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Approach of the pulmonary valve using right heart bypass and bicaval cannula: experimental study

Abordagem da valva do tronco pulmonar por desvio direito e uso de cânula bicaval: estudo experimental

Ana Maria Rocha Pinto e SILVA[1], Luís Augusto Palma DALLAN[2], Valquiria Pelisser CAMPAGNUCCI[3], José CARUSO[4], Sylvio M. Aquino GANDRA[5], Luís Antônio RIVETTI[6]

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Abstract

Objective: **To reproduce the surgery for correction of pulmonary valve anomalies using right heart bypass and a new bicaval cuffed venous cannula for minimal access surgery.**

Methods: **Fifteen Large-White pigs were used for this study. The standard technique model was established with the first five pigs, the experiment was done with nine animals by sternotomy, and one was submitted to a minimally invasive procedure, but has been excluded of the sample. Bicaval drainage by a single cannula was obtained through the internal jugular vein. The cuffs were inflated to increase blood flow to the machine. The return was established by putting the arterial cannula into the pulmonary artery trunk. Pre-bypass parameters were measured and compared with the parameters during the right bypass: Median Arterial Tension (MAT); Heart Rate (HR); arterial Oxygen Saturation (SaO_2); CO_2 end title measures ($PetCO_2$); Temperature (T). The statistical analysis was done comparing the pre-bypass and during bypass values.**

Results: **Pre-bypass values: MAT: 90.8 mmHg; HR = 101.6 beat/min; O_2 SAT = 93.8%; $PetCO_2$ = 28.4 mmHg; T = 36.1ºC. During bypass the obtained values were: MAT: 88.1 mmHg; HR = 98.0 beat/min; O_2 SAT = 93.1%; $PetCO_2$ = 25.3 mmHg; T = 36.9ºC. Comparing the average values between the two abovementioned moments, no significant difference occurred in MAT, HR and O_2 SAT; $PetCO_2$ and T presented significant differences.**

Conclusions: **The bicaval cuffed venous cannula showed efficient drainage of both venae cavae with appropriate hemodynamic parameters during right bypass allowing access to the pulmonary valve.**

Descriptors: **Pulmonary valve. Pulmonary valve stenosis. Extracorporeal circulation, methods. Surgical procedures minimally invasive.**

1. Associate Professor for Cardiac Surgery at Faculdade de Ciências Médicas da Santa Casa de São Paulo (FCMSCSP).
2. FCMSCSP Alumnus
3. Assistant Professor for Cardiac Surgery at FCMSCSP.
4. Former Head Anesthesiologist – Experimental Surgery Unit - FCMSCSP.
5. Associate Professor for Cardiac Surgery at FCMSCSP.
6. Associate Professor, FCMSCSP Head of Cardiac Surgery Discipline.

This study was carried out at Faculdade de Ciências Médicas da Santa Casa de São Paulo, São Paulo, SP.

Correspondence address:
Profa. Dra. Ana Maria Rocha Pinto e Silva. Faculdade de Ciências Médicas da Santa Casa de São Paulo. Rua Cesário Mota Jr, 112 São Paulo – SP.
E-mail address: ana.mrp@uol.com.br

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Resumo

Objetivo: **O objetivo deste estudo foi reproduzir a cirurgia de abordagem da valva do tronco pulmonar por desvio direito, avaliando-se uma nova cânula venosa bicaval com balonetes insufláveis para uso por miniacesso.**

Métodos: **Utilizaram-se 15 suínos da raça Large-White, sendo cinco para a padronização técnica das vias de acesso e monitorização hemodinâmica, nove submetidos ao experimento por meio de esternotomia, e um animal excluído da amostra, operado por mínimo acesso ao tórax. O desvio direito foi estabelecido pela drenagem bicaval, sendo a cânula introduzida pela veia jugular interna direita e locada nas veias cavas cranial e caudal. Os parâmetros medidos foram: Pressão Arterial Média (PAM); Freqüência Cardíaca (FC); Saturação O_2 (SAT O_2); Capnografia ($PetCO_2$) e Temperatura (T). A análise estatística foi feita comparando-se os valores antes e durante o desvio direito.**

