「様式３－B」

Project number　42

Combined in silico and in vitro assessment of valve dynamics

［１］Research group

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［２］Research setup

Cardiovascular disease associated with insufficient valvular function could deteriorate circulatory function as well as induce haemolytic or thrombosis. Also the role of venous valve in lower pressure condition in circulatory systems remains poorly understood. In this study, we focused on the fluid velocity changes of congenital pulmonary heart valve disease and adult vein valves, which could cause increase of blood shear or stress concentration of the leaflets as well as stagnation with thrombogenesis under the low pressure gradient circulatory conditions. Computational approaches for the medical physics analysis for these valvular diseases include multi-physics boundary interactions between vascular materials characteristics and fluid dynamics of blood.

［３］Research outcomes

（３－１）Results

An ePTFE (expanded polytetrafluoroethylene) heart valve is alternatively selected for the restoration of physiological pulmonary blood flow in pediatric patients with congenital heart failure. The valve has fan-shaped tri-leaflets with bulging sinuses in an ePTFE vascular prosthesis, which is to be surgically sutured and installed as the pulmonary heart valve between the right ventricle and the pulmonary artery by end-to-end anastomosis. The authors have been developing a hydraulic heart valve test loop to examine the hemodynamic function of the ePTFE heart valves. The higher rate of the feasibility of the ePTFE valve than that of bioprosthetic heart valves as right ventricular outflow tracts for congenital heart failure patients has been reported through more than ten years of clinical applications. On the other hand, the valvular leaflet motion under the pulsatile flow in varying pressure-flow conditions remains to be seen.

We aimed for further improvement of the dynamic performance of the valve leaflet and the conduit with regard to the hemodynamic interactions and the materials dynamic characteristics between the conduit wall and the leaflet sinuses. We developed a new test pulse duplicator for the valve with the dynamic measurement system by the high-speed camera to detect the leaflet deformation under the pulsatile flow condition representing the right ventricular-pulmonary artery flow conditions. In this study, we have reconstructed and examined the ePTFE leaflet structures by using synchronised high-speed cameras in our valve testing systems by using multi-digital image correlating analyses.

The valve tester consisted of a valve holder with a nozzle-shaped inflow and a linear actuator which is capable of simulating the transvalvular flow as shown in Figure 1. The valve and cameras were placed in the bottom of the water reservoir, and the recording trigger was controlled from the outside via the Wi-Fi synchronization. The originally designed T-shaped Wi-Fi extension aerials were attached on the cameras to synchronise the image frames of each camera in underwater measurement conditions. Each image was captured at an angle of every 32 degrees in the same plane with the distance from the subject by around 150mm. Prior to the measurement, the surface data validation was performed using a cylindrical phantom, the diameter of which was 20mm. The speckle patterns of the 1mm-diameter black coloured circles with the density and the variation of 75 and 75 %, respectively, was generated by Speckle Generator (Correlated Solutions, Irmo, SC, USA). The filtering coefficient was also examined by the phantom validation processes. The leaflet of the 0.1mm-thickness ePTFE sheet was sutured on the ePTFE conduit, and then the leaflets annulus was glued on the valve holder. The high-speed cameras (DSC-RX0, Sony, Tokyo, Japan) with the underwater wide close-up lenses (UCL-G165 M55, Inon, Kanagawa, Japan) were used for simultaneous multilateral visual recordings at the frame sampling rate of 960Hz with active pixel numbers of 1136 x 384. Prior to the valve leaflet measurement, the valve leaflets were sutured on the valve holder housing with the diameter of 18mm, on which the speckle patterns were printed as shown in Figure 2. The valve holder was vertically supported and driven by reciprocating the linear actuator. The sequence of the pictures obtained at each camera was analysed by the digital image correlation process using Mathematica, Version 11 (Wolfram Research, Champaign, IL, USA), and Matlab, 2018a (Mathworks, Natick, MA, USA).

Overview of brief results are as follows:

a) Surface parallax reconstruction using the phantom

Geometric transform was applied to the left, centre, right images, and the parallax images between the left-centre and the centre-right data were calculated. Figure 3 shows the changes in relative depth at the distance from 146 to 154 mm, and the surface variations were accurately obtained from the parallax images.

b) Valve leaflet deformations

The synchronised multilateral images of the leaflet were successfully derived with the system. The leaflet shapes with systolic opening or diastolic closed phases were calculated and represented as 3D data using image correlation analyses (Figure 4). Therefore, it was indicated that the 3D reconstruction images in high-frequency valve leaflet behaviour could provide the relationship between the valve leaflet regional stress distribution and the hemodynamic characteristics under the pulsatile flow motion conditions.

（3－2）**Future perspectives**

Based on the funding support by the Joint Research Program of Joint Usage/Research Center at the Institute of Development, Aging and Cancer, Tohoku University, the physical communication and data exchanges could be carried out among the researcher to publish papers for the new approach. This international communication will be associated with pre-clinical studies for the implantable cardiovascular devices with the sophisticated biomedical scientific examination in each country.

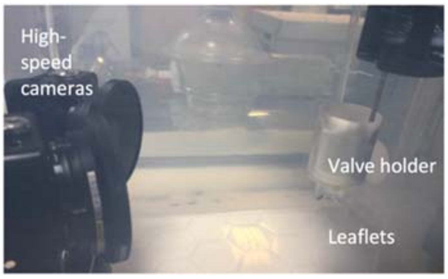

Fig. 1 The multi cameras and the pediatric ePTFE valve leaflet model in the water reservoir used in the in vitro study.

［4］**List of Papers**

(1) Shiraishi Y, Iwamoto N, Narracott AJ, Yambe T, Yamagishi M. 3D ePTFE Heart Valve Leaflet Deformation Analysis Using Multi High-Speed Camera Digital Image Correlation, Proc 3D Image Conference, P-12, July, 2019.

(2) Iwamoto N, Shiraishi Y, Yamada A, Inoue Y, Tachizaki Y, Morita R, Hashimoto M, Ibadurrahman MF, Narracott A, Fenner J, Yamagishi M, Yambe T. Measurement accuracy of the ePTFE valve motion visualisation with multi camera systems, Jpn J Artif Organs, 48(2), S-236, 2019. (in Japanese)

(3) Morita R, Shiraishi Y, Hanzawa K, Qian Y, Narracott A, Inoue Y, Yamada A, Iwamoto N, Tachizaki Y, Ibadurrahman AF, Hashimoto M, Yambe T. Development of an aortic dissection model for hydrodynamic simulation studies, Jpn J Artif Organs, 48(2), S-239, 2019 (in Japanese).

(4) Shiraishi Y, Narracott A, Iwamoto N, Fenner J, Qian Y, Ibadurrahman AF, Uematsu M, Yambe T, Yamagishi M. Dynamics of a pulmonary ePTFE valve by usgin a multi-camera high-speed 3D reconstruction system. Jpn J Artif Organs/8th IFAO Proc, 48(2): S-136, 2019