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The Cardio Vascular Simulator (*CardioVASS*) Device on Monitoring the Physiology of Blood Flow Circulation via Angiographic Image for Medical Trainee

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ABSTRACT

The World Health Organization (WHO) reported the most killer disease throughout the world is cardiovascular disease. Every year, there are millions of deaths because of the catastrophic event of cardiovascular diseases. Therefore, it's crucial to understand the blood flow through the heart mechanism in the human body. In Malaysia, heart simulator normally used a conventional technique to run the procedure. The typical problem arises in carrying out the procedures was time-consuming as the medical educators need to handle for approximately 20 to 30 minutes. This lead to exhaustion both educators and students. The existing device in the market is not affordable and too expensive. Therefore, the objective of this study was to develop a new simulator for cardio that namely the Cardio Vascular Simulator (*CardioVASS*) device. The *CardioVASS* device is established for the learning and teaching process. The *CardioVASS* has three modes which are to study the physiology of blood circulation in the human heart, to observe the coronary artery disease mechanism and to understand the pathophysiological condition heart during catheter insert to the small arteries. This device also lightweight and portable so the cardiac training process can be conducted anytime during the learning session in class. This adequate to overcome long-term cardiovascular learning process. This device is also simple, easy to handle and more accurate because we used an automated control system.

Keywords:
Cardiovascular; medical device; angiography image; simulator; medical trainee

1. Introduction

The cardiovascular illness commonly includes contracted or blocked blood vessels that cause a stroke, heart attack or chest pain. One of the treatments for cardiovascular illness is cardiac catheterization [1]. The cardiac catheterization is a common treatment for a cluster of techniques

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that are achieved, such as the left ventricle angiography and coronary angiography imaging. When the catheter is inserted into the heart, a number of procedures can be performed including catheter ablation, balloon septostomy, and coronary angioplasty. These procedures can be therapeutic or diagnostic. As an example, the famous procedure coronary angiography image is an indicative procedure which consents the interventional from a cardiologist in order to visualize the small image of coronary arteries. Nevertheless, to perform this procedure, the cardiologist or surgeon need to do some practice or simulator as similar as in the real procedure. The existing device related to this procedure called Squishy Artificial Heart (SAH). The function of SAH normally to observe the real heartbeat and blood flow through the overall heart chamber. However, the SAH not an automatic controller and the mutual procedures not include measuring the blood pressures thru the exact four heart chambers. The market price also expensive is about RM20,000 to RM30,000. Normally, the cardiologist intervention can't use the cardiac catheterization in order to assess cardiac productivity and the quantity of blood pumped [2]. To overcome this problem, a Cardio Vascular Simulator (*CardioVASS*) device has been developed [3,4] based on previous research in experimental Heart-S apparatus [5,6] and numerical simulation [7-10]. In an example, the existing research in computational fluid dynamics (CFD) simulation mostly focuses on the study the effect of hemodynamics factor on heart valves [9] and the physiological condition of blood flow circulation in the human heart [10]. The device is proposed for cardiologist or medical educators in practical training especially in the clinical skills learning process. There are three modes of study by using this device which is to study the physiology of blood circulation in the human heart, to observe the heart mechanism and to understand the pathophysiological condition heart during insert the catheter (Cardiac catheterization) in the small artery. The *CardioVASS* device necessitates the use of fluoroscopy to envisage the path of the catheter insert in the small coronary arteries [11]. The coronary arteries are recognized as "epicardial vessels" as they are found in the epicardium [12], the farthest layer of the heart [13]. According to the cardiologist, a patient with certain comorbidities have potential with a higher risk of contrary in the procedure of cardiac catheterization [14]. These situations contain obesity, renal insufficiency, hypertension, aortic aneurysm, aortic stenosis, unstable angina, uncontrolled hypertension, and extensive three-vessel coronary artery disease [15]. By using this device, the cardiologist or medical educator can perform cardiac routine training at their own convenience with low maintenance. The device is also affordable to purchase and long-term usage or training for medical students.

