Right heart mini-pump bypass for coronary artery bypass grafting: experimental study

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Abstract

Background: Visualization of the left circumflex arteries during off-pump coronary artery bypass grafting (CABG) causes hemodynamic disturbance. We investigated whether right heart mini-pump bypass (RHB), using a centrifugal pump, improved the safety of this procedure by studying the influences of different heart displacement positions, the Trendelenburg maneuver and RHB on hemodynamics.

Method: Hemodynamic parameters in eight mongrel dogs (15.5–20 kg) were continuously monitored at a fixed heart rate of 80 beats/min through a conventional median sternotomy. The posterior descending artery (PDA) and left circumflex artery (LCX) were exposed using an Octopus tissue stabilizer. After evaluating the influence of the Trendelenburg maneuver on hemodynamics, a heparin-coated centrifugal pump without an oxygenator was introduced and the impact of different pump flows was investigated during RHB.

Results: LCX exposure caused significant decreases in aortic flow (to 35.1 ± 12.8%) and arterial mean pressure (to 66.1 ± 9.3%) compared with baseline (P < 0.001). In contrast to PDA exposure, values remained significantly decreased during the Trendelenburg maneuver. On the contrary, RHB significantly improved the hemodynamic impairments caused by both heart displacement procedures, especially LCX exposure, although 100% pump flow significantly increased left atrial pressure to 131.3 ± 19.5% (P < 0.01).

Conclusion: Exposure of the LCX caused severe hemodynamic deterioration, which was not fully reversed by the Trendelenburg maneuver. In contrast, RHB significantly improved hemodynamics, and therefore this technique can be beneficial for CABG of LCX in the limited cases.

Keywords: Right heart mini-pump bypass; Left circumflex artery exposure; Posterior descending artery exposure; Coronary artery bypass grafting

1. Introduction

Recently, coronary artery bypass grafting without cardiopulmonary bypass (off-pump CABG) has become an alternative technique for myocardial revascularization. Compared with conventional CABG, this approach is considered advantageous in high risk patients [1,2]. Interest in the use of off-pump CABG for multivessel disease is now increasing; however, this approach requires visualization of the left circumflex arteries, which frequently causes hemodynamic disturbance. Grundeman et al. [3] proposed that the primary cause of hemodynamic disturbance during displacement of the pig heart was right ventricular dysfunction due to mechanical interference. Although Jensen and colleagues [4] reported the feasibility of using the Octopus method, even for the posterolateral circumflex branches, this approach resulted in considerable decreases in arterial pressure and aortic flow. Assuming that the cause of hemodynamic disturbance is impairment of venous return to the right heart, we investigated right heart mini-pump bypass (RHB), using a centrifugal pump with heparin-coated tubes but without an oxygenator, as a method for improving safety.

The objectives of this study were to assess the influences of different heart displacement positions on hemodynamics, and to evaluate the effects of the Trendelenburg maneuver and RHB on these hemodynamic changes.

2. Materials and methods

2.1. Surgical technique

Eight mongrel dogs (15.5–20 kg) were anesthetized with pentobarbital sodium (30 mg/kg). Respiration was maintained with a volume-controlled respirator on 100% oxygen. A continuous electrocardiogram was recorded and monitored throughout the procedure. Arterial blood gases were sampled every 30 min, and bicarbonate was added as needed to maintain a physiologic pH between 7.35 and 7.45. Aortic
blood pressure was monitored via a catheter introduced through the right femoral artery. In the same way, right and left atrial mean pressures were monitored through the right femoral vein and the left atrial appendix, respectively. In this study, Swan–Ganz and conductance catheters were not useful to evaluate the hemodynamic parameters of the dog, because of the establishment of right heart bypass and the changes in the left ventricular geometry caused by tilting of the heart using the Octopus stabilizer. Therefore, we chose to use aortic flow for the evaluation of cardiac function, we used propranolol in order to decrease the heart rate, and maintained a fixed rate of 80 beats/min with a pacemaker, as previously described [3]. An ultrasound transit time flow probe (Transonic Inc., Ithaca, NY) was placed around the aorta to allow on-line measurement of the cardiac output. For stepwise cardiac retraction, an Octopus tissue stabilizer (Medtronic, Inc., Minneapolis, MN) was used.

