 Schematic of experimental setup.

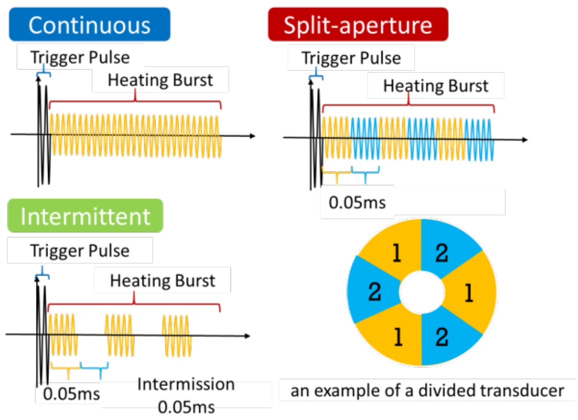
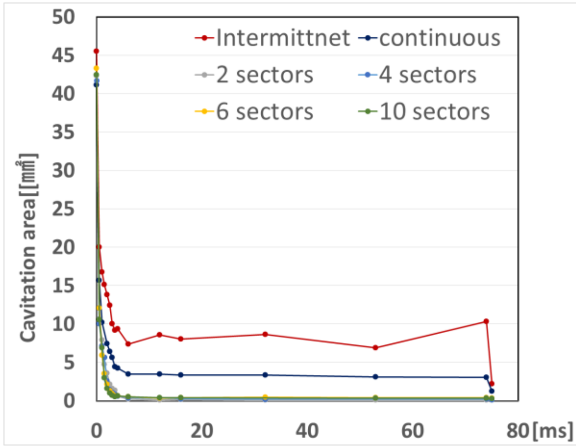


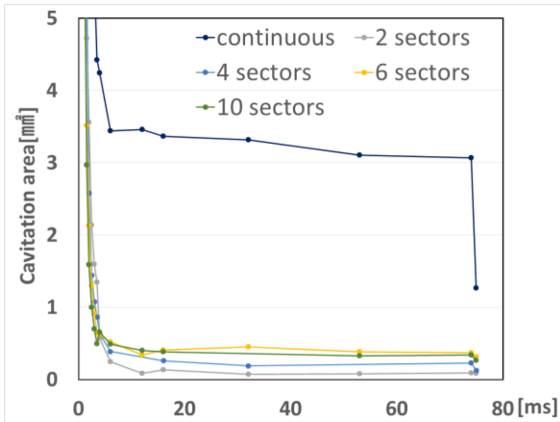
Fig. 2 HIFU exposure sequences and an example of aperture division.

3. Result and Discussion

Fig. 3 shows the temporal change of cavitation areas by full- and split-aperture transmissions. The cavitation areas averaged over 0 - 0.1 ms during the trigger pulse exposure at the glass were the largest in each sequence. After the end of the trigger pulse, i.e. the star of the heating burst, the areas decreased in several ms. Immediately after the heating burst stopped at 75.1 ms, the areas sharply decreased. The split-aperture sequences significantly reduced cavitation areas compared with the full-aperture sequences. This is probably because the standing wave components were suppressed by the alternate transmission from the elements 1 and 2. In addition, the area differences among the split-aperture sequences were significantly smaller than that between the continuous and intermittent transmission sequences, regardless of the number of aperture divisions in the split-aperture sequences, although the trend that smaller number of aperture division resulted in the smaller cavitation area was observed. To optimize the aperture division, it will be necessary to also consider the localization of cavitation bubbles and the efficiency of tissue heating in the focal region.



(a)



(b)

Fig. 3 Temporal change of cavitation areas in full vertical range (a) and in the range from 0 to 5 mm^2 (b).

4. Conclusion

In this study, we compared cavitation areas on a glass in prefocal position by full-aperture and split-aperture transmissions. The result showed that the cavitation area was significantly reduced by the split-aperture transmissions compared with the full-aperture transmissions, regardless of the number of aperture divisions for the alternate firing. In HIFU treatment, the split-aperture transmission method will reduce the risk of skin burns caused by cavitation bubbled compared with the full-aperture transmission method.

References

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