2. Methodology

2.1 Components of The Cardiovass Device

The *CardioVASS* device consists of three main components which are the reservoir tank, human heart model with coronary arteries and controller system. In Figure 1(a), the reservoir tank is showed to keep the circulation water during the device operation and for the transparent tank as shown in Figure 1(b) affords with high discernibility for the catheter to use in simulation. This tank limited to six liters of water in one procedure. The pulsatile pump can be set between 40-60bpm and inflow volume between 1600-2000ml/min. Representative coronary images are acquired by specific configurations of the cylinder movement. The tank and pump are linked with easy to prepare to circumvent time losses and water leaks. In Figure 1(b) show, the example 3D printed human heart model which is appropriate for practical or training in the Human Engineering Group (HEG) laboratory. To ensure this *CardioVASS* device function well the controller system is set up as shown in Figure 1(c).

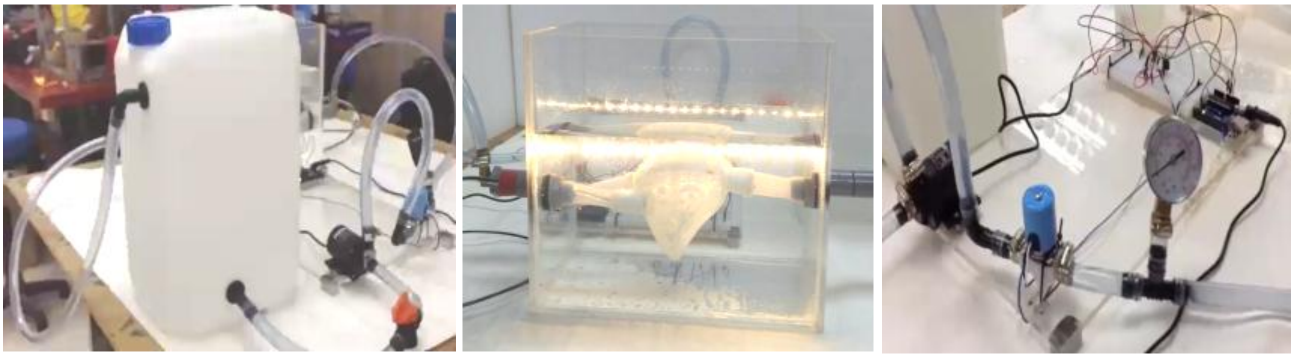


Fig. 1. (a) Reservoir tank, (b) Human heart model, and (c) Controller of the system

2.2 Materials and Specification

In this study, the Magma Flex TPU Transparent Filament (thermoplastic elastomer) is used in order to build a transparent and flexible real human heart model as shown in Figure 1(b). This filament is plastics type where it can be molten and shaped via FDM method and has related characteristics to rubber. This kind of filament is selected to accomplish the flexibility (high elasticity, high elongation at break and high strength) and the limpidity condition of the human heart model. Table 1 shows the details about the specification of the material used. In use of the material of the flexible filaments, however, there are characteristically harder to print than stiff filaments meanwhile they are simply twisted into the extruder during the printing manner.

