CFD STUDY ON AORTIC CANNULA (FLOW CHARACTERISTICS)

NABILA BINTI SULAIMAN

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ABSTRACT

During cardio-pulmonary bypass (CPB) machine operation, aortic cannula is placed in the right side of the heart. One of the complications in current aortic cannula usage is the sandblasting effect of cannula jet. This study aims to reduce the exit force and jet velocity of blood flow, thereby reducing the sandblasting effect. Five new aortic cannula designs are investigated using numerical techniques. All cannula have straight and grooves geometries respectively which produce different swirl flow characteristics. Pressure drop, outflow velocity, helical density and wall shear stresses are the components analysed for all case studies. It is shown that the spiral flows induced by straight cannula body employs the lowest pressure drop, lowest outflow velocity, farthest distance of helical flow, and lowest wall shear stress distribution. It is also shown that the flow from cannula with two revolutions and four groove displays the highest pressure drop, low outflow velocity, shortest distance of helical flow and the highest wall shear stress distributions.

ABSTRAK

Semasa mesin *'cardio-pulmonary bypass'* beroperasi, kanula aorta diletakkan pada bahagian kanan jantung. Satu daripada komplikasi pada penggunaan kanula aorta terkini ialah kesan '*sandblasting*'daripada pancutan kanula. Kajian ini bertujuan untuk mengurangkan daya keluar dan kelajuan pancutan aliran darah, sekaligus mengurangkan kesan '*sandblasting*'. Lima model kanula aorta baru dikaji dengan menggunakan kaedah pengiraan. Semua kanula mempunyai geometri lurus dan berlekuk di mana ia menghasilkan karakter aliran lingkaran yang berbeza. Pengurangan tekanan, kelajuan aliran keluar, ketumpatan aliran lingkaran dan daya ricih adalah komponen yang dianalisis untuk semua kajian. Ini meninjukkan yang aliran lingkaran yang terhasil dari rekabentuk yang lurus mempunyai pengurangan tekanan paling rendah, aliran keluar paling rendah, aliran lingkaran paling panjang dan tebaran daya ricih paling rendah. Ia juga menunjukkan di mana kanula yang mempunyai dua pusingan dan empat lekuk mempamerkan pengurangan tekanan paling tinggi, aliran keluar yang rendah, aliran lingkaran paling pendek dan tebaran daya ricih paling tinggi.

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D, d	-	Diameter
F	-	Force
g	-	Gravity = 9.81 m/s
I	-	Moment of inertia
l	-	Length
m	-	Mass
N	-	Rotational velocity
P	-	Pressure
Q	-	Volumetric flow-rate
r	-	Radius
T	-	Torque
Re	-	Reynolds number
V	-	Velocity
w	-	Angular velocity
x	-	Displacement
z	-	Height
θ	-	Angle
ρ	-	Density

CHAPTER 1

INTRODUCTION

1.0 Introduction

The use of cardiopulmonary bypass (CPB) technology allows cardiac surgical procedures to be performed in a motionless, bloodless surgical field. It incorporates an extracorporeal circuit to provide physiological support. Typically, blood is gravity drained from the heart and lungs to a reservoir via venous cannulation and tubing, and returned oxygenated to the cannulated arterial system by utilizing a pump and artificial lung (oxygenator or gas-exchanger). The tubing and cannula are manufactured of clear polyvinyl chloride, while the oxygenator casing and connectors consist of polycarbonate[1]. Figure 1.1 showed the diagram of a 'closed' extracorporeal circuit for cardiopulmonary bypass.

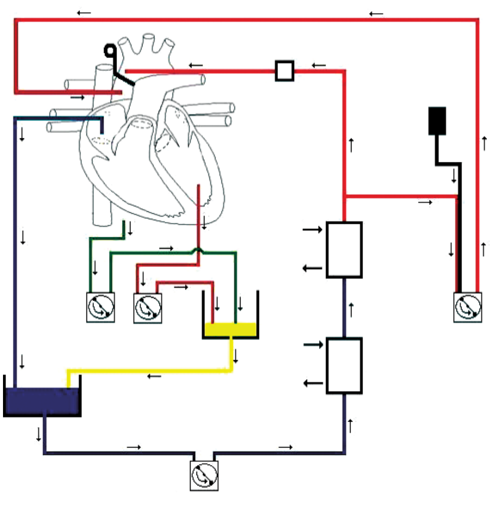


Figure 1.1 Diagrammatic representation of a 'closed' extracorporeal circuit for cardiopulmonary bypass.

