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Asymmetric Three-dimensional Pulsation of Rat Carotid Artery Bifurcation Observed Using a High-resolution Ultrasound Imaging

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The arterial structure experiences cyclic pulsation in three-dimension (3-D) by cardiac output and blood flow. The evaluation of arterial wall motion and hemodynamics may contribute to early diagnosis of arterial diseases such as atherosclerosis. Ultrasound could evaluate arterial wall motion in real time by its high frame rate. Although many previous studies discussed mechanical property of carotid artery in two-dimensional view, the 3-D pulsation of carotid artery geometry *in vivo* is not yet investigated in detail. In this study, we acquired cross-sectional images of carotid artery bifurcation from three rats using a high frequency ultrasound imaging system and post image process was applied to quantify 3-D asymmetric variation of CAB.

1. Experiment Setup

A Spargue-Dawley rat (8 weeks old) was anesthetized with isoflurane and oxygen via a vaporizer and placed in a supine pose on a heated stage. A physiological monitoring unit (THM 100, Indus Instruments, Houston, TX, USA) was installed to monitor rectal temperature, heart rate, and electrocardiogram (ECG). The neck fur on the left side was gently removed using thioglycolate depilatory cream (Veet, Reckith Benckiser Inc., Toronto, ON, Canada) and pre-warmed ultrasound gel was used as an acoustic coupling medium. All procedures performed on animals were approved by the Animal Care and Use Committee of Jeju National University (Jeju, South Korea) to ensure that they were appropriate and humane (**Fig. 1**).

The left CAB images (**Fig.1.c**) were collected by a Vevo 770 ultrasound imaging system (VisualSonics Inc., Toronto, ON, Canada) using a single-element crystal mechanical transducer (RMV 704; VisualSonics Inc., Toronto, ON, Canada). The axial and lateral resolutions are 40 µm and 80 µm, respectively and focal length of the scanhead is 6 mm and depth of field (DOF) is about 1.5 mm. A 4×4 mm^2 field of view (FOV) was set to obtain the cross-sectional images of CAB [1]. The scanhead was mounted in a XYZ positioner of an integrated rail system which allowed variety of positions and angles. An additional 2 axis platform (TPS-1, NAMIL O.P. Co., Korea) with 10 µm step resolution was mounted on an animal stage in order to manually adjust the platform to shift to the following scan position. After adjusting the scanhead using B-mode window, the high-temporal resolution cross-sectional images were acquired by switching to an ECG-gated kilohertz visualization (EKV) mode. [2].

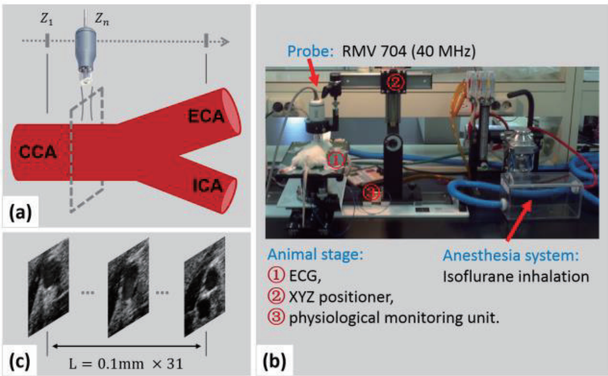

Fig. 1. A protocol of ultrasound image acquisition with setting. (a) Mechanical linear scanning from common carotid to external and internal carotid artery. (b) Experiment setting. (c) The portion slices of acquired 3-D data set

2. Image processing

I. Lumen boundary segmentation

Manually outlined boundaries were adopted as references for evaluation. The manual segmentation procedure was performed by two small-animal researchers using the commercial image processing software ScanIP (Simpleware Inc., Exeter, ON, UK). First, several standard points (SPs) and the brightest gray level pixels were selected on the distinct lumen edge along the lumen boundary [3]. Then the entire lumen area was filled using a circular brush (one of the processing tool) by treating the SPs as the critical edge. A set of 31 segmented lumen contours were imported to an additional image processing software, Amira for 3-D reconstruction and volume rendering.

