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Thin catheter bending to the perpendicular direction of ultrasound propagation using 2-dimensional array transducer

2 次元アレイトランスデューサによる音波伝搬の直交方向への極細カテーテルの屈曲

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1. Introduction

Because the diameter of a guide wire is at least 500 μm, conventional catheter therapy is difficult to apply to blood vessels smaller than 1 mm. To develop new possibilities of more precise therapies using a thin catheter, which diameter is expected to be less than 200 μm, we have proposed to utilize acoustic force to bend a thin catheter. Since an object in an acoustic field is propelled in the direction of acoustic propagation, we have confirmed the displacement of the tip of the catheter in proportion to sound pressure using a single transducer[1)]. However, it is not enough for clinical application because installation position of ultrasound transducers on body surface is limited to adopt to various shape of *in vivo* blood vessel. Therefore, it is necessary to develop a method to bend a catheter to an arbitrary direction, which is independent of the direction of acoustic propagation. We have studied a method to distract a catheter away from propagation direction[2)]. Because we have already developed 2-dimensional (matrix) array transducers to control the behavior of microbubbles[3-5)], not only the shape of acoustic field but also multiple focal area can be produced and steered simultaneously by changing delay time in sound elements. In this study, we examined to bend the thin catheter to the perpendicular direction of ultrasound propagation using a 2D array transducer.

2. Theory

According to the conventional Langevin theory, acoustic radiation force F_p applied on a cylinder, representing the shape of a thin catheter, which axis was set in the perpendicular direction of ultrasound propagation, is expressed as eq. (1) with acoustic radiation function Y_p :

$$F_p = E\, S_p\, Y_p \,, \qquad (1)$$

where E and S_p indicate acoustic energy density and the effective area on the cylinder, respectively. In this equation, it is possible to consider that the thin catheter received the force to be bent because of the energy difference, which locates in front and behind of the catheter. Therefore, if such an energy difference can be produced around the catheter, there is a possibility to bend the catheter in any direction, which is independent of the direction of ultrasound propagation.

Meanwhile, acoustic energy density is known to be expressed in proportion to the square of the sound pressure. Also, in case that a burst wave is applied on a catheter, whereas we have ever used continuous wave, acoustic energy is directly in proportion to the duty ratio. Thus, to confirm the above assumption, where the energy density is dominant to propel a catheter regardless of ultrasound propagation, the displacement of catheter should be measured by varying sound pressure in acoustic field and the duty ratio of the applied burst wave.

3. Experimental method

Figure 1 shows the experimental setup, where we prepared a concave 2D-array transducer with 256 elements (central frequency of 1 MHz, radius of curvature of 120 mm). The direction of the thin catheter, which was made of PFA material with outer and inner diameters of 0.2 mm and 0.05 mm, respectively, was set to be perpendicular to the surface of the transducer. As shown in Fig.1 (a), we produced an acoustic field including two focal points with opposite phases[5)], where the distance of the points w = 4 mm, and the distance from the transducer l = 60 mm. The tip of the catheter was 4 mm ahead of the focal points towards the transducer. In the next, as shown in Fig.1 (b), the position of two focal points was shifted electrically in the

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perpendicular direction of the catheter with the step of 0.2 mm and 0.5 sec, where the maximum shift of the focal points was 1.8 mm. We have recorded the reaction of the tip of the catheter to measure displacement d_{max} using a optical microscope (Omron VC-7700).

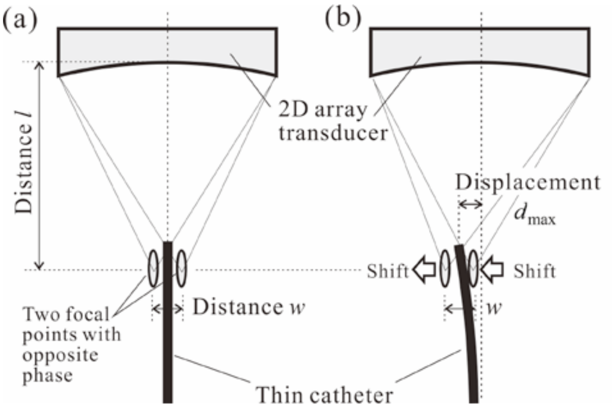

Fig.1 The experimental setup for thin catheter bending to the perpendicular direction of ultrasound propagation.