In the early day of Cardio-Pulmonary Bypass (CPB), arterial inflow was via the subclavian or femoral artery but currently it is usually via a cannula inserted into the ascending aorta.

During cardio-pulmonary bypass (CPB) machine operated, a narrow bore catheters which is known as aortic cannula is placed in the right side of the heart, allowing oxygen addition to the blood from the machine to the patients for open heart surgery. The aortic cannulation has various advantages in preference to femoral artery or iliac artery cannulation as the method is having low complication rate, saving time, visibility of cannula and no second operation site of doubtful sterility[2][3]. The site for cannulation is selected based on the type of cannula to be used, the operation planned (how much of the ascending aorta must be available), and the quality of the aortic wall.

However, there are some drawbacks detected from current aortic cannula because of high flow through narrow cannulas which may lead to sand-blasting effect, hemolytic damaged and thromembolism etc that will cause stroke and cerebral hypoxia[4].

One of the main drawbacks is atherosclerosis. Atherosclerosis with or without calcification frequently involves the ascending aorta and poses problems regarding arterial cannulation and application of clamps and vascular grafts[5]. Dislodgement of atheromatous debris either by direct mechanical disruption or from the "sand-blasting" effect of the jet coming out of the arterial cannula is thought to be a major cause of perioperative stroke. Atherosclerosis is also considered a risk factor for perioperative aortic dissection and postoperative renal dysfunction.

Besides, many potential complications of aortic root cannulation exist[6], including inability to introduce the cannula (interference by adventitia or plaques, too small an incision, fibrosis of wall, low arterial pressure), intramunal placement, dislodgement of atheroemboli and air embolism from the cannula or if the aortic pressure is very low, injury to the back wall of the aorta; persistent bleeding around the cannula or at the site after its removal; malposition of the tip to a retrograde position or even across the aortic valve, against the vessel wall, or into the arch vessels; abnormal cerebral perfusion; obstruction of the aorta in infants; aortic dissection; and high CPB line pressure[7]. High systemic flow line pressure may be a clue to malposition of the tip against the vessel wall or into an arch vessel, cannula occlusion by the aortic cross-clamp, aortic dissection, a kink anywhere in the inflow system, including a line clamp still on, or use of too small a cannula for the intended CPB flow.

Inadvertent cannulation of the arch vessels or the direction of a jet into an arch vessel may cause irreversible cerebral injury and reduced systemic perfusion[8]. Suggestive evidence includes: high systemic line pressure in the CPB circuit; high pressure in the radial artery if supplied by the inadvertently cannulated vessel (or low pressure if not supplied by the cannulated vessel); unilateral facial blanching when initiating bypass with a clear priming solution; asymmetric cooling of the neck during perfusion cooling; and unilateral hyperemia, edema, petechial, otorrhea, or dilated pupils. Before CPB, the radial artery catheter may reveal sudden clamping if the cannula is inserted in the arch vessel supplying the monitored radial artery.

Furthermore, the emboli generation during CPB is profoundly affected by the hemodynamic properties of aortic cannula used[6]. This emboli released by the jet emerging from the aortic cannula, the aorta clamping and declamping procedures from the surgery site.

One of the main sources of complications is the outflow cannula, due to the altered flow conditions it creates in the aortic arch and the sandblast effect of the cannula jet. Many approaches to analyzing flow conditions during CPB have been tried in the past, and several cannula designs have been presented aiming to avoid detrimental effects. Figure 1.2 showed the example of aortic cannula and Figure 1.3 showed three aortic cannula with different tip types.

