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Cavopulmonary anastomosis without cardiopulmonary bypass[†]

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Abstract

OBJECTIVES: There is an increasing trend to perform the bidirectional superior cavopulmonary (Glenn) anastomosis without cardiopulmonary bypass. In this report, we present our results of off-pump bidirectional Glenn operation done without using a venoatrial shunt to decompress the randomized comparative study was superior vena cava during clamping.

METHODS: A prospective, non-randomized comparative study was conducted in 50 patients with functional single ventricle anomalies who underwent bidirectional Glenn anastomosis without cardiopulmonary bypass. The patients were divided into two groups: Group I ($n = 25$), where it was done without a veno-atrial shunt, and Group II ($n = 25$), where it was done with a veno-atrial shunt. Two patients in Group I and 4 patients in Group II had a bilateral bidirectional Glenn shunt. Five patients in Group I and three patients in Group II had a previous left modified Blalock–Taussig shunt. All patients underwent a complete neurological examination both preoperatively as well as postoperatively.

RESULTS: The early hospital mortality was 4% (2/50), one in each group. The median follow-up was 14 months. The mean internal venous pressure on clamping the superior vena cava was 37.07 ± 7.12 mmHg in Group I and 24 ± 4.4 mmHg in Group II. The mean clamp time was 9.85 ± 3.52 min in Group I and 21.3 ± 4.4 min in Group II. The transcranial pressure gradient was 62.37 ± 15.01 mmHg in Group I, while 65.08 ± 13.89 in Group II. The mean intensive care unit stay was 2.57 ± 75 days in Group I, 3.3 ± 1.09 in Group II. There were no major neurological complications apart from treatable convulsions in one case in Group I (4%), 2 cases in Group II (8%), and delayed recovery in one case (4%) in Group I.

CONCLUSIONS: Off-pump bidirectional Glenn operation without caval decompression is a safe, simple and more economic procedure.

Keywords: Coronary heart disease • Univentricular heart • Bidirectional Glenn shunt • Off-pump surgery

INTRODUCTION

The bidirectional superior cavopulmonary anastomosis, commonly referred to as bidirectional Glenn shunt (BDG), is a commonly performed procedure for a variety of cyanotic congenital heart diseases that leads eventually to single-ventricle repair [1]. It is an important intermediate palliation in patients with a structurally or functionally univentricular heart who are ultimately destined to have a Fontan-type operation [2].

It is usually performed under cardiopulmonary bypass (CPB), with its associated complications and costs. Avoiding the use of CPB is associated with significant elevation of the proximal superior vena cava (SVC) pressure, which may lead to neurological insults. However, the safety of performing BDG without CPB has been reported by many authors and most of these reports have recommended some decompression techniques of the SVC at the time of clamping [3–10]. In this article, we report our results of off-pump BDG without decompression of the SVC compared to the use of the veno-atrial shunt as an example of the decompression techniques of the SVC during the time of clamping.

MATERIALS AND METHODS

Between August 2007 and May a prospective, non-randomized comparative study was conducted at the Ain Shams University in 50 patients with functionally single ventricle anomalies who underwent BDG without CPB, after approval of the local ethics committee and obtaining written informed consent. Our inclusion criteria were functional single ventricles with arterial oxygen saturation <80%, McGoon ratio >1.5 and mean pulmonary artery pressure <20 mmHg. All these patients had adequate atrial septal defects and none of these patients required any intra cardiac repair. Patients with complex congenital cardiac anomalies amenable to biventricular or one and half ventricular repair, patients <6 months of age and patients with pulmonary venous obstruction or systemic outflow obstruction were excluded from this study.

Fifty patients were divided into two groups according to the operative technique. In Group I (25 patients), where their age ranged between 8 and 48 months (mean 15.96 ± 8.53) and their

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weight ranged from 7 to 20 kg (mean 9.9 ± 5.4), BDG was done without a veno-atrial shunt. In Group II (25 patients), where their age ranged between 10 and 108 months (mean 36 ± 20.63) and their weight ranged from 9 to 25 kg (mean 15.7 ± 5.4), it was done with a veno-atrial shunt. Two patients (8%) in Group I and 4 patients (16%) in Group II had left SVC and needed bilateral BDG. Five patients (20%) in Group I had a previous modified Blalock–Taussig shunt, as did 3 patients (12%) in Group II. All Blalock–Taussig shunts had been performed by a left thoracotomy and they were patent.