4. Results

As expected, the catheter was bent according to the shift of the focal points. Fig.2 shows the displacement d_{max} versus the peak sound pressure of the two focal points, where duty ratio was varied from 0.3 to 0.6 and pulse repetition time (PRT) was fixed to be 10 ms. The curved line were approximated for quadratic function using least squares method. The displacements d_{max} were obviously in proportion to the squares of the sound pressure for every duty ratio setting.

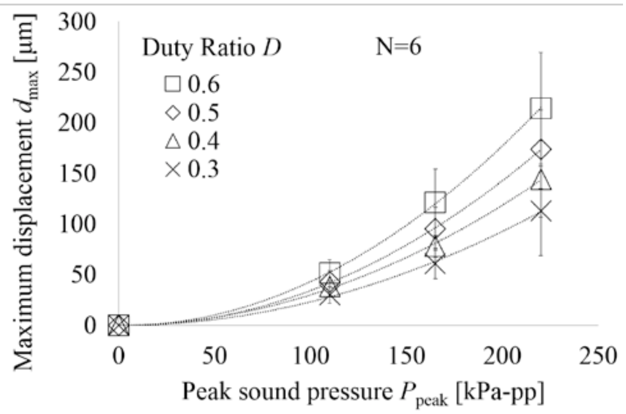

Fig.2 The maximum displacement of thin catheter versus the peak sound pressure in the focal points.

Fig.3 shows the displacement d_{max} versus duty ratio D, where the peak sound pressure was varied from 110 to 220 kPa-pp. The straight lines were approximated for linear function using least squares method. In the contrary of Fig.2, the displacement d_{max} were in proportion to the duty ratio for every sound pressure settings.

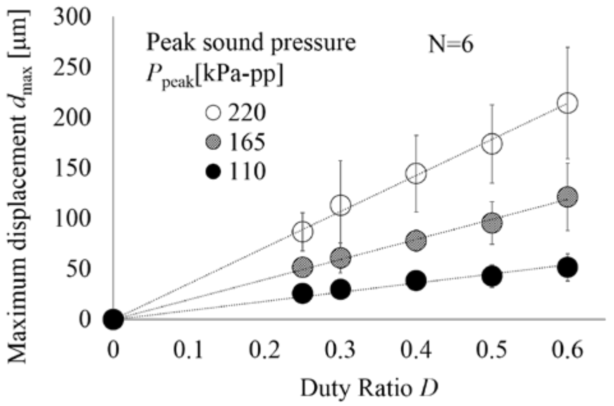

Fig.3 The maximum displacement of thin catheter versus duty ratio of ultrasound emission.

From the above results, the displacement of thin catheter was in proportion to both of the squares of the peak sound pressure and duty ratio. In other words, the thin catheter was moved by the gap of acoustic energy between two focal points. We found the possibility that the conventional Langevin theory to produce acoustic radiation force can be applied in the perpendicular direction of ultrasound propagation.

5. Conclusions

We have confirmed the phenomena to bent a thin catheter to the perpendicular direction of ultrasound propagation by producing acoustic field including two focal points with opposite phases. The maximum displacement of the catheter was found in proportion to the squares of the peak sound pressure, and duty ratio, respectively. Thus, the assumption that the acoustic energy density in front and behind of the catheter has a potential to propel a catheter toward the area of lower energy density. We are going to investigate ultrasound conditions for more effective way to obtain more displacement of the thin catheter.

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References

1. T.Mochizuki, N.Tsurui, N.Hosaka, et al: JJAP, Vol.53, 07KC09, 2014.
2. T.Mochizuki, N.Hosaka, N.Tsurui, K.Masuda: Proc. IEEE Ultrasonic Symp., 2015.
3. N.Hosaka, R.Koda, S.Onogi, et al: JJAP, Vol.52, 07HF14, 2013.
4. R.Koda, J.Koido, N.Hosaka, Advanced Biomedical Eng., Vol.3, pp.21-28, 2014.
5. K.Masuda, N.Hosaka, R.Koda, et al: Proc. IEEE Ultrasonic Symp., pp.1057-1060, 2014.