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Comparison between theory and experimental data in development of thin catheter navigation using acoustic radiation force
超音波放射力を用いた細径カテーテル開発における実験値と理論との比較

Takashi Mochizuki, Nobuhiro Tsurui, Naoto Hosaka, Ren Koda, Kohji Masuda 1
([1]Grad. School of Bio-Applications and Systems Eng., Tokyo Univ. of Agriculture and Technology)
望月剛 [1]，鶴井信宏 [1]，保坂直斗 [1]，江田廉 [1]，桝田晃司 [1]
([1] 東京農工大学大学院　生物システム応用科学府)

1. Introduction

Nowadays, anticancer agents are injected into the vein directly for therapy. In this case, the density of the drug that reaches at the cancer portion decreases since the drug is diffused in the whole body. Therefore, much drug has to be injected in order to increase the density in the blood to the effective level and it causes the problem of side effects. To resolve this, drug should be carried in microbubbles to be isolated in normal tissue. Whey they flow around the body and reach to the cancer tissue, they are broken and the inside drug is intensively delivered to the cancer cells. Furthermore, in order to increase the effect, the microbubbles can be manipulated by the acoustic radiation force [1, 2].

In our study, a thin catheter is proposed. This is thinner compere to the conventional ones, so it is able to access closer to the tumor through the feeding artery and releases the anticancer agents or the former microbubbles more effectively. In case that the conventional catheter is injected into the deep area in the body, a guide wire is used for catheter navigation in general. It, however, restricts the catheter available access area. To get rid of this limitation, we have developed a method in which a thin catheter is introduced by acoustic radiation force instead of the guide wire. In the previous study, we made it successful that a simulated catheter of 0.4 mm diameter could be controlled in Y shape bifurcation of the 2 mm width and introduced to the aimed channel of it [3]. In this paper, the estimation of the force for introducing the catheter is carried out in comparison between actually measured data and calculation values from the theory.

2. Method

Figure 1 shows an experimental setup. Upper in the figure is top view of a water tank, and lower is the side view of it. TD is a 2 MHz flat circular transducer having 15 mm diameter aperture. A 39 mm length tube (outer 0.4 mm and inner 0.1 mm of diameters and its material PFA) is set in horizontal plane (X-Y plane) at 80 mm distance from the transducer in a water tank. And an end of it is held on a fixed base. In this experiment, displacement of the catheter, which is produced by acoustic pressure due to applied voltage to the transducer, is measured directly by using the camera from bottom of the tank. A sheet of very thin film is installed 5 mm in front of the catheter, which has an effect to prevent affection due to acoustic streaming in water.

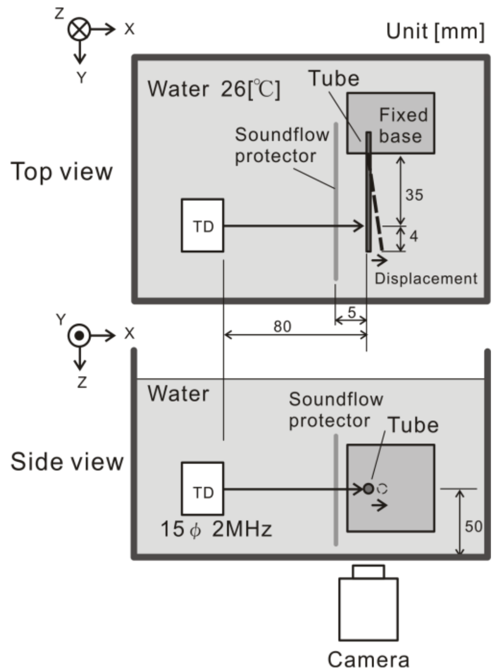

Fig. 1. Measurement system of acoustic radiation force by displacement of catheter (tube).

3. Experimental results

Figure 2 shows the graphs of the results measured. The acoustic pressure values of emitting ultrasounds are on horizontal axis and displacements of the catheter are on vertical axis of the figure. The graphs show the displacement results of 35 mm length catheter (L=35) and of 52 mm catheter (L=52), respectively. These actual

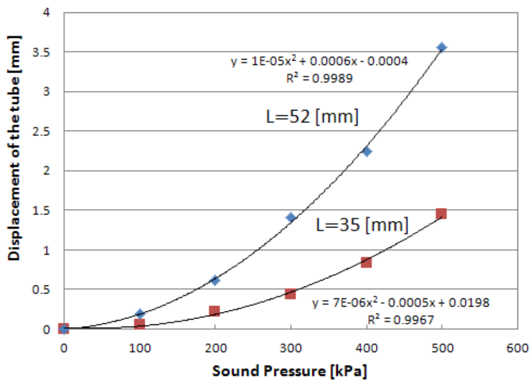

Fig. 2. Displacements of the irradiated tube by ultrasoud.

lengths are 39 mm and 56 mm, and centers of ultrasound axes are set at the 4 mm distance from the top of the catheters, respectively.

It has been understood that all data is related to square function against the acoustic pressure since the fitting curves are all square relation curves. Thus, those data are caused by acoustic radiation force. These two data are converted to the forces that are pushing the catheter according to the equation of cantilever beam. The values of the forces are shown in right side of Table I.

Table I. Comparison of forces between from calculations of acoustic energy and calculation of displacement of catheter.

Pressure [kPa]	Radiation force calculated by acoustic energy [μN]	Force calculated by displacement [μN]
0	0.0	0.0
100	3.8	3.0
200	15.3	10.7
300	34.5	22.8
400	61.3	39.6
500	95.7	66.0

On the other hand, the force pushing the catheter is able to be estimated from acoustic pressure value. The Left side of the Table I shows the forces calculated from the each acoustic pressure. And the both forces are compared in each pressure condition and furthermore, plotted in Fig. 3. The graph shows that there is a strong correlation (correlation efficiency $R^2 = 0.9983$) between the forces. Regarding to the absolute value, however, the force calculated by the displacement is approximate 70 percent of the force calculated by the acoustic pressure.

4. Discussions

The causes that the absolute values are not coincide in spite of their coming closer each other compere to the former study [3], are thought as followed.

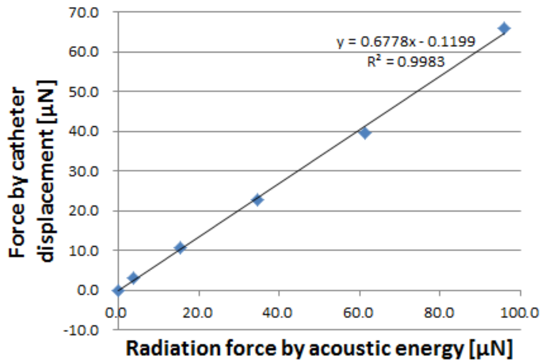

Fig. 3. Correlation between acoustic radiation force and calculated force by displacement of the catheter.

1) Ignoring affections of acoustic diffraction or ultrasound streaming around the catheter in this estimation is not appropriate in the situation that 0.4 mm diameter of the catheter is thinner than 0.75 mm wave length of the used ultrasound.
2) More measurement data in the different conditions are needed for getting more precise results.

5. Conclusion

This paper shows the potential that it is possible to let the catheter of less than 0.5 mm diameter be introduced and access near the target tissue by the acoustic radiation force without any guide wire, and that the drug can be directly delivered to the target through the thin catheter. From the experimental results, it is estimated that the catheter was pushed by the force of several ten micro Newton. For more precise estimation, an equation needs to be derived, that can estimate the force affecting the tube with a diameter of less than the wave length. That is our future work.

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