Research methods
The A-Med right heart support for off-pump coronary artery bypass grafting

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Coronary artery bypass grafting; Coronary artery disease; Beating heart surgery.

Background. **Off-pump coronary artery bypass grafting (OPCAB) presents several advantages but, mainly due to the impaired diastolic filling of the right ventricle, the displacement of the heart can cause hemodynamic instability. The aim of this study was to investigate the possible role of the A-Med right heart support during OPCAB.**

Methods. **We report our early experience with the A-Med system (A-Med, West Sacramento, CA, USA) during OPCAB. The system consists of a coaxial cannula, a microcentrifugal pump and a control console. The coaxial cannula is passed through the right atrium with the tip of the cannula positioned in the main pulmonary artery. Thus the blood is actively removed from the right atrium and returned to the pulmonary artery.**

Results. **We successfully used this right heart support in 2 patients undergoing elective OPCAB. In both cases the system was used during the exposure of the proximal portion of the obtuse marginal branch. A mean pump flow of 3.2 l/min guaranteed normal cardiac output and hemodynamic stability during the exposure of the posterior target area. No complication occurred and the patients were discharged shortly after surgery.**

Conclusions. **In our early experience the A-Med right heart support was safe and effective and allowed achievement of hemodynamic stability during exposure of the posterior areas of the left ventricle.**

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Introduction

The advantages of off-pump coronary artery bypass grafting (OPCAB) have been demonstrated in selected cases[1]. Particularly, coronary artery bypass grafting on the beating heart allows one to avoid the well-known damaging effects of cardiopulmonary bypass[2,3]. Nevertheless OPCAB presents several problems: adequate exposure of the posterior coronary branches requires a vertical displacement of the beating heart and it can cause marked hemodynamic instability[4].

To provide hemodynamic support during OPCAB several left ventricular assist devices have been proposed including centrifugal[5] or axial flow pumps[6,7].

Based on the concept that displacement of the heart causes instability, mainly due to right heart dysfunction, other authors have proposed a right heart support for hemodynamic sustenance during OPCAB[8].

We report our early experience with the A-Med right heart support system (A-Med systems, West Sacramento, CA, USA) for beating heart coronary artery bypass grafting.

Methods

The device. The A-Med right heart support is a mini-support system for OPCAB. It consists of a control console, a microcentrifugal pump and a coaxial cannula (Fig. 1). The control console is easy to use and allows to control operations simply by touching the screen.

The centrifugal pump is a miniature pump which requires a very low priming volume (7 ml); it causes only slight hemolysis and includes a priming port and a syringe.

The coaxial cannula is a one cannula system which provides simultaneous access to the right atrium and pulmonary artery. The coaxial cannula is passed through the right atrium with the tip of the cannula positioned in the main pulmonary artery (Fig. 2). Thus blood is removed from the right atrium and returned to the pulmonary artery.

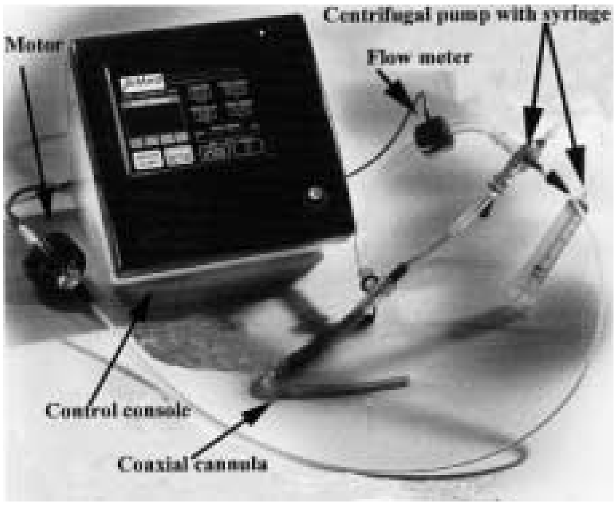

Figure 1. *The A-Med right heart support.*

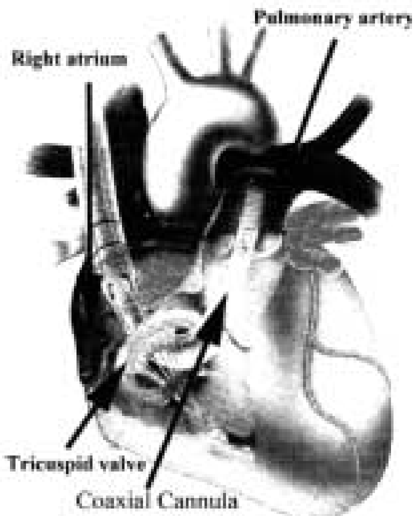

Figure 2. *The coaxial cannula is passed through the right atrium and the tip of the cannula positioned in the main pulmonary artery.*

Perioperative monitoring. Standard cardiovascular monitoring including 5-lead ECG, end-tidal CO_2 determination, capillary pulse oxymetry and urinary output was employed. A Swan-Ganz catheter (Baxter Healthcare, Irvine, CA, USA) was introduced through the right internal jugular vein and a 20G catheter was inserted into the left radial artery for invasive arterial blood pressure measurement and blood gas monitoring respectively. The mean arterial pressure, central venous pressure, mixed venous oxygen saturation, and systolic and diastolic pulmonary pressures were recorded. The cardiac output was determined by the thermodilution technique. Values were registered at baseline, with the heart dislocated and the pump off, with the heart dislocated and stabilized and the pump on, and finally at the end of the procedure (pump off).