Resultados: **No momento pré-desvio direito, obtiveram-se os seguintes valores médios: PAM = 90,8 mmHg, FC = 101,6 bat/min, SAT O_2 = 93,8%, $PetCO_2$ = 28,4 mmHg, T = 36,1ºC. Durante o desvio direito, obtiveram-se os seguintes valores médios: PAM = 88,1 mmHg, FC = 98,0 bat/min, SAT O_2 = 93,1%, $PetCO_2$ = 25,3 mmHg e T = 36,9ºC. Comparando-se as médias obtidas entre os dois momentos, verificou-se não haver diferenças significantes para a PAM, FC e SAT O_2 e diferenças significantes para a $PetCO_2$ e a T.**

Conclusão: **A cânula bicaval com balonetes promoveu drenagem eficaz de ambas as veias cavas, permitindo a manutenção dos parâmetros hemodinâmicos durante o desvio direito, sendo possível realizar a abordagem da valva pulmonar.**

Descritores: **Valva pulmonar. Estenose da valva pulmonar. Circulação extracorpórea, métodos. Procedimentos cirúrgicos minimamente invasivos.**

INTRODUCTION

The first approaches to pulmonary valve under direct vision were experimentally performed by Felipozzi [1] in 1954 using right heart bypass without an oxygenator, with autologous oxygenation by draining the venae cavae and returning the drained blood volume directly to either the pulmonary trunk or to the branches of pulmonary artery, according to a previous experiment performed by Dodrill [2], and based on the azygos vein flow principle [3,4].

In the past few years, with the advent of minimally invasive cardiac surgery [5-7], as well as the increase in circulatory support indications in postoperative heart transplantation or high complexity surgeries that present left/right ventricular failure [8-13], a number of cannula models have been developed and assessed in order to find more adequate cannulae [14-16], including those for percutaneous usage [17].

Aiming at not using oxygenators in an attempt to minimize the inflammatory reaction after cardiopulmonary bypass as well as the costs, the right heart bypass has been performed nowadays in some surgical procedures.

The purpose of the present experimental study, performed in swine, was to reproduce the surgical approach of pulmonary stenosis with intact ventricular septum through right heart bypass and to evaluate a new bicaval venous cannula with inflate balloons attached at the tip for peripheral approach.

METHODS

This study was carried out with FCMSCSP Research Support Funds at the Experimental Surgery and Surgical Technique Unit. The protocol was conducted according to the international guidelines for the use of animals in experimental research. The study was approved by the FCMSCSP Experimental Research Ethics Committees in September 8, 2002, under protocol number # 34.

Fifteen Large-White swine, weighing between 26 and 32 kg, were used. The first five swine was used for standardization of both access pathways and hemodynamic monitoring. Nine animals underwent median sternotomy and pericardial opening for better vision of the bicaval cannula with inflatable balloons positioning introduced through right jugular vein (Figure 1). In one animal, the access was performed through minithoracotomy, which was excluded from the sample (Figure 2).

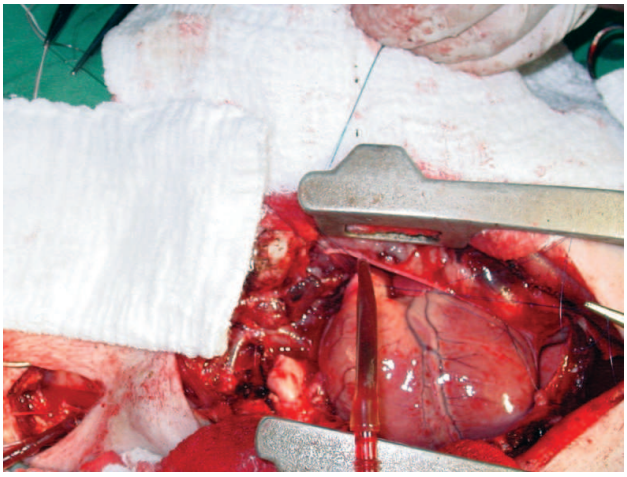

Fig. 1 – Median sternotomy and pericardial opening for better visiono f the placement of the bicaval venous cannula with inflatable balloons introduced via right internal jugular vein