Heparin (1 mg/kg) was given intravenously and the activated clotting time was controlled at 150–200 s before the right atrium and pulmonary artery trunk were canulated for RHB. A heparin-coated centrifugal pump (Terumo Corp., Tokyo, Japan) without an oxygenator was used for RHB, and was carefully connected to both cannulae to avoid air embolization.

2.2. Experimental protocol

Baseline hemodynamic values were recorded after at least 15 min of pacing. Using the Octopus tissue stabilizer, the heart was displaced by 90° to expose the posterior descending artery (PDA) branch. Good exposure to the operative field was achieved without the aid of additional supportive tools. Five minutes later, the operating table was tilted 20° into the head-down position (the Trendelenburg maneuver) without changing the position of the heart relative to the body. After a further 5 min, the operating table was returned to the horizontal and the heart was placed back in its normal position.

After a period of stabilization, further baseline hemodynamic values were recorded. Using the Octopus tissue stabilizer, the heart was then displaced by 90° to expose the circumflex branches. Again, good exposure to the operative field was achieved. Subsequently, after hemodynamic stabilization, unsupported displacement was carried out for 5 min, followed by 5 min of displacement with the Trendelenburg maneuver. The operating table was then returned to the horizontal position and the heart was placed back in the pericardial cradle.

After a 30-min resting period, the heart was retracted to expose the PDA branch for 3 min. RHB was then initiated. 25–100% flow was calculated, considering 100% flow as 100 ml/min per kg. Hemodynamic values were recorded at 25, 50, 75 and 100% flow, and each measurement was taken 3 min after stabilization. In the same way, after exposure of the LCX branch, the heart was displaced and hemodynamic values were recorded for each bypass flow volume (Fig. 1).

2.3. Statistical methods

All hemodynamic values are expressed as mean ± SE of the mean (SEM) (percentage of basal values). Student’s t-test was used to assess the modifying effect of the Trendelenburg maneuver or RHB compared with the protocol control values, and the threshold for statistical significance was set at \( P < 0.05 \).

Fig. 1. Intraoperative views. (a) The heart displaced by the Octopus tissue stabilizer to expose the posterior descending artery. (b) Displacement for exposure of the left circumflex branches.
2.4. Ethical considerations

All animals received humane care in compliance with the ‘Guide for the Care and Use of Laboratory Animals’ published by the National Institutes of Health (NIH publication 85-23, revised 1996).

3. Results

All animals survived the entire procedure without the need to defibrillate or administer inotropic drugs. There were no differences in baseline hemodynamic values between the various maneuvers, and maximum flows did not differ significantly between the dogs (data not shown).

3.1. PDA exposure (Figs. 2–5)

As the PDA was exposed, aortic flow (AF) and the arterial mean pressure (AP) were significantly decreased to $71.1 \pm 7.8\%$ ($P < 0.001$) and $88.4 \pm 5.8\%$ ($P < 0.001$) of their baseline values, respectively. Right atrial mean pressure (RAP) was elevated to $113.4 \pm 10.5\%$ ($P < 0.05$); however, there was no significant change in left atrial pressure (LAP). During the Trendelenburg maneuver, both AF and AP returned to baseline, although RAP remained significantly elevated at $175.3 \pm 69.2\%$ ($P < 0.05$). Following the induction of RHB, AF and AP were maintained within the normal range. Moreover, RAP gradually decreased to baseline as the pump flow increased. On the contrary, 100% pump flow caused significant elevation of LAP to $134.4 \pm 22.8\%$ ($P < 0.01$) and conferred a preload to the left atrium.

3.2. LCX exposure (Figs. 2–5)

LCX exposure caused significant decreases from baseline in both AF (to $35.1 \pm 12.8\%$; $P < 0.001$) and AP (to $66.1 \pm 9.3\%$; $P < 0.001$). In contrast to PDA exposure, values remained significantly different from baseline during the Trendelenburg maneuver, despite the fact that AF and AP increased to $55.9 \pm 6.7$ and $84.2 \pm 13.7\%$, respectively, during the maneuver. With 50% pump flow during RHB, AF and AP increased into the normal range, while RAP gradually decreased as the pump flow increased. However, LAP was significantly elevated to $116.7 \pm 11.9\%$ ($P < 0.01$) and $131.3 \pm 19.5\%$ ($P < 0.01$) at pump flow volumes of 75 and 100%, respectively.