Table 1
Specification

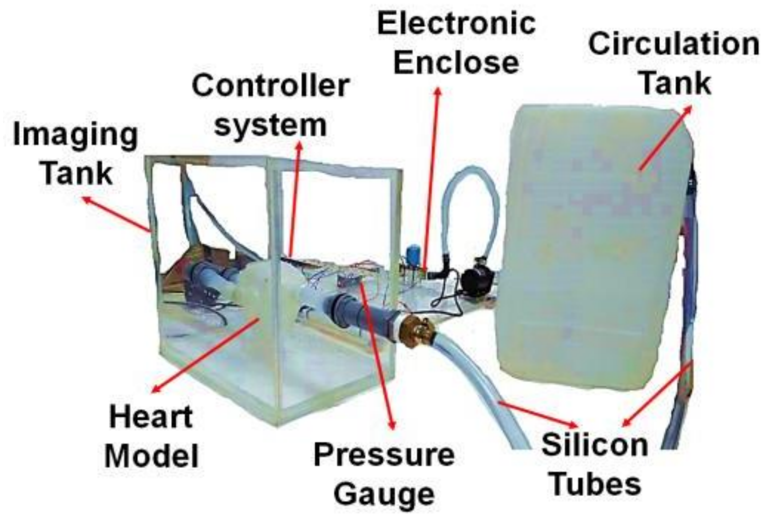
Material	Flex TPU/ Transparent
Length	335mm
Print Temperature	200-230^{o}C
Recommended printing speed	20/60 mm/s
Diameter	1.75mm +/- 0.03mm
Heated Bed Temperature	50-60^{o}C

2.3 Control System

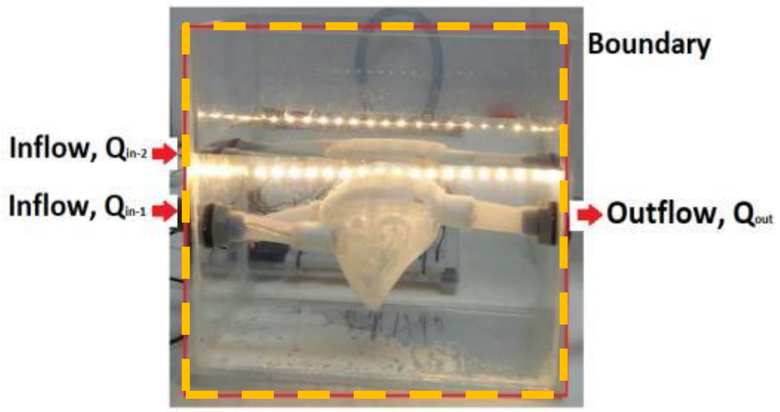
In this *CardioVASS* device, the microcontroller Arduino Uno is used. Based on easy to use software and hardware, the Arduino is created as an open-source electronics platform. Arduino envisioned for manufacture a cooperative surface. The function is to obtain the value of heart rate in beats per minute (BPM) based on the photoplethysmograph (PPG) data from MAX30100.

2.4 The Function of The CardioVASS Device

The device is continuously operating motors and also portable and lightweight thus, it makes the teaching and learning process easier anytime, anywhere. The device is developed so it is easy to be handled which includes a small LCD display and a controller knob. There are three modes which are to study the physiology of blood circulation in the human heart, to observe the heart mechanism and to understand the pathophysiological condition heart during catheter insert to the small arteries as shown in Figure 2(a). The pressure, contraction and heartbeat mode can be changed to suit the real operating of heart requirement based on the boundary condition setup as in Figure 2(b).



(a)



(b)

Fig. 2. Represented the (a) Cardio-Vascular Simulator (*CardioVASS*) device for medical training and (b) Boundary condition set up for the *CardioVASS* system

3. Results

In the present market survey, the current device is too expensive, about RM30,000-40,000 [15]. This does not cost astute and inexpensive even to a cardiovascular center. The existing product is not developed in Malaysia. The present product is relatively heavy about 10 kg, which is suitable for training purpose especially for medical students or cardiologist in Malaysia. As the new product, *CardioVASS* device is lightweight around 2kg, ease of use or handle, affordable and portable. The market size is immense particularly for the NGO/NPO center and also teaching hospitals. The *CardioVASS* device has three main modes which are to study the physiology of blood circulation in the human heart, to observe the coronary artery disease mechanism and to understand the pathophysiological condition heart during catheter insert to the small arteries.