All patients underwent complete preoperative evaluation by full clinical examination especially cardiac and neurological examination and routine laboratory investigations. The decision to conduct the procedure without CPB was made after complete evaluation with echocardiography and cardiac catheterization. The preoperative data are given in Table 1. The mean haemoglobin (g/dl) level was 16.1 ± 0.99 (range 15–18) in Group I, and in Group II it was 17.2 ± 1.4 (range 15–20).

The procedure was performed under general anaesthesia. All patients had routine intraoperative monitoring, including five-lead electrocardiogram, pulse oximetry and capnography for end-tidal carbon dioxide (Drager PM 8040-CATO, Lübeck, Germany). Venous pressure monitoring was done via a multiport (triple lumen) cannula into either of the femoral veins and a short cannula placed in the internal jugular vein. An invasive arterial pressure line was placed in the radial or femoral artery.

After routine median sternotomy, the pericardium was opened in the midline and stay sutures were taken. The Blalock–Taussig shunt, if present, was dissected and looped to be ligated later. The SVC was dissected completely throughout its length from the atrio-caval junction to the innominate vein junction. The azygous vein was identified to be ligated later except in 2 patients (1 patient in each group) where there was an interrupted inferior vena cava with an azygous continuation. The branch pulmonary arteries were completely dissected from their origin to near the hilum of the lung. We electively clamped the pulmonary artery for 2 min to test for any haemodynamic disturbances or changes in the oxygen saturation. The CPB machine was kept primed as standby for any disturbance that might occur, so we can complete the procedure on bypass safely.

In Group I, dobutamine in a dose of 5 μg/kg/min was electively given before clamping the SVC and a volume load (5 ml/kg) of a colloid (fresh frozen plasma or blood according to the haemoglobin level) was given to elevate the mean arterial pressure to maintain an adequate transcranial pressure gradient (30–40 mmHg). All patients were given 30 mg/kg methylprednisolone, and the head of the operating table was elevated 30° upwards to allow better venous drainage by gravity through the collateral pathways. Then the azygous vein at this stage was ligated except in 1 patient with an interrupted inferior vena cava where upon it was left open with a temporary clamping during performing the anastomosis This was followed by direct clamping of the SVC to be transected near the veno-atrial junction with enough length left for the anastomosis. After closing the right atrial stump with a 5/0 continuous polypropylene suture, the SVC stump was flushed with heparinized saline. The right pulmonary artery was clamped and laid open on the superior aspect and an end-to-side anastomosis of SVC to the right pulmonary artery was performed with 6/0 continuous polypropylene suturing.

In Group II, systemic heparin (2 mg/kg) was administered to achieve an activated clotting time of 180 s or more. A veno-atrial shunt was established between the innominate vein and the right atrium using two right-angled metal tipped cannulas after deairing of the circuit. After establishing the shunt, the azygous vein was ligated except in 1 patient with an interrupted inferior vena cava where upon it was left open with temporary clamping during performing the anastomosis The SVC was transected and an end-to-side anastomosis of SVC to right pulmonary artery was performed with 6/0 continuous polypropylene suturing.

The Blalock–Taussig shunt, if present, was ligated in all patients. In cases of bilateral BDG, the right one was done first, and the left SVC was still draining to decrease the systemic venous hypertension. After completion of the anastomosis, adequate function of the Glenn shunt was ensured by a mean SVC pressure of 18–20 mmHg, and the decision to leave the forward pulmonary flow was made according to arterial oxygen saturation and SVC pressure. Antegrade pulmonary flow was controlled by pulmonary artery banding in 19 cases in Group I and 15 cases in Group II. The tightness of the band was decided according to the measurements on oxygen flow of 0.3–0.5 for 5 min.

Postoperatively, the patients were stabilized in the intensive care unit (ICU) and after monitoring the SVC pressure for 12 h, the internal jugular vein cannula was removed to prevent any jugular vein thrombosis. The patients were started on aspirin (5 mg/kg/day), which was continued indefinitely.