Fig. 2 – Right heart bypass established: Vena cavae drainage through the cannulation of right internal jugular vein and venous return into the pulmonary trunk through minithoracotomy in the left second intercostal space performed in an animal

All animals were administered intramuscular preanesthetic medication with midazolan 0.3 ml/kg body weight. Anesthesia was induced, by intravenous injection, with fentanyl citrate, 100 µg/kg body weight, and lidocaina hydrochloride, 1 mg/kg body weight. Afterwards, propofol, 2 mg/kg body weight was administered and, finally, a bolus dose of rocuronium, 50 mg, for muscle relaxation.

The animals underwent orotracheal intubation, placed in assisted mechanical ventilation with a ventilatory rate of 20 breath (cycles) per minute, tidal volume of 7 mL/kg body weight and fraction of inspired oxygen (FiO2) of 40%, maintained in the Takoaka KT15 – Bonsai plus® series ventilator (K. Takaoka Industria e Comércio Ltda, São Paulo, Brazil). The anesthetic plan was maintained by continuous injection of propofol in a dose of 2–3 mg/min/kg body weight during the course of the experiment, using the ST680® volumetric syringe pump (Santronic Ltda, São Paulo, Brazil).

Venous and arterial dissections were performed. Left femoral artery was catheterized to monitor mean arterial pressure (MAP) using a siliconized 8-Fr plastic catheter (MarkMed Industria e Comércio Ltda, São Paulo, Brazil). The right internal jugular vein was dissected and used to introduce the bicaval venous cannula promoting cranial and caudal vena cavae drainage during the right heart bypass.

The animals were monitored throughout the experiment, using computerized readings from the Hewlett Packard™ model M1960A (Hewlett Packard Co., USA) equipment, with acquisition channels of invasive and non-invasive pressure, allowing the evaluation of the pressure curves on a monitor.

The following parameters were monitored throughout the experiment: Mean arterial pressure (MAP), arterial oxygen saturation (SaO_2), electrocardiogram (ECG), heart rate (HR), capnography (PetCO2), and surface temperature (rectal thermometer). The measurement values before and during the right heart bypass are described in Table 1.

An extracorporeal circulation roller pump machine (MACCHI) was used in all but one experiment, in which a

Table 1. Study variable description and comparison between 2-moment observations

Sample		PAM (mmHg)		HR (bpm)		SaO_2 (%)		CO_2 (mmHg)		T (ºC)	
Elements	Peso (kg)	pre	drhb	pre	drhb	pre	drhb	pre	drhb	pre	drhb
1	28.0	83.0	90.0	100.0	98.0	98.0	94.0	30.0	27.0	36.0	37.0
2	25.0	79.0	91.0	108.0	104.0	90.0	89.0	28.0	25.0	35.1	36.0
3	30.0	95.0	92.0	110.0	95.0	94.0	93.0	28.0	24.0	36.8	37.2
4	32.0	100.0	95.0	85.0	104.0	95.0	95.0	29.0	28.0	36.0	36.6
5	27.0	80.0	73.0	102.0	95.0	92.0	93.0	32.0	28.0	36.5	37.0
6	30.0	108.0	96.0	95.0	93.0	93.0	94.0	27.0	23.0	36.0	36.8
7	28.0	100.0	92.0	88.0	95.0	95.0	95.0	27.0	24.0	36.8	37.8
8	30.0	117.0	104.0	126.0	100.0	95.0	92.0	28.0	24.0	36.5	37.5
9	26.0	55.0	60.0	100.0	98.0	92.0	93.0	27.0	25.0	35.3	36.5
mean	28.4	90.8	88.1	101.6	98.0	93.8	93.1	28.4	25.3	36.1	36.9
Standard deviation	2.2	18.6	13.3	12.3	4.0	2.3	1.8	1.7	1.9	0.6	0.5
significance (p)	-	0.388		0.423		0.299		<0.001		<0.001	