Transesophageal echocardiography was used to record the physiologic consequences of heart displacement.

Surgical technique. After a median sternotomy, the pericardium was opened. The left internal mammary artery (LIMA) and saphenous vein were harvested according to standard technique.

The pericardium was incised along the right diaphragmatic reflection down to within a few centimeters of the inferior vena cava and the right pleura was opened.

A 3.0 mg/kg bolus of heparin was administered just before starting the grafting procedures to reach a target activated clotting time of at least 2 times baseline values.

A single pericardial suture (1-0 Ethicon) was passed through a folded gauze tape and then placed deeply between the left inferior pulmonary vein and the vena cava. The suture was snared with a tourniquet and pulled caudally in the midline. The tape was thus divided into two arms which were passed behind the heart, pulled towards the surgeon and the assistant respectively, and clamped to the drapes. This maneuver allowed elevation of the heart outside the chest and visualization of the left anterior descending coronary artery (LAD) which was further improved by a laparotomy pack placed behind the heart. A 4-0 polypropylene suture encircling the target vessel, silicone pledgets and rubber tourniquets were used in order to obstruct the coronary artery. A 3-min period of preischemic conditioning, achieved by vessel occlusion, was followed by a 3-min period of reperfusion to evaluate the patient's tolerance to ischemia. After such "preconditioning" the LAD was re-secured. The Octopus tissue stabilizer system (Medtronic, Inc., Minneapolis, MN, USA) was then applied, and distal anastomosis of the LIMA to the LAD was performed according to standard technique. A 2-0 polypropylene purse-string suture was placed on the right appendage and the tip of the A-Med coaxial cannula was passed through the right atrium and positioned in the main pulmonary artery. The microcentrifugal pump was kept in the surgical field while the remote motor with console was placed outside it. Two gauze tapes were passed through the transverse sinus and underneath the inferior vena cava as suggested by Calafiore et al.[9]. One end of each tape was fixed to the right arm of the retractor and the other end crossed just above the obtuse marginal branch and fixed to the drapes. Thus the heart was gradually elevated with its apex pointed towards the ceiling and herniated into the right pleura. Lateral rotation of the operating table to the patient's right and the Trendelenburg position were used to improve the surgical exposure of the obtuse marginal branch area. With the heart dislocated, the pump was started and stabilization of the beating heart was achieved by utilizing the Octopus stabilization system. Hemodynamic stability was achieved with a pump flow not higher than 3.2 l/min in order to avoid an excessive left ventricular preload. At the end of the anastomosis the heart was relaxed and the pump stopped.

The operation was then routinely completed.

Results

Case 1. A 72-year-old man with a strong family history of coronary artery disease, a medical history of hypertension and with unstable angina (CCS class III), underwent elective OPCAB.

Cardiac catheterization had revealed severe two-vessel disease with critical stenosis of the LAD and subocclusion of the circumflex branch; the left ventricular function was normal (left ventricular ejection fraction 52%). The anastomosis on the LAD was performed first: having positioned the heart, the native vessel was occluded proximally and the LIMA anastomosis was performed according to standard technique. During exposure of the circumflex area, with the displaced heart stabilized and in position for obtuse marginal branch anastomosis, a 3.2 l/min flow guaranteed satisfactory hemodynamics (Table I). Right heart support lasted 23 min. No alteration was detected at intraoperative transesophageal echocardiography or ECG. There were no intraoperative complications and it was not necessary to resort to inotropic drugs.

The patient was weaned from mechanical ventilation within a few hours and discharged from the Intensive Care Unit on the first postoperative day.

The remainder of the patient's recovery was uneventful and he was discharged on the fifth postoperative day.

Case 2. A 62-year-old man, with a medical history of hypertension and diabetes and with recent-onset unstable angina (CCS class III) was admitted to our Institution.

Cardiac catheterization showed severe three-vessel disease with involvement of the left main coronary artery, 95% stenosis of the LAD, 90% stenosis of the obtuse marginal branch and almost total occlusion of the right coronary artery. The left ventricular ejection fraction was normal (48%).

The patient underwent non-urgent OPCAB. The LIMA and reverse saphenous vein were chosen for the left internal thoracic artery and obtuse marginal branch respectively.

After performing LAD anastomosis as previously described, the flow was restored by opening the LIMA. With the heart in position, displaced and stabilized, the pump was switched on and a 3.2 l/min flow allowed achievement of hemodynamic stability (Table II). No inotropic drugs were used during and at the end of the procedure. The pump was kept on until the anastomoses were completed (19 min). There were no intraoperative complications. The patient was weaned from mechanical ventilation after 4 hours and moved from the Intensive Care Unit on the first postoperative day. There were no postoperative complications and the patient was discharged home on the sixth postoperative day.

