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Effect of contact condition of blood vessel wall in thin catheter bending using acoustic radiation force

音響放射力を用いた極細カテーテル屈曲における血管壁接触状態の影響

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1. Introduction

Because we have already developed the methods to control the behavior of microbubbles by making use of acoustic radiation force, we have applied the method to bend a thin catheter[1)]. Using a 2D array transducer[2)] (hereinafter referred to as 2D array) which can produce an aubitrary shape of acoustic field and bring about dynamic changes in the sound field, we succeeded to bend it in water and viscous liquids and do it in the direction perpendicular to ultrasound propagation[3)]. In addition, we sucseeded to bend the catheter in any direction by forming an interference acoustic field using multiple 2D arrays. However, in clinical application, there is a possibility that the tip of the catheter may come into contact with the blood vessel wall, but the effect of contact has not been studied so far. The purpose of this study is to invesigate the effect of contact a catheter with a latex membrane or rat abdominal aorta.

2. Method

Please refer to previous study[4)] for the theory of catheter bending by ultrasound. **Fig.1** shows the in experimental setup. A 2D array (128 elements, frequency 3 MHz) was placed in the water tank so that the sound axis was in the positive *x*-axis direction. The catheter, which was made of PFA material with outer and inner diameters of 0.2 mm and 0.05 mm, respectively, was placed ,resulting in that the tip was the origin of coordinates and the advancing axis was on the *z*-axis. Furthermore, the vessel wall was set between the 2D array and the catheter so as to be parallel to the *y-z* plane. A latex membrane and a rat abdominal aorta were used as a vessel wall. Regarding the contact condition between the catheter and the vessel wall, the vessel wall was come into contact with the position *l* [mm] from the tip of the catheter by a width *w* [mm]. Further, the contact strength was set by the offset *h* [mm] of the catheter tip from the origin by bringing the blood vessel wall into contact with the catheter. In this experiment, *l* was fixed to be 0 mm, and *w* [mm] and *h* [mm] were varied as verification parameters. As the ultrasound wave to be irradiated, a pulse wave having a pulse repetition time (PRT) of 10 ms and a duty ratio of 60% was used. The focal point was formed at positions a_1 [mm] from the tip of catheter in the case of a single-focal sound field, a_1 [mm] and a_3 [mm] from the tip of catheter in the case of a bifocal sound field, and a_1 [mm], a_2 [mm], and a_3 [mm] from the tip of the catheter in the case of a trifocal sound field. The multi-focal sound field was formed by repeating the electronic change of the focal position with the time interval of tempo-spatial division emission set to 0.01 s. We recorded the reaction of the tip of the catheter to measure displacement *d* [mm] using a high-speed camera (Photoron, PCI-1024). **Fig.2** shows the observed tip of the catheter before and after the ultrasound irradiation.

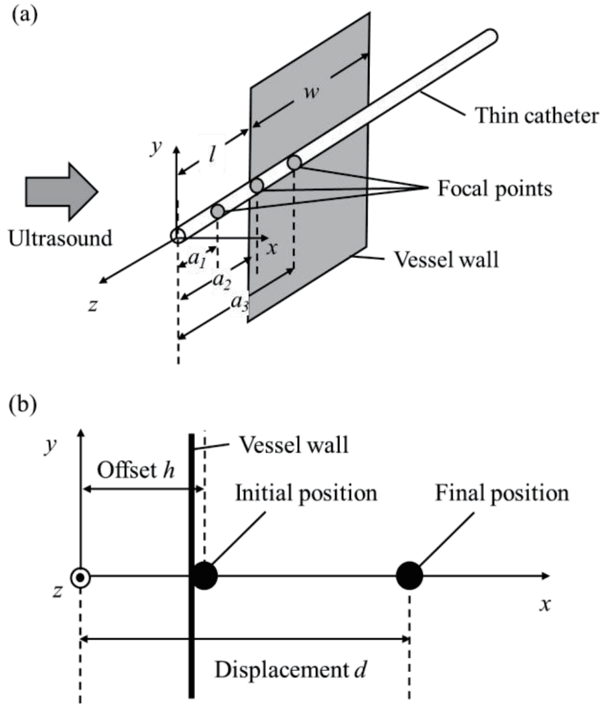

Fig.1 Experiment of the effect of vessel wall contact on catheter bending

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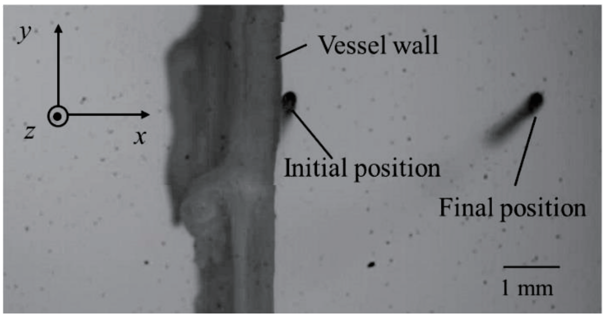