After repositioning the heart into its cradle and releasing it from the Octopus, hemodynamic status improved within a few minutes and all values returned to baseline after all maneuvers (data not shown).

4. Comments

Our data indicate that, compared with PDA exposure, LCX exposure through a conventional median sternotomy causes more severe hemodynamic deterioration, which is not fully reversed even by the Trendelenburg maneuver. On the contrary, our RHB technique significantly improved the hemodynamic impairments caused by both heart displacement procedures, especially LCX exposure, although 100% bypass flow significantly increased LAP.

Recently, coronary artery bypass grafting without cardiopulmonary bypass (off-pump CABG) has become an accepted alternative technique for myocardial revascularization for patients with poor ventricular function, who may not tolerate cardiopulmonary bypass (CPB), and in those

![Fig. 2. Relative changes in aortic flow after use of the Octopus tissue stabilizer (Baseline, normal position; Dis., displacement of the heart; Tren., Trendelenburg maneuver; 25–100%, 25–100% pump flow during total right heart bypass). Statistical comparison with baseline values: *P < 0.01, **P < 0.001. PDA, posterior descending artery; LCX, left circumflex artery.](https://academic.oup.com/ejcts/article-abstract/18/3/276/472970)

![Fig. 3. Relative changes in aortic mean pressure after use of the Octopus tissue stabilizer (Baseline, normal position; Dis., displacement of the heart; Tren., Trendelenburg maneuver; 25–100%, 25–100% pump flow during total right heart bypass). Statistical comparison with baseline values: *P < 0.05, *P < 0.01, **P < 0.001. PDA, posterior descending artery; LCX, left circumflex artery.](https://academic.oup.com/ejcts/article-abstract/18/3/276/472970)
with associated diseases in whom CPB, hypothermia or aortic cannulation is not desirable [1]. This approach has many advantages, since it conserves blood products, avoids global myocardial ischemia, preserves interventricular septal function, and may avoid neuropsychological deficits caused by malperfusion, microemboli from CPB and atheromatous emboli from manipulation of the aorta [2]. Given these advantages, it is not surprising that interest in off-pump CABG for multivessel disease has grown rapidly among surgeons, considering that nearly 65% of surgical referrals have triple vessel disease [5,6].

Nevertheless, off-pump CABG may have certain drawbacks. Buda and colleagues [7] suggested that incomplete revascularization was an essential determinant of the early return of angina, while Tasdemir and colleagues [8] concluded that non-bypassed circumflex disease was associated with a high incidence of perioperative myocardial infarction and a low cardiac output state.

From this point of view, the greatest problem associated with multivessel CABG would most likely be rotation of the heart, especially exposure of the circumflex artery. A good operative field and good visualization of the target vessels are of paramount importance when performing this type of surgery, and inadequate exposure or stabilization of the anastomotic site is a major cause of acute graft occlusion and incomplete revascularization [9], which might result in unfavorable mortality and morbidity rates. In 1996, Borst et al. [10] showed that grafting of the left anterior descending artery and right coronary artery without CPB might be achieved, without hemodynamic compromise, by immobilizing the relevant area of the cardiac wall, using a mechanical suction device, the ‘Octopus’. Jansen and colleagues [4] later reported that off-pump CABG of the posterolateral circumflex branches of beating pig heart was feasible using this method. They also demonstrated that the Trendelenburg maneuver or fluid administration and some inotropic drug support helped to maintain arterial pressure in their clinical experience [2]. Cartier et al. [6] showed that four pericardial stay sutures located around the base of the heart allowed easy access to obtuse marginal arteries without hemodynamic instabilities. On the other hand, Grundeman et al. [11] reported that left circumflex artery exposure in the beating pig heart decreased the stroke volume to 58 ± 6% and cardiac output to 42 ± 6% of baseline, and increased the right ventricular end-diastolic pressure to 176 ± 16%. In our clinical experience, exposing posterior branches by displacement tends to cause a considerable decrease in arterial pressure. The results of the present study also revealed that the Trendelenburg maneuver was not enough to maintain normal hemodynamics during LCX exposure, because aortic flow and aortic pressure were still decreased.