3.1 Physiology of Blood Flow Circulation in The Human Heart

The heart and blood flow circulatory system basically functions as a network that delivers the blood to the whole body's tissues. In Figure 3, the healthy and normal physiology of blood flow circulation during entering the small artery in human heart model via the *CardioVASS* device is shown. The nonabnormal pattern of blood flow is occurred during the training performed.

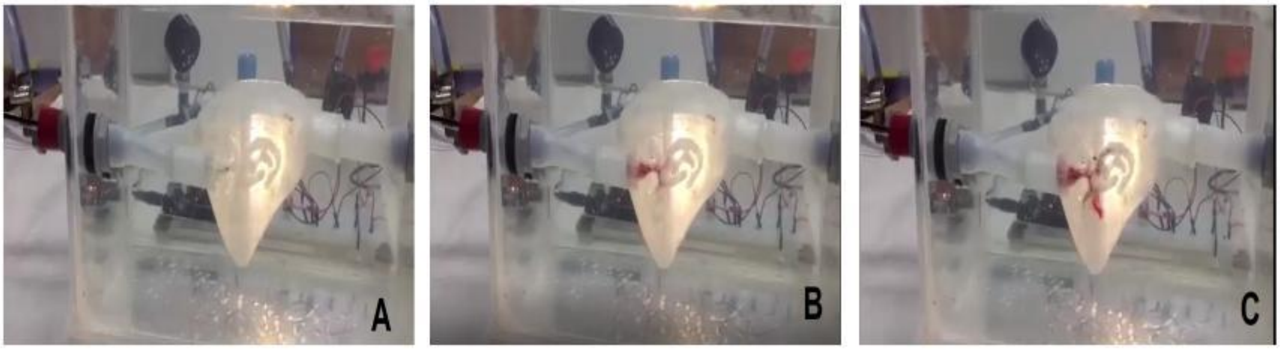


Fig. 3. Normal physiological blood flow entering the small arteries in the human heart model

3.2 Coronary Artery Disease Mechanism

The coronary artery disease mechanism includes a decrease of blood flow and oxygen to the heart muscle due to atherosclerosis of the arteries of the heart. Figure 4 shows, the mechanism of the heart model which is set as a healthy (without any leaking) and unhealthy (with hole and causes of leaking) coronary artery during the training performed. Results show during unhealthy condition the heartbeat will be increased and the flow pattern drastically changed to an unstable period.