Discussion

Coronary artery bypass grafting without cardiopulmonary bypass was first introduced by Kolesov[10] in

Table I. Hemodynamics of the 2 patients.

	Baseline (pump off)	OM anastomosis		End of procedure (pump off)
		Heart in position (pump off)	Heart in position (pump off)	
Patient no. 1				
CVP (mmHg)	11	16	11	7
pABP (mmHg)	115	48	84	130
mABP (mmHg)	80	34	60	95
CO (l/min)	6.0	2.3	4.1	5.4
CI (l/min/m^2)	3.5	1.3	2.4	3.1
sPAP (mmHg)	19	24	16	23
dPAP (mmHg)	17	19	14	17
ET-CO_2 (%)	24	15	27	28
Pump flow (l/min)	–	–	3.2	–
Patient no. 2				
CVP (mmHg)	11	16	10	7
pABP (mmHg)	120	63	80	110
mABP (mmHg)	70	40	54	98
CO (l/min)	5.5	3.7	4.9	5.4
CI (l/min/m^2)	2.8	1.9	2.5	2.7
sPAP (mmHg)	18	26	20	21
dPAP (mmHg)	13	16	14	19
ET-CO_2 (%)	23	18	24	26
Pump flow (l/min)	–	–	3.2	–

CI = cardiac index; CO = cardiac output; CVP = central venous pressure; dPAP = diastolic pulmonary artery pressure; ET-CO_2= end-tidal CO_2; mABP = mean arterial blood pressure; OM = obtuse marginal branch; pABP = peak arterial blood pressure; sPAP = systolic pulmonary artery pressure.

1967. This approach has the advantage of avoiding the well-known drawbacks of an extracorporeal circulation. These include activation of the proteolytic and inflammatory systems, immune system depression and the consumption of clotting factors and platelets, all occurring during standard cardiopulmonary bypass[11].

Even though it has been demonstrated that OPCAB is a safe procedure[12,13] and that it decreases mortality in high risk patients[14], it still represents a surgical challenge because of the difficulty in reaching the posterior and lateral coronary branches with the heart beating.

The introduction of mechanical stabilizers[15], polypropylene or polyester “snares” sutures[16] or silastic tapes[17] to encircle the coronary arteries and of intracoronary shunts[18] and blowers[19] has allowed more accurate OPCAB surgery.

Furthermore, the use of deep pericardial sutures (“LIMA stitches”)[20] or fabric tapes[9,21] and an incision in the right lower corner of the pericardium combined with the opening of the right pleura[22] have facilitated the displacement of the heart and the achievement of the posterior and inferior walls of the left ventricle.

However, displacement and tilting of the beating heart, necessary in order to reach the target vessels, result in hemodynamic changes and instability[23], with a consequent decrease in cardiac output and systolic blood pressure[24].

The hemodynamic impairment of the left ventricle had firstly been believed to be responsible for hypotension secondary to cardiac displacement. Thus, several left cardiac assist devices have been proposed[6,7,25] to provide hemodynamic support during OPCAB.

More recently, the impaired diastolic filling of the right ventricle has been found to be the major cause of hemodynamic instability occurring with heart displacement during beating heart surgical procedures[4,26]. Indeed the Trendelenburg maneuver is widely used to increase the right heart filling by a fluid load or fluid redistribution.

Other maneuvers (volume expansion with intravenous fluids, right hemisternum elevation, release of restricting pericardium) have been advocated to support the right heart[10] and, in a recent study, Nierich et al.[27] demonstrated that fluid redistribution was sufficient to correct the cardiac output during OPCAB.

All these observations have led to the theory that right heart assistance would achieve heart stability during OPCAB. Gründeman et al.[28] demonstrated right heart bypass to be effective for hemodynamic normalization during exposure of the circumflex artery and left heart bypass to fail to restore the systemic circulation.

Some experimental studies reported the use of right heart circulatory support[8,23]. Recently, Mathison et al.[11] presented 17 patients successfully undergoing OPCAB with right heart support.

We reported our early experience with A-Med right heart support system used in 2 patients undergoing OPCAB. There were no accidents or complications during the procedures; in both cases the exposure of the obtuse marginal branch was satisfactory and achieved with stable hemodynamics. Patients were discharged after an uncomplicated recovery.

The microcentrifugal pump system resulted easy to implant and to set up. Furthermore, it needs a low priming volume and only causes negligible hemolysis.

On the other hand, valvular or chamber lesions during cannula insertion might occur and whether the extracorporeal circuit may cause any systemic inflammatory insult remains to be determined.

The A-Med system was not used electively but only in case of systemic hypotension and hemodynamic instability following dislocation of the heart during OPCAB; however, in our experience, this occurred in a limited number of cases during heart displacement; thus, in our opinion, the use of a right heart support system can be justified only in case of persistent hemodynamic instability despite the employment of maneuvers (i.e. volume loading, Trendelenburg positioning, inotropic agents) act to restore systemic pressure, which we routinely used during OPCAB.

In conclusion, this early clinical experience has demonstrated the A-Med right heart support to be a safe and effective system guaranteeing hemodynamic stability during exposure of the posterior areas in case of OPCAB.

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