II. Reconstruction of 3-D Geometry

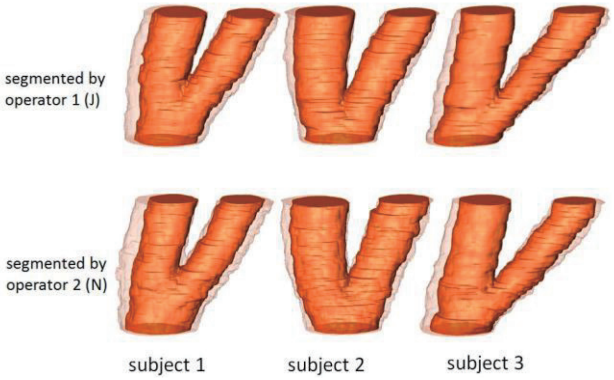

Fig. 2. Reconstructed 3-D geometry of CAB. Two phases at peak systole and diastole were overlapped for visualization. Darker geometry inside is a peak diastolic phase and lighter geometry outside is a peak systolic phase.

The segmented lumen boundaries were transferred to a visualization software, Amira (FEI Visualization Sciences Group, Hillsboro, ON, USA) for 3-D reconstruction. The *SurfaceGen* function in Amira was used for 3-D surface generation and the rendered geometry is illustrated in **Fig. 2**. The manually segmented lumen boundaries were also rendered through the Amira software.

III. Quantitative Analysis

To measure the variation of CAB geometry, the multiple cross-sectional contours were extracted from the constructed geometries. An adjusted cutting was implanted to eliminate the influence of oblique geometry by a fixed image scanning plane. The geometry was rotated to about 24 degree on Z axis to place it on the perpendicular angle to CCA. Six sets of cross-sectional contours of CAB on the adjusted cutting plane were extracted for quantitative analysis. The systolic and diastolic cross-section contours were overlapped and the distance of these contours from the geometrical center on the diastolic contour was measured. Then, the systolic contour was mapped with index of distance ratio (systolic distance/ diastolic distance).

3. Results

As shown in **Fig. 3** and **Table. 1**, the asymmetrical expansion of CAB has been measured and visualized. From this measurement we could confirm the common carotid artery and external carotid artery favorably expand to anterior direction and internal carotid artery favorably expands to posterior direction.

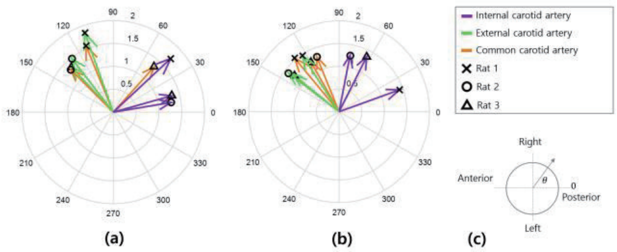

Fig. 3. Quantification of asymmetrical expansion of CAB in terms of distance in mm and angle in degree during a cardiac cycle.

	Parameters	CCA	ECA	ICA
Rat 1	Diameter ratio (%)[a]	123.7 ± 2.5	130.1± 8.7	126.1 ± 7.2
	Area ratio (%)[b]	151.8 ± 6.0	165.8 ± 20	156.9 ± 18
Rat 2	Diameter ratio (%)[a]	115.4 ± 3.1	120.4 ± 3.9	114.0 ± 2.6
	Area ratio (%)[b]	130.8 ± 7.2	144.0 ± 9.1	127.5 ± 5.2
Rat 3	Diameter ratio (%)[a]	114.5 ± 3.3	116.8 ± 3.1	116.3 ± 2.9
	Area ratio (%)[b]	129.4 ± 3.4	130.5 ± 7.9	134.2 ± 6.5

[a] Diameter ratio (%) = (systolic diameter/ diastolic diameter) × 100.
[b] Area ratio (%) = (systolic cross-sectional area/ diastolic cross-sectional area) × 100.

Table 1. The quantitative measurement of Fig. 3. Quantification of asymmetrical expansion of CAB during a cardiac cycle.

Conclusions

In this study, we reconstruct the 3-D carotid artery bifurcation (CAB) geometry from three rat subjects to observe the behavior of the carotid artery by high resolution ultrasound imaging. Manual segmentation of the artery was performed by two experienced researchers based on the same protocol. From the constructed geometries, the 3-D asymmetric pulsation of CAB was observed. This asymmetrical pulsation in 3-D could improve our understanding of hemodynamic etiology of cardiovascular disease and also provide more realistic input data for computer simulation of hemodynamics.

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