Although the exact cause of these hemodynamic changes is not fully understood in humans, Grundeman et al. [3] suggested that heart displacement primarily caused right ventricular dysfunction as a result of mechanical interference with diastolic expansion, without concurrent valvular incompetence, in the pig model. We also speculate that the main cause of hemodynamic deterioration after displacement would be impairment of venous return to the right heart, with the secondary decrease in cardiac output leading to a reduction in coronary blood flow. Consequently, left ventricular function might be impaired. In our present study, when compared with PDA exposure, LCX exposure apparently caused hemodynamic disturbances, which were normalized by right heart bypass. If direct compression of the left ventricular outflow tract was the cause of these hemodynamic disturbances, our RHB technique would not improve hemodynamics, but would enhance the left ventri-

![Fig. 4. Relative changes in left atrial mean pressure after use of the Octopus tissue stabilizer (Baseline, normal position; Dis., displacement of the heart; Tren., Trendelenburg maneuver, 25–100%, 25–100% pump flow during total right heart bypass). Statistical comparison with baseline values: *P < 0.01. PDA, posterior descending artery; LCX, left circumflex artery.](https://academic.oup.com/ejcts/article-abstract/18/3/276/472970)

![Fig. 5. Relative changes in right atrial mean pressure after use of the Octopus tissue stabilizer (Baseline, normal position; Dis., displacement of the heart; Tren., Trendelenburg maneuver, 25–100%, 25–100% pump flow during total right heart bypass). Statistical comparison with baseline values: *P < 0.05, *P < 0.01, **P < 0.001. PDA, posterior descending artery; LCX, left circumflex artery.](https://academic.oup.com/ejcts/article-abstract/18/3/276/472970)
cular dysfunction or fail to maintain an effective pump flow since a centrifugal pump was used.

Like off-pump CABG, minimally invasive direct coronary artery bypass grafting (MIDCABG) with a smaller incision (such as an anterior left thoracotomy, partial sternotomy or parasternal thoracotomy [12–14]) has recently gained the attention of cardiovascular surgeons. These approaches have, however, been limited to vessels located on the anterior surface of the heart and to those accessible by either the right or left internal mammary artery [3]. At the present time, we consider the standard median sternotomy to be preferable to these smaller incisions, and it is the only approach possible for multivessel disease. Furthermore, median sternotomy is essential for the establishment of RHB.

Although further studies will be needed to investigate whether intergroup differences might also be influenced by different surgical maneuvers, such as cold cardioplegic arrest and global ischemia in the CPB setting, off-pump CABG has been shown to be associated with reduced cytokine responses and less myocardial injury than conventional CABG [15]. Buffalo and colleagues [16] also reported that the latter technique produced a cost-saving of approximately US $3000 per case, due to decreased use of operating room equipment. Even if RHB was included during off-pump CABG, pump oxygenators, cardiac arrest, cardioplegia and hypothermia could be all be avoided. Moreover, lower doses of heparin are required during RHB, and this might reduce the incidence of coagulopathy and the need for blood product transfusions [17]. Lately, Richter et al. [18] demonstrated, in their prospective randomized clinical study, that ventilation and perfusion of the lungs during CPB and exclusion of artificial oxygenators from CPB circuit significantly decreased the activation of inflammatory response. Therefore, we believe that the advantages of RHB, which also provides good visualization of the target vessels and stable hemodynamics during the entire procedure, outweigh any cost disadvantage.

5. Study limitations

In contrast to the healthy dogs used during the present study, displacement of the beating heart in patients with ischemic heart disease and coexisting cardiomegaly or severe left ventricular dysfunction may be poorly tolerated, and biventricular dysfunction may primarily occur in humans. In addition, our model was relatively small animals. The impact of the adult heart stabilizer on pump function in these small hearts may result in the right ventricular compression.

Our results suggest that the most suitable pump flow volume for RHB is around 50%. However, 75 or 100% flow significantly increased left atrial pressure, which might result in overloading of an impaired left ventricle. Consequently, the heart might not be able to tolerate augmentation of the pump flow. Moreover, the geometry of the chest wall differs in dogs and humans chest. Therefore, further investigations will be needed before RHB can be widely applied to humans in the clinical setting.

6. Conclusions

In conclusion, displacement of the heart to allow exposure of the left circumflex artery through a conventional median sternotomy caused severe hemodynamic deterioration, which was not fully reversed by the Trendelenburg maneuver. However, our right heart mini-pump bypass technique significantly improved the hemodynamic impairments caused by displacement. Therefore, this method could improve the safety of patients during displacement of left circumflex artery by ensuring proper blood flow which does not result in left ventricular overload.

References