The follow-up extended from 6 to 20 months (median of 14 months). All this patients underwent a full clinical examination especially a complete cardiac and neurological examination. It also included oxygen saturation, routine echocardiography to demonstrate shunt flow patency and a computerized axial tomography of the brain for patients with neurological complications.

All statistical analyses were performed using the SAS statistical software (version 9.1; SAS Institute, Cary, NC, USA). Data are presented as frequency, median with range or mean ± SD as appropriate, with the number of non-missing values indicated.

Table 1: Preoperative data

	Group I	Group II
Anatomical and morphological types		
1. Tricuspid atresia		
I	8 (32%)	5 (20%)
II	7 (28%)	4 (16%)
2. Single ventricle and pulmonary stenosis	9 (36%)	15 (60%)
3. Double inlet left ventricle	1 (4%)	1 (4%)
Associated anomalies		
1. Left persistent superior vena cava.	2 (8%)	4 (16%)
2. Inferior vena caval interruption	1	1 (4%)
Previous Blalock–Taussig shunt	5 (20%)	3 (12%)
Ventricular assessment	23–52%	30–48%
Left ventricular ejection faction	46 ± 1	42 ± 2
Pulmonary artery assessment	1.5–2.1	1.7–2.2
McGoon's ratio	1.84 ± 0.19	1.94 ± 0.13

Tricuspid atresia (I) with concordant ventriculoarterial connection; (II) with discordant ventriculoartrial connection.
Note: in Groups I and II, there was no single case with anomalous pulmonary venous drainage, a moderate or severe degree of valvular incompetence, restricted atrial shunt or systemic outflow obstruction. These findings were excluded from this study.

Unrelated two-group comparisons were done with unpaired, 2-tailed t-tests for continuous variables and χ^2 or Fisher exact tests for categorical data.

RESULTS

There were two early postoperative deaths: one in each group with the same cause of death, which was related to high SVC pressure. This resulted in right pleural chylothorax that required prolonged drainage and hospital stay with subsequent deleterious nutritional and immunological deficits that in turn give rise to systemic inflammatory response syndrome and mortality.

There was no significant difference between the two groups in terms of mean SVC pressure before, during and after SVC clamping ($P > 0.05$), as shown in Table 2. The mean SVC clamp time was 9.85 ± 3.52 min in Group I and 21.3 ± 4.4 min in Group II with no significant difference between the two groups. The transcranial pressure gradient was comparable between the groups ($P > 0.05$) as shown in Fig. 1.

There was no haemodynamic instability during any of the procedures and oxygen saturation was maintained at >65–70% through the procedure (Table 2). The mean ICU stay was 2.57 ± 0.75 days in Group I, and 3.3 ± 1.09 days in Group II. The mean time for mechanical ventilation was 8 ± 15 h in Group I, and 10 ± 18 h in Group II. There were 1 patient in Group I and 4 patients in Group II who had a right-sided pleural effusion with subsequent high SVC pressure and manifestations of partial SVC obstruction that were treated by intercostal tube drainage and by maximizing the dosage of vasodilators. There were no postoperative dysrhythmias. There was postoperative bleeding in one case in Group II that required exploration and there was another case in the same group complicated by phrenic palsy with subsequent mild respiratory distress, which was treated conservatively. There were neurological complications in two cases in each group; in Group I, one case developed neurological convulsions on the first postoperative day and the second case showed delayed recovery for ~18 h after reaching the ICU; in Group II, both cases suffered neurological convulsions: one was immediate postoperative and the second case was after 3 days while the patient was in the ward. In both groups, patients with neurological convulsions were controlled on phenytion treatment, which was gradually tapered and stopped in the later follow-up period. A computerized axial tomography of the brain was done for all these patients and revealed mild brain oedema but without any ischaemic or venous infarcts or any cerebral haemorrhage. On follow-up, all the patients were doing well with no major sequelae.

Table 2: SVC pressures during the procedure

Time	SVC pressure (mmHg)		Oxygen saturation (%)	
	Group I	Group II	Group I	Group II
Before clamping	9 ± 2.1	7 ± 1.6	74.9 ± 0.7	70 ± 0.5
During clamping	37 ± 7.1	24 ± 4.4	74.1 ± 0.5	68.4 ± 0.9
After clamping	14.3 ± 1.8	18.7 ± 2.6	90.9 ± 1.03	88.6 ± 2.5

SVC: superior vena cava.

DISCUSSION

Patients with a single-ventricle physiology usually require first-stage palliation in the form of BDG before completion of the Fontan procedure. It is commonly performed using CPB with satisfactory early and late results; however, its deleterious effect is well known. Performing BDG shunt without CPB has been adopted by many centres and studied by many authors using various techniques of decompression of the SVC during the anastomosis [3–11]. We report our experience of performing off-pump BDG shunt without use of any decompression techniques of the SVC and compared it with the results of performing it using the common technique of aveno-atrial shunt.

Many criteria of the patients have been described for performing BDG shunt. The current accepted optimal age for the BDG is in 3–9 months [12]. The mean pulmonary artery pressure should be <18 mmHg or ideally <15 mmHg, with a calculated pulmonary vascular resistance of <2 units/m^2 [12, 13]. The estimated safest pulmonary artery index in terms of postoperative haemodynamics should exceed 250 mm^2/m^2 as described by Senzaki *et al*. [14]. A mild atrioventricular regurgitation and a mean ventricular end-diastolic pressure <12 mmHg were added criteria for better outcomes [12, 13]. Most of our patients fulfilled these selective criteria. They were >6 months of age, the mean pulmonary artery pressure was <18 mmHg, the pulmonary index was from 200 to 250 mm^2/m^2 and they had mild atrioventricular regurgitation. Caution is indicated when considering off-pump BDG if patients are too young or have hypoplastic pulmonary arterial branches with a McGoon index of <1.4 or a pulmonary artery index of <200 mm^2/m^2.

As early as 1942, Starr and his colleagues concluded that extensive cauterization of the canine right ventricle caused only minimal increase in peripheral systemic venous pressure. This realization led Rodbard and Wagner in 1948 into experimental attempts to completely bypass the right ventricle by anastomizing the right atrial appendage to the main pulmonary artery that was ligated proximally to the anastomosis [15].

Carlon (of Padova), in 1951, employed his experimental shunt, in a canine model, using the azygous vein to connect the right pulmonary artery to the SVC, and the proximal right pulmonary artery and SVC were ligated [16].

The classic Glenn shunt was first performed in 1958 and performed as off-pump through thoracotomy by an end-to-end anastomosis between SVC and the divided right pulmonary artery without any significant neurological sequelae. However, this operation was largely abandoned in favour of the end-to-side

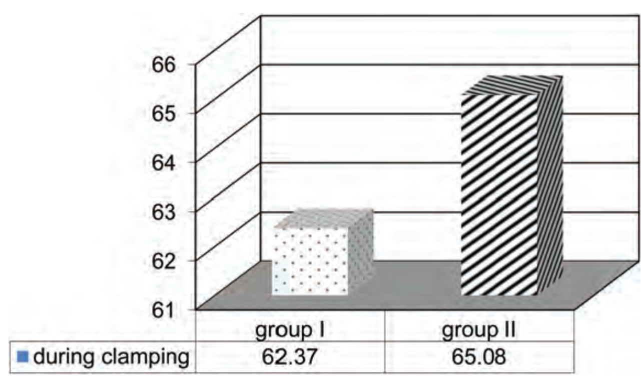

Figure 1: Transcranial pressure gradient during superior vena cava clamping.

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anastomosis of the transected SVC to the right pulmonary artery using CPB with excellent early and long-term results [2].

It was not before 1972 when Azzolina (of Massa) extended the concept of bidirectional cavopulmonary shunt in which an end-to-side anastomosis without division of the right pulmonary artery was attempted – which was employed in 9 patients with tricuspid atresia, the youngest just 5 months of age. The Azzolina shunt was performed through a right thoracotomy without bypass. An interesting feature was the use of an adjustable snare on the proximal SVC [16].

In 1990, Lamberti *et al*. [3] described the technique of BDG without CPB in 7 patients. In 6 patients, an SVC-right atrial temporary shunt was used to prevent elevation of intracranial pressure during the period of SVC clamping while in 1 patient with bilateral SVC no shunt was used.

Lal and Mahant [4] reported their experience with 6 patients who underwent BDG without CPB. Two patients had bilateral SVC and did not require any shunt. In the remaining 4 patients, it was not a true BDG without CPB as a roller pump and an extracorporeal membrane was required to facilitate veno-atrial bypass from the SVC to the right atrium. Murthy *et al.* [5] described a novel technique in 5 patients, in which a temporary shunt, using two standard right angle cannula, between SVC and the contralateral pulmonary artery for SVC decompression was established till the anastomosis was completed. They reported a temporary increase in oxygenation during this technique because this shunt acted as a temporary Glenn shunt. Jahangiri *et al*. [6] described BDG shunt in 7 patients, through a right thoracotomy without using any shunts during the clamping of the SVC. The median SVC pressure during clamping was 26 mmHg. They attempted to maintain the cerebral perfusion (transcranial pressure) at a minimum of 30 mmHg. This was done using inotropic agents whenever required. They did not report any neurological injuries.

In their series Liu *et al*. reported BDG without CPB using a veno-atrial shunt in 15 patients and a veno-pulmonary shunt in 5 patients. The mean SVC clamp time was 24.3 ± 4.7 min; and they reported a mean SVC pressure of 26.9 ± 5.5 mmHg during clamping. They used near-infrared spectroscopy to continuously monitor the oxyhaemoglobin in the brain tissue. There was no postoperative neurological complication. However, they reported one case in whom they had to establish emergency CPB because of sudden supraventricular arrhythmia with low blood pressure and they reported one case with postoperative manifestation of partial SVC obstruction that needed nitric oxide inhalation and prolonged ventilation [7]. Tireli *et al*. [8] reported their series of 30 patients who had BDG performed without CPB, with the use of SVC-left pulmonary artery shunt. Three of their patients had seizures during the hospital stay: two of them were apparently febrile in nature but one had permanent seizures. Luo *et al*. performed off-pump Glenn operation in 36 patients. They used a temporary SVC-right atrial shunt in 28 patients who had single SVC, while not using any shunts in the remaining 8 patients with bilateral SVC. They reported no neurological complications in their patients. On comparing the results with 35 patients who had earlier undergone the Glenn procedure on CPB, they demonstrated that the off-pump group showed better postoperative results in terms of lower pulmonary artery pressure, shorter duration of ventilatory support and less thoracic fluid drainage [9]. In a study very similar to ours, Hussain *et al.* reported off-pump BDG without any SVC decompression in 37 patients. The procedure was done with temporary clamping of the SVC; 4 patients had bilateral BDG and one had a right pulmonary artery-plasty done. The mean SVC pressure on clamping was 34.04 ± 10.15 mmHg and the mean clamp time was 6.85 ± 1.52 mmHg. There was no postoperative neurological complication. They used the neuro-developmental scales to assess the cognitive outcome as a reflection for any subtle neurological insult and there was no deterioration of developmental quotient/intelligence quotient score during the follow-up evaluation [10].

We agree with the opinion that clamping the SVC without a temporary shunt can lead to decreased cerebral blood flow and put the brain at risk [17]. Liu *et al*. observed by using near-infrared spectroscopy that the oxyhaemoglobin in brain tissue decreased significantly as SVC pressure increased during clamping of the SVC [7]. Rodriguez *et al*. [18] found that the blood flow velocity in the middle cerebral artery decreased 50% when clamping the SVC. In a second study, Rodriguez *et al*. [19] also found significant electroencephalogram changes during SVC clamping. In our study, in Group I of patients, we did not use any conventional decompression techniques. However, we electively used inotropic agents and we gave a good volume load to the patients to maintain a better transcranial pressure gradient during clamping of >30 mmHg. The mean transcranial pressure gradient in our patients was 62.37 ± 15.01 mmHg (range 33–92 mmHg). In addition, we conducted the procedure while the head of the operating table was elevated, so that the venous drainage was assisted by gravity through alternative pathways keeping the SVC pressure as low as possible. During clamping of the right or left pulmonary artery, we made sure that perfusion of both lungs was adequate and maintained either by a previous Blalock–Taussig shunt or antegrade pulmonary flow or through collateral perfusion of the lungs. Actually, we did a clamping test of the relevant pulmonary artery before starting the anastomosis with observation for any oxygen desaturation or haemodynamic instability. However, none of the patients had any haemodynamic compromise or significant decrease in systemic oxygen saturation on clamping. In our patients, oxygen saturation was maintained at >65–70% throughout the procedure. On the other hand, the clamp time in our study was relatively short (9.85 ± 3.52 min) and we did not encounter any brain injury. We suggest keeping the clamp time as short as possible without compromising the anastomosis so that reducing the possibility of any brain insult and this can be achieved by doing this technique with an experienced surgeon and by a good selection of the cases. In group II of patients, we conducted the procedure in same steps using the veno-atrial shunt. We ensured adequate matching of the cannulae to the patients' age and weight. We attempted to cannulate the innominate vein and the right atrium in a proper position for proper drainage.

The role of accessory pulmonary blood flow in the setting of a BDG remains contentious. An additional source of pulmonary blood flow may mitigate some of the benefits of a BDG physiology by offsetting the reduction in ventricular volume load and increasing the likelihood of pulmonary vascular complications. On the other hand, it may offer some advantages over a pure cavopulmonary shunt physiology: the increased oxygen saturation may be sufficient to reduce baseline cyanosis, and the additional source of pulmonary blood flow may allow for modestly improved exercise tolerance. In addition, by providing hepatic blood directly to the lungs, introducing an element of pulsatility to the pulmonary flow and increasing flow rates, an additional source of pulmonary flow may in fact reduce the likelihood of pulmonary vascular complications (such as arterio-venous fistulas and aortopulmonary collaterals) and improve pulmonary artery growth [20]. This was the pattern observed in our patients in terms of higher oxygen saturation achieved in the subgroup of patients with patent antegrade pulmonary flow in both groups but unfortunately it was found that the SVC pressure was higher among this subgroup as well.

Many authors have reported higher morbidity and mortality in the early postoperative period among patients with additional pulmonary blood flow in the form of higher incidence of prolonged pleural effusion, development of SVC syndrome and prolonged duration of hospital stay [21–23]. This was the case in our patients as we had 5 cases of pleural effusion, one in Group I and 4 in Group II, with signs of variable degrees of partial SVC obstruction, and all these cases were in the subgroup with patent antegrade pulmonary flow.

In the present study, there are several limitations that should be considered. The most important is that it did not assess the psychometric or the developmental evaluation of the patients which could reflect any subtle brain damage. Indeed, we need to include more advanced diagnostic tools for such minor brain insults in further studies. Also, we only discussed the accessory pulmonary blood flow, and the advantages and disadvantages in BDG in brief, as it is beyond the scope of the present study. However, in our opinion, further in-depth studies are needed to determine its role and its drawbacks when combined with our technique.

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Conflict of interest: none declared.

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eComment. Superior caval clamping without a cavoatrial shunt during bidirectional Glenn operation

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We read with interest the paper by Mostafa *et al.* [1], in which they presented the results of two groups of single ventricle patients, who underwent bidirectional cavopulmonary anastomosis with and without a veno-atrial shunt. The authors indicate a mean venous pressure of 37.07 ± 7.12 mmHg in the non-shunted group for a mean clamp time of 9.85 ± 3.52 min. The mean intensive care unit stay was 2.57 ± 75 days in the non-shunted patients. The authors performed bidirectional Glenn operation in a cohort of patients aging between 8-108 months [1]. The superior vena cava carries at least half of the blood volume in the early periods of life [2,3]. With growth, the inferior vena cava dominates [3] and proportions become 1/3-4 in adulthood [2,3]. Thus, although superior vena cava clamping may be uneventful in later childhood or adulthood, clamping of the superior caval vein in the early periods of life may not be easily haemodynamically tolerated. The manoeuvre may lead to cardiac failure and an increased amount and number of inotropic agents may be required [2]. Moreover, although authors state the manoeuvre had not led to serious neurologic sequelae during clamping of the superior vena cava, intracerebral pressure increases and cerebral arterial flow diminishes for sure.

The literature includes animal experiments of superior vena cava clamping in monkeys [4] and dogs [5]. Research indicates that temporary occlusion of the superior vena cava is safe, despite decreased cerebral blood flow during clamp application [4,5]. First of all, it seems that these experiments were performed on adult animals in both studies [4,5]. Moreover, Masuda *et al.* indicated