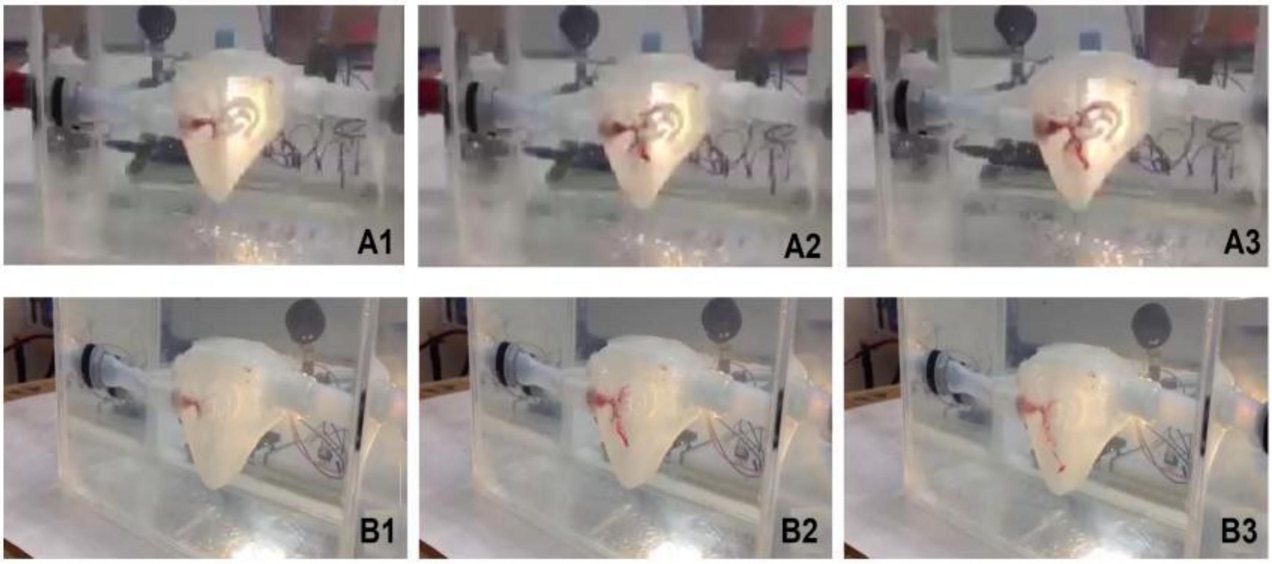


Fig. 4. *Top:* Healthy coronary artery; and *Bottom*: Unhealthy coronary artery

3.3 Heart Blockage

Numerous tests can be used to understand if there are areas of the heart that have cooperated blood flow, such as the implementation of nuclear scans and stress tests. This preliminary test is not faultless nevertheless it shows in patients gritty to be an important risk, the regular way to directly evaluate the heart blockage is to expression at the outline of the real vessel itself with a technique called a coronary angiogram image as realized in Figure 5. In the heart blockage, if severe sufficient can prevent the muscle attainment the blood its essentials to function, particularly at times when more blood flow is compulsory such as when exercising, foremost to symptoms such as shortness of breath and chest pain.

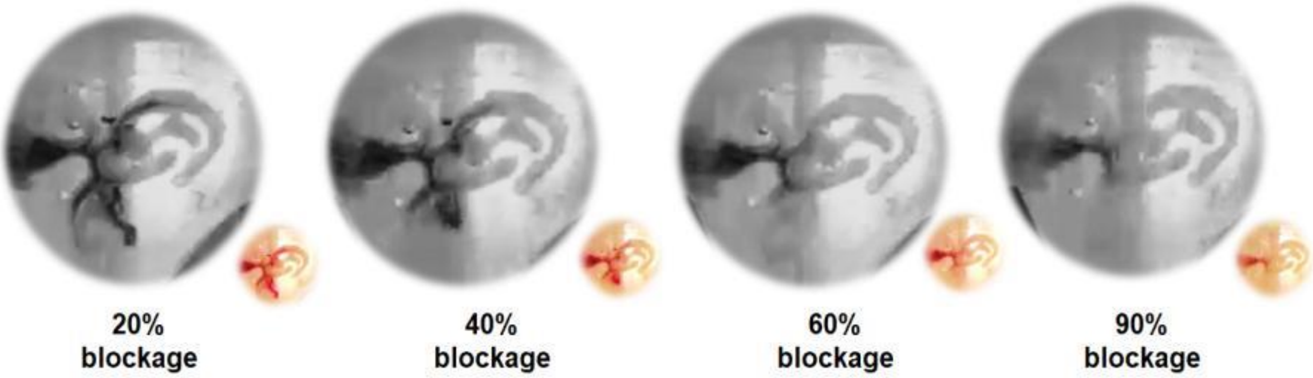


Fig. 5. Represented the normal blood supply of the heart with 20% to 90% heart blockage

3.4 Pathophysiological Condition Heart During Insert the Catheter in The Small Arteries

Cardiac catheterization is a group of techniques that are accomplished using left ventricle angiography and coronary angiography. When the catheter is inserted to the small arteries, it can be used to achieve a number of techniques including electrophysiology and angioplasty. Figure 6 shows the process of insertion of the catheter in the small arteries via *CardioVASS* device. Normally, the maximum time taking to complete the task is around 5 to 6 minutes depending on the skills of the person in charge.