Legend: MAP – Mean Arterial Pressure; HR – Heart Rate; SaO_2 – Oxygen Saturation; CO_2- expired carbon dioxide; T - Temperature; pre = moment prior to right heart bypass; ddd – moment during the right heart bypass. Significant for $p < 0.050$

centrifugal pump (Medtronic) was used. A blood container (Edwards Vital; Edwards Life-. sciences, Irvine, CA, USA) and a set of 3/8" siliconized tubes were used. The perfusate was 500 mL of Ringer lactate.

Bicaval cannula with balloons was especially manufactured for this experiment by Braile Biomédica. It is composed of holes placed in two different levels to allow cranially and caudally drainage of both superior and inferior vena cavae separately and two inflatable balloons which were designed to occlude vena cavae internally, thus allowing the complete blood shunt to the propulsion pump, eliminating the need of tourniquets. The cannula has a plastic conductor which allows its introduction through peripheral access and aids directing it to the correct position in the vena cavae (figures 3 and 4).

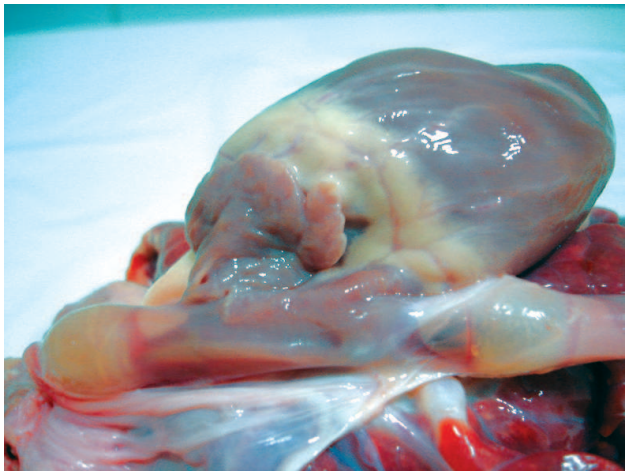

Fig. 3 –Anatomical sample – bicaval venous cannula with inflated balloons

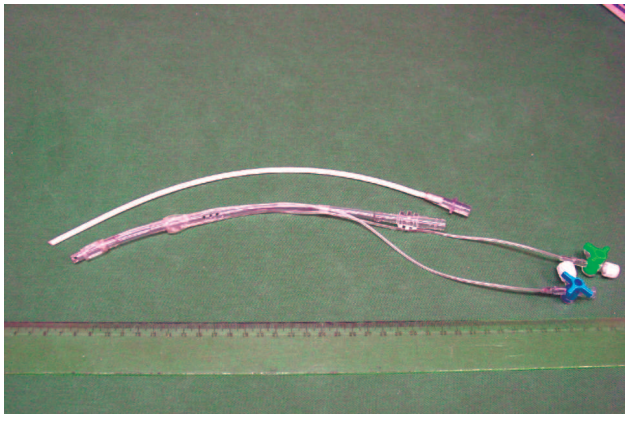

Fig. 4 –Bicaval cannula with a plastic tube and inflatable ballons

The procedure was started with heparinization of the animals through heparin sodium intravenously, at a dose of 3.0 mg/kg body weight, following the introduction of bicaval venous cannula with balloons through right internal jugular vein placed on cranial and caudal vena cavae. Afterwards, an arterial cannula (Braile Biomédica) was fixed with a purse-string suture placed on the pulmonary trunk using 5-0 polypropylene thread.