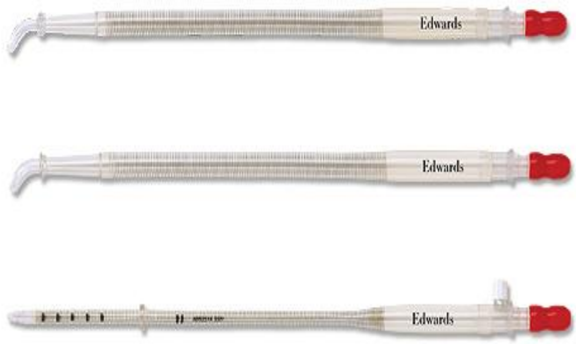
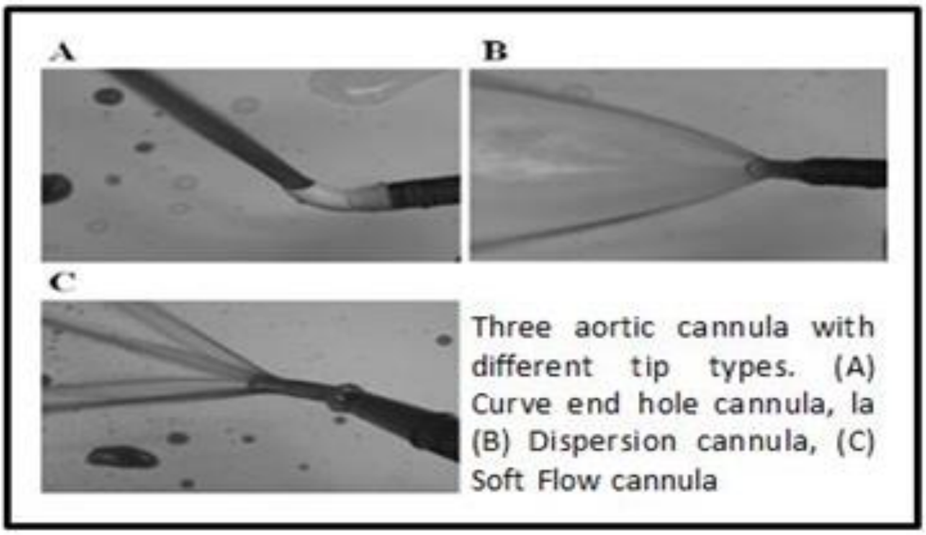


Figure 1.2 Examples of aortic cannula



Three aortic cannula with different tip types. (A) Curve end hole cannula, la (B) Dispersion cannula, (C) Soft Flow cannula

Figure 1.3 Three aortic cannula with different tip types[9]

1.1 Research Background

Over the past few years, many different cannulas types are available and made of various materials. Some that are designed for insertion into the ascending aorta have right angled tips, tapered, end-hole, coning types and some have flanges to aid in fixation. Nonetheless, aforementioned designs are unable to induce the physiological spiral flow pattern. Large vortices were still present at the aortic despite inducing lower outflow velocity among the flow stream pattern.

New arterial cannulae are designed specifically to reduce the exit force and velocity of blood flow, thereby reducing the “sandblasting” effect of the exiting blood jet and may help to attenuate those problems of aortic cannulation complications by improving hydrodynamics [10].

In this study, there are five models of novel aortic cannula design to be studied by using numerical method in observing helical flow from the tip of cannula to the aorta. All designs will be compared to determine any improvements of inducing helical flow. The flow characteristics by virtue of the helical flow inducing design features will be our focus in terms of pressure drop across the cannulas, outflow velocities of models, flow patterns, helicity density and wall shear stress in order to confirm that the designs will induce swirl flow profile of blood in aorta.

1.2 Research Objectives

The research objectives of this study are to determine the blood flow characteristics in aortic cannula with varied inlet velocity by using numerical method and to establish aortic cannula geometry properties for inducing spiral flow in order to determine the best design of aortic cannula used in CPB surgery.

1.3 Problem Statement

This study will provide the blood flow characteristic across the cannula and identify the best design of cannula in order to reduce the complications and detrimental effects such as ‘sandblasting effect’[11], atheroembolism, hemolysis etc.

1.4 Scope of Research

There are several other limitations to this study. Even though the numerical simulations were validated in terms of hemodynamics and hemocompatibility, they do not represent in vivo conditions[12]. The boundary conditions used in the simulations might vary from those in patients, which might have an impact on the results. A verification of the CPB simulation in vivo is not yet possible. In this study, we only looked at standard conditions and neglected the huge range of patient-specific conditions during CPB. Furthermore, the design was based on continuous-flow CPB and might not be valid for pulsatile CPB.

In the discussion, we observed a reduced jet effect due to the reduced velocities in the jet. However, it is not yet known if there is a threshold velocity associated with mobilization of plaques. Thus, the presented methodology can only be used to compare two different designs rather than provide quantitative values for the jet effect and plaque mobilization. Another limitation of this study is that the simulations used to develop the swirl inducer aortic cannula did not account for movement of the vessel walls[13].

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