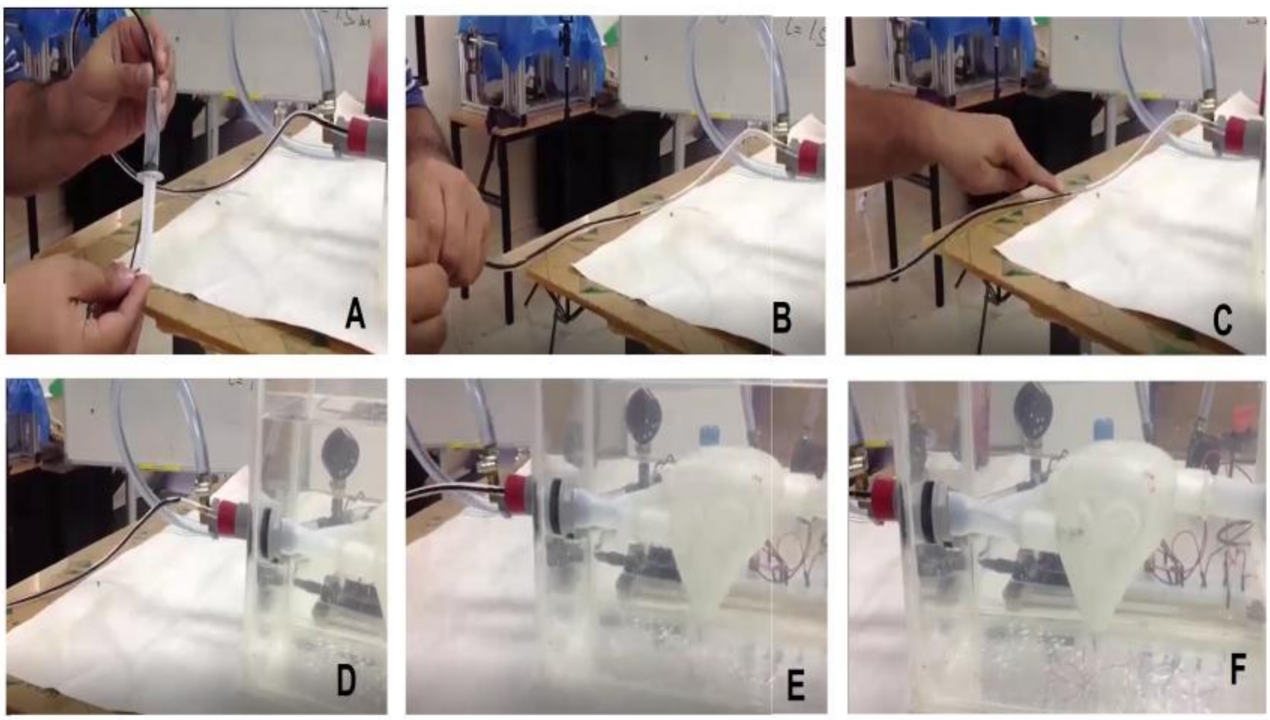


Fig. 6. Insertion catheter process in the small arteries at the human heart model

3.5 Validity Test

Medical devices are also becoming smaller and more complex in design, sometimes using the advanced 3D printer and engineered plastics. The simply validity test is conducted not only to obey regulations but also design the highest-quality part and production process. The results of the validity test as shown in Figure 7. We have compared the scanned image between *CardioVASS* device and phase-contrast MRI. The result obtained from *CardioVASS* device presented very clear in viewing the physiology of blood flow circulation in heart model and almost 95% similar in detected the coronary heart disease that completely represents the arteries blockage in phase-contrast MRI.