Once the cardiopulmonary bypass was established, the blood was drained from the vena cavae into the blood container propelled by the pump to pulmonary artery cannula. The blood flow (an average of 1.5 L/min) was calculated according to the animal weight. Normothermia was maintained by the coil system into the container. The assisted circulation with right heart bypass was maintained over 20 minutes. The balloons were kept inflated during this time interval allowing total blood bypass from cranial and caudal vena cavae into the pulmonary artery trunk, which was clamped near by the cannulation site and an arterial incision was made to approach the pulmonary valve.

At the end of the experiment, the right heart bypass was discontinued. Animal euthanasia procedure was performed with an intravenous infusion of 19.1% potassium chloride following the guidelines to avoid unnecessary pain and distress to the animal.

Statistical analysis

In all tests, statistical significance was defined with an á of 0.05. All statistical analyses were performed using SPSS (Statistical Package for Social Sciences) for Windows software (version 13.0, SPSS Inc., Chicago, Ill.)

Unpaired data were tested with Student's t test. Despite the small number of animals (n=9) in our study, this statistical test could be performed because the normal distribution of the data was confirmed by a Kolgomorov-Smirnov test.

RESULTS

The experiment was carried out in nine swine and the following mean parameters were evaluated: MAP, HR, SaO_2, $PetCO_2$ and *t*, at the moment prior to right heart bypass (pre) and during the right heart bypass (drhb). At the moment pre-right heart bypass, the following mean values were obtained: MAP = 90.8 mmHg; HR = 101.6 beats per minute; SaO_2 = 93.8%, $PetCO_2$ = 28.4 mmHg; and *t* = 36.1ºC. During the right heart bypass, the following mean parameter values were obtained: MAP = 88.1 mmHg; HR = 98 beats per minute; SaO_2 = 93.1%, $PetCO_2$ = 25.3 mmHg; and *t* = 36.9ºC.

Comparing the values obtained for each parameter, at these two moments already described, it was verified that there were no statistically significant difference among the

following measurements: MAP (p=0.388); HR (p=0.423); and SO_2 (p=0.299). PetCO2 and t values did not show statistically significant differences (p<0.001).

The parameter values, as well as the results obtained by statistical study are shown in Table 1.

DISCUSSION

More and more we are seeking new ways to correct heart diseases through less invasive methods, and many times we have reported techniques already described in the past. These techniques can be adapted to update technologies in order to allow less aggressive procedures to the patient. Taking the abovementioned into consideration, we sought to experimentally evaluate whether the surgeries through the pulmonary artery trunk to treat pulmonary valve stenosis with intact ventricular septum could be performed using cardiopulmonary bypass provided by right heart bypass in order to avoid oxygenator, aortic clamping, and infusion of cardioplegia solution. Darling *et al.* [8] recommend the right ventricular support with autologous oxygenation stressing the benefits of how to reduce thromboembolism, maintain coagulation, minimize hemolysis, and reduce the inflammatory response. The right heart bypass has been mostly used rather as a circulatory support in cases of postoperative right ventricular failure than as an auxiliary to the surgical procedure. Several indications have been described regarding the right heart bypass, such as heart transplantations, correction of congenital heart diseases, mitral valve surgery with pulmonary arterial hypertension, and coronary artery diseases [8-13]. Its use has been perfectly standardized.

A new bicaval cannula was manufactured to accomplish this experiment. It should be introduced through either a percutaneous or a peripheral approach, should promote the complete drainage of superior and inferior vena cavae, and should have two inflatable balloons in order to avoid the tourniquets. This such a cannula was manufactured by Braile Biomédica (São José do Rio Preto, São Paulo, Brazil). Several cannulas have been designed following the procedures performed through miniincisions. In 2004, Demirsoy *et al.* [7] report the use of a 2-stage single venous cannula to repair interatrial communication. In our study, we also used the 2-satge principle to simultaneously drain both superior and inferior vena cavae, but we believe that the presence of the balloons is critical not only to promote the drainage of vena cavae alone, but also to allow the increased blood volume drained, as described by Al'Ebrain *et al*. [15].

