경동맥에서 혈관벽 근처 유동의 정확한 측정과 유체 구조물 상호 작용 분석을 위한 딥러닝 기반의 경계 탐지 및 보정 기법

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Deep learning-based boundary detection and compensation technique for the accurate measurement of near-wall flow and fluid-structure interaction in the carotid artery

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Abstract : Fluid–structure interaction (FSI) anlaysis at compliant arteries is difficult for several imaging studies. In this study, we propose a deep learning-based boundary detection and compensation (DL-BDC) technique that segments vessel boundaries by employing the convolutional neural network and compensates wall motion in near-wall flow dynamics. Its segmentation performance is evaluated through *in vitro* experiments. The neural network performs well with high structural similarities of over 0.9. Then, the performance of wall motion compensation is verified through *in vitro* compliant phantoms. When DL-BDC is applied to flow influenced by wall motion, bias errors are less than 0.0002 cm/s DL-BDC is utilized for analyzing FSI according to the elasticity of the phantom. Results show that the flow dynamics and wall shear stress values are consistent with the expected values of the compliant phantoms. DL-BDC is applied to human carotid artery to verify its clinical applicability. As a result, DL-BDC can provide fast, accurate, and robust segmentation of vessel wall and high measurement accuracy in near-wall flow by wall motion compensation. This approach can be beneficial for FSI analysis in carotid artery.

1. 서 론

Vessel wall and blood flow motions are clearly coupled and affect each other continuously[1]. Thus, the simultaneous analyses of cardiovascular wall and blood flow dynamics are required to obtain accurate diagnostic information on the corresponding vascular pathologies. Several studies have sought to analyze arterial wall motion and blood flow simultaneously by ultrasound (US) imaging. However, its diffraction limit and tradeoff between the spatial resolution and penetration depth preclude accurate and quantitative fluid-structure interaction (FSI) analysis.

A deep learning-based segmentation approach can be used for accurate FSI analysis. However, practical constraints are encountered when the conventional deep learning-based approaches are applied to the FSI analysis of hemodynamic studies.

In this study, we propose a deep learning-based boundary detection and compensation (DL-BDC) technique that can accurately identify vessel wall boundaries by implementing the U-net architecture[1] and compensate for the effect of wall motion in flow velocity measurement in the near-wall region.

2. 본 론

2.1. Method

2.1.1. DL-BDC

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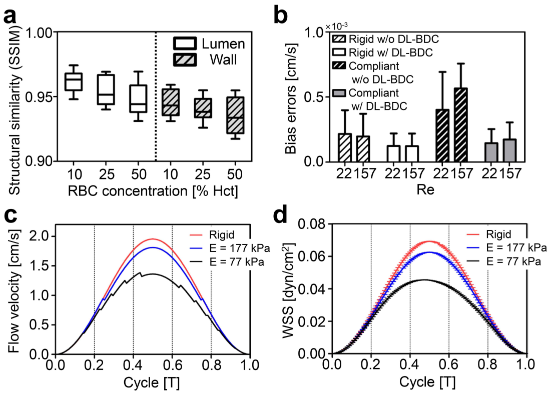

Fig. 1 (a) Box plots of SSIM for in vitro phantom according to RBC concentration. (b) Comparison of bias errors for the various elastic moduli of the phantom and flow velocities with and without DL-BDC. Periodic variations in (c) flow velocities and (d) WSSs in the phantoms with three different elastic moduli

The designed U-net was employed to segment the vessel wall and lumen from the captured US images. The segmented wall and lumen images could be employed to calculate wall and flow velocity respectively by speckle image velocimetry (SIV). The velocity vectors were subtracted by the corresponding components of the wall velocity to compensate for moving wall effect on blood flow.

2.2. Evaluation of segmentation and wall compensation performance

Mean structural similarity (SSIM) values for the lumen and wall were over 0.94 and 0.93 for red blood cells (RBCs) (Fig. 1(a)). The DL-BDC could provide precise segmentation even if the boundaries of neighboring vessel are slightly indistinguishable.

DL-BDC slightly improved the measurement accuracy of the flow velocity in the rigid phantom. The DL-BDC improved the measurement accuracy of flow velocities affected by wall motions in the compliant phantom (Fig. 1(b)).

2.3. Clinical application to carotid artery

Phase variation in the compensated velocity and

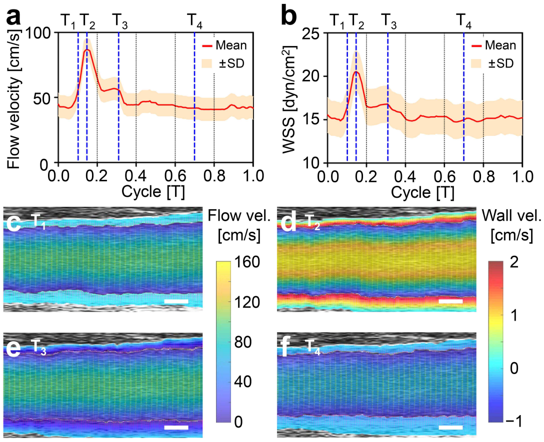

Fig. 2 Phase variations in (a) average flow velocity and (b) WSS in a cardiac flow cycle. (c–f) Representative results at certain cardiac phases: T_1, T_2, T_3 and T_4.

WSS value were consistent with the phase of the cardiac cycle (Figs. 2(a) and (b)). Figs. 2(c–f) show the wall and flow velocities of the human carotid artery at certain phases. Their velocities accelerated and decelerated along the propagating pulse wave.

3. 결 론

In this study, DL-BDC is proposed for automatic vessel boundary segmentation and wall motion compensation in the near-wall region based on U-net and SIV. Flow and wall dynamics can be mapped simultaneously from the corresponding US images. Hence, fast and robust DL-BDC can be utilized for FSI analysis not only in experimental investigations but also in clinical practice.

참고 문헌

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