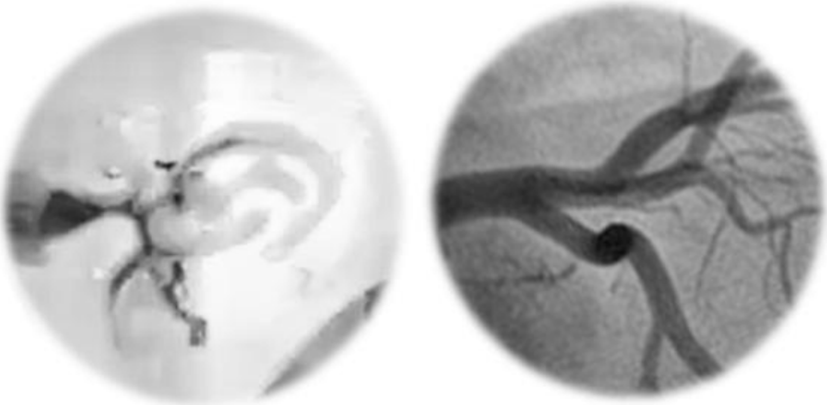


Fig. 7. Validation of the scanned image between *CardioVASS* device (left) and phase-contrast MRI (right)

The computed flow characteristic in modeling simulation is also compared directly to our own *in vivo* measurement using a *CardiovVASS* device, as well as shown in Figure 8. There is an overall agreement between our simulations and the *CardioVASS* data. Compared to the data, the simulated heart hemodynamics is less curly, doubtless due to the fact that we ignored flow reflections in the system.

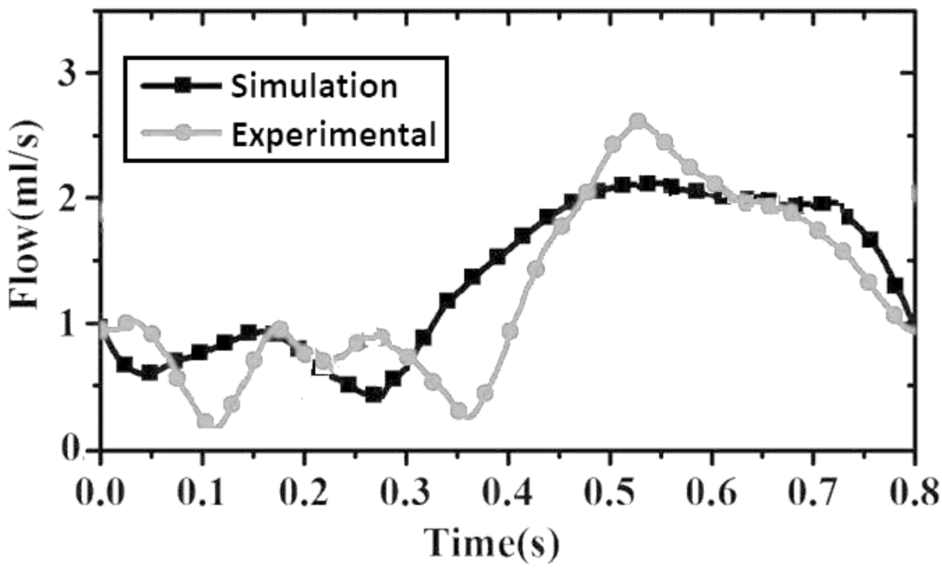


Fig. 8. Comparison of the flow characteristic from modeling simulation and CardioVASS measurement data

3.6 Novelty and Inventiveness of The Device

The *CardioVASS* device shows the most affordable device, especially for medical training. The device is a supplementary portable and compact design with less than 2kg. This device also appropriates for the medical student, medical educator, all trainer and cardiologist to be used. Throughout the cardiac training, this device can familiarize actual patient complaint as contraction, speed and heart rate controls.

4. Conclusions

The *CardioVASS* device is well developed. This device is very eased of the handle and use, lightweight, portable and too affordable. Expectantly, the developer of *CardioVASS* device prototype can help the medical educators, cardiologist, medical student, and all the trainee to recover the capability to use the *CardioVASS* device specifically in handling the angiography surgery.

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