This cannula was designed for minimally invasive procedures and its has an internal plastic conductor, which assists to drive it from the peripheral access into the venae cavae [6]; maintenance of the adequate flood flow through its small holes for circulatory support [14], thus optimizing the drainage with the inflated balloons [15]. We believe that to verify the adequate balloon positioning when miniincisions are used, it is necessary to visualize the cannula either through radioscopy or videoscopy.

According to the results obtained before and after right cardiopulmonaru byss, it is verified that there was no statistically significant difference regarding MAP, HR, and SaO_2, which confirms the hemodynamic status maintained during the right heart bypass. The increase in temperature has occurred as a result of the use of the container heating system in order to preserve the animals' normothermia. The values obtained were slightly superior to those measured before the right heart bypass support. There was a statistically significant difference, but no harm at all was caused to the animals.

The capnography showed a somewhat PetCO2 lower absolute values during the right heart bypass presenting a significant difference, probably in consequence of pulmonary vascular resistance changes, which may occur as a result of the blood flow change either through cardiopulmonary bypass or through alveolus-capillary perfusion variations. This issue remained unclear and could be better evaluated placing a catheter in either pulmonary artery branches or trunk to measure the pressure yielded by the pump flow to the pulmonary vessels. Measurement of the pulmonary artery pressure during the right heart bypass was described by Lima *et al.* [18] in which they used right circulatory support for CABG surgery. In this study the pulmonary artery pressure ranged from 17 to 18 mmHg during the procedure.

Despite the reduced PetCO2 values during the right heart bypass, there was no repercussion in MAP, HR, and SaO2 parameters in this time interval. The animals remained free of hemodynamic disorders for 20 minutes, suggesting an adequate drainage by the cannula and a pulmonary blood flow capable of maintaining properly volumetric return to the left atrium, once a low deficit did not occur in this period.

The steady-flow was adequate, what was in accordance with the study carried out by Myers *et al*. [19] where they show parameter uniformity when comparing pulsatile and steady-flow.

In this study, we have used the roller pump with excellent results. The vacuum-assisted venous drainage of the container was not necessary in order to improve drainage as described by some authors [20,21].

Regarding surgical approach using right heart bypass, we believe that it is possible to perform surgeries through both pulmonary trunk and right ventricle as it was described by Shivaprakasha *et al*. [22], who used bidirectional Glenn shunt surgeries (cavopulmonary anastomosis) in order to minimize the circuit, thus avoiding an oxygenator, by reducing the inflammatory deleterious effects after

cardiopulmonary bypass. A greater number of specific studies comparing the both methods are further needed. Actually, some authors have been seeking other approaches to right ventricular outflow tract (RVOT) transannular patch (TAP) augmentation without the use of cardiopulmonary bypass (off-pump) [23] and replacement of the pulmonary valve and tricuspid annuloplasty with beating heart under extracorporeal circulation [24], aiming at to perform less invasive procedures leading us to think about the importance of seeking new methods.

We performed a study in nine swine under direct vision of the surgical field through sternotomy and measured the hemodynamic parameters. After this evaluation, it was possible to carry out the last experiment n swine 10th through miniincision at the left second intercostal space with access to pulmonary trunk cannulation and drainage of superior and inferior venae cavae without direct vision of the surgical, by using then parameters obtained with previous experiments in animals of similar size, which will the issue of a further study emphasizing the possible changes in pulmonary circulation during right heart bypass.

CONCLUSION

We have concluded that in this previous experimental study, we have managed to reproduce a pulmonary valve approach using a right heart bypass and to test a new bicaval cannula with balloons using a peripheral access.

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