Fig.2 Catheter bending observed by high-speed camera

3. Results

Fig.3 shows the displacement for each sound pressure when the catheter is in contact with the vessel wall ((a) the latex membrane, (b) the rat abdominal aorta) and irradiated with a single-focal sound field (a_1 = 4 mm). The latex membrane was investigated with multiple w [mm] and h [mm]. On the other hand, the rat abdominal aorta was investigated with w = 3.6 mm and h = 0.3 mm. From Fig.3, when w [mm] and h [mm] are small in both the latex membrane and the rat abdominal aorta, the displacement transition with respect to the sound pressure was similar to that in previous study[3]. However, as shown in Fig.3(a), w = 20 mm and h = 2 mm, the catheter was adhered to the vessel wall, and the displacement due to the ultrasound wave was about 5% of that when not adhered. And the same effect was shown when w = 20 mm, h = 2 mm and sound pressure 400 kPa-pp. This is considered to be an effect of interfacial tension. Also, from Fig.3(b), when the sound pressure is small, the displacement with contact is smaller than without contact.

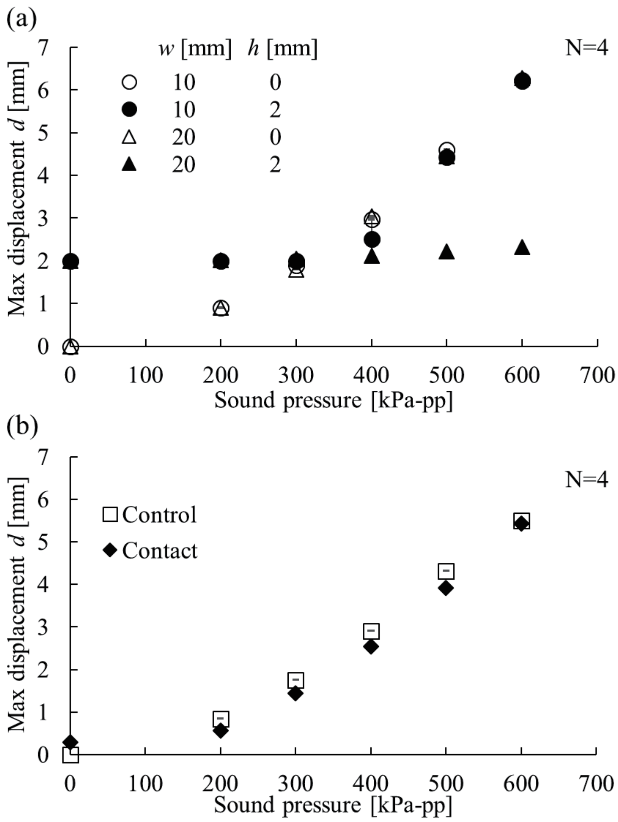

Fig.3 Catheter bending displacement during vessel wall contact ((a) the latex membrane, (b) the rat abdominal aorta)

Next, a multifocal sound field (a_1 = 4 mm, a_2 = 10 mm, a_3 = 16 mm) was formed on the catheter to investigate the optimal sound field for adhesion. The maximum sound pressure was set at 600 kPa-pp for all sound fields. The contact conditions were w = 20 mm and h = 2 mm with the latex membrane for which adhesion was confirmed in Fig.3(a). As shown in **Fig.4**, a larger displacement was obtained with smaller number of the focal points.

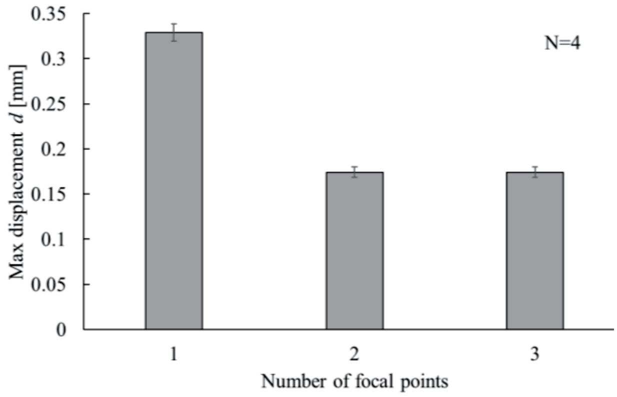

Fig.4 Catheter bending displacement during adhesion of the latex membrane at each focal number

4. Conclusions

We investigated the effect of vessel wall contact on the bending of the catheter by bending the catheter with acoustic radiation force when the catheter was in contact with the vessel wall. Since there may or may not be an effect depending on the contact width and the contact strength, the existence of a threshold value of the contact width and the contact strength that affects bending is suggested. Furthermore, it was suggested that the optimal focal number for effect is one. We will examine the threshold values when touching the actual vessel wall, and the sound field to minimize the effect.

Acknowledgement

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