Blood vessel model equipped with ultrasound sensors for evaluation of intravascular treatment

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Abstract: Intravascular surgery, such as coil embolization and stent placement, has been widely performed for treatment of cerebral aneurysms. Doctors must be skillful and sufficiently experienced to successfully manipulate and insert a guidewire and a catheter into the aneurysm via carotid and cerebral artery. Though blood vessel model is useful for training of the doctors in the field of the intravascular surgery, evaluation of doctor’s skill and efficacy of training is insufficient. In this study, an ultrasound sensor was fabricated and equipped in the cerebral blood vessel model to measure the displacement of the vessel wall that is contacted and pushed by a guidewire or a catheter. It is confirmed that the fabricated ultrasound sensor could measure the displacement of blood vessel wall by the inserted catheter.

Keywords: Intravascular treatment, Catheter procedure, Cerebral blood vessel model, Ultrasound sensor

1. Introduction
Intravascular treatments, such as coil embolization and stent placement, are one of the minimally invasive treatment of cerebral aneurysms without opening of the skull and aneurysm clipping, which reduce patient’s burden. In this treatment, surgeons insert a guidewire and a catheter into the aneurysm via carotid and cerebral artery and coil embolization or flow diverter stent placement is performed.

Through a small incision in the groin, the doctor manipulates the guidewire and the catheter in the blood vessel to the targeted cerebral aneurysm. When the guidewire or the catheter goes through steep curved blood vessel, unexperienced doctors often contact the guidewire or the catheter to the inside wall of the curved blood vessel, and the guidewire or the catheter pushes the inside wall as shown in Fig. 1 (a), black stars indicate contact areas. On the other hand, experienced skillful doctors less frequently the guidewire or the catheter to the inside wall of the curved blood vessel by rotating the guidewire or the catheter at the front of curved blood vessel. In this study, the blood vessel model was made of poly vinyl alcohol-hydrogel (PVA-H), which is close to friction coefficient of inside wall of human blood vessel [1]. And hardness of the PVA-H model is also close to that of human blood vessel [2], the wall displacement of the blood vessel model caused by the guidewire or the catheter is relatively similar to that of human blood vessel.

In this study, blood vessel model with ultrasound sensors was developed to measure the displacement of the vessel wall when the guidewire or the catheter contacts and pushes the inside wall of curved blood vessel model. It is expected that this model is useful to evaluate skillfulness of doctor’s technique in the procedure of intravascular treatment and to evaluate effectiveness of training.

2. Measurement principle
An ultrasound sensor is set parallel to the tangent of curved blood vessel as shown in Fig. 2. The ultrasound sensor transmits pulse echo signal. After that, the same sensor receives reflected echo signal from the blood vessel wall. Delay time of the reflected echo signal from transmission represents distance between the sensor and the vessel wall as ultrasound velocity in water is constant. An oscilloscope measures received signals that converted into voltage.

(a) Unexperienced case  (b) Skillful case
Fig. 1 Catheter procedure in curved blood vessel

Fig. 2 Ultrasound sensor and measurement system

Resolution time : $1.6 \times 10^{-10}$ s
3. Design of ultrasound sensor

Fig. 3 shows a design and cross-section structure of the ultrasound sensor. The size of the sensor is 0.5 mm long, 1.0 mm wide, and 96 µm thick. The resonance frequency of the sensor is around 20 MHz. The distance resolution is mainly defined by the resolution time of the oscilloscope. The piezoelectric material of the ultrasound sensors is Pd(Mg_{1/3}Nb_{2/3})O_3-PbTiO_3 (PMN-PT) that has higher electromechanical coupling coefficient than Pb(Zr,Ti)O_3 (PZT). The thickness of backing layer is around 1.3 mm that is longer than ultrasound wavelength.

The front side electrode of transducer is connected to the electrode pad of the circuits on flexible sheet through the bottom of backing layer (B-B'). The other electrode is connected through the upside of backing layer. The backing layer attenuates unnecessary ultrasound waves and makes width of pulsed ultrasound wave short.

The substrate to mount the ultrasound transducers is a polyimide film (25 μm thick) with copper layer. Because polyimide film is flexible, it is useful to relatively accurate alignment of the ultrasound sensor to the blood vessel model.

4. Fabrication results

Ultrasound sensor was fabricated as shown Fig. 4. However, the thickness of the PMN-PT and backing layer was different from designed value. The thickness of PMN-PT was 195 µm, which was thicker than design value 96 µm. And the thickness of backing layer was about 1.6 mm, which was thicker than design value 1.3 mm.

5. Experiment

Fabricated ultrasound sensor was set outside the wall of the PVA-H blood vessel model and evaluated whether the sensor can receive reflected echo signals from outside wall of the blood vessel model. The shape and the wall thickness of the vessel model imitated to that of human carotid and cerebral arteries. The vessel model was set in an acrylic box and water was filled around the vessel model in the acrylic box as shown Fig. 6.

Figure 7 shows reflection echo signals received by the same ultrasound sensor. The wall thickness of the blood vessel model and the inner and outer diameter of the vessel model can be calculated using received four ultrasound reflected echo signals.
By using the same experimental setup as shown Fig. 6, a catheter was inserted into the blood vessel model. When the catheter contacted and pushed the curved wall of vessel model from inside, reflected echo signals shifted as shown Fig. 8. Since delay time was 0.114 µs, displacement of blood vessel wall was calculated as 0.086 mm.

6. Discussion
As the result of experiments, wall displacement of the PVA-H blood vessel model was measured. In this study, number of the measurement area was one. To measure displacement of other area of blood vessel, other sensors should be located around the vessel model.

7. Conclusion
To evaluate skillfulness of doctor’s technique in the procedure of intravascular treatment and to evaluate effectiveness of training, an ultrasound sensor was fabricated and equipped in a PVA-H cerebral blood vessel model to measure the displacement of the vessel wall. Wall displacement of the blood vessel model was measured. It is also expected that the model with the sensor is effective to evaluate therapeutic effect and safety of newly developed medical devices. In the future, the acrylic box will be filled with 5 wt% PVA-H instead of water to imitate perivascular tissue.

Reference

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