

Total Anomalous Pulmonary Venous Drainage. Surgical Therapy for the Infradiaphragmatic and Mixed Anatomical Types

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Objective - To study the in-hospital evolution of patients with the infradiaphragmatic and mixed types of total anomalous pulmonary venous drainage (TAPVD), who underwent surgical therapy.

Methods - Of the 65 patients diagnosed with isolated TAPVD and operated on from December 1993 to March 2002, 7 (10.8%) patients with the mixed and infradiaphragmatic forms were retrospectively selected. Their ages ranged from 5 days to 19 months (mean of 7 months), 5 (71.4%) were males, and their clinical diagnosis was established with 2-dimensional echocardiography. Four (57.1%) patients had the mixed form, which was intrinsic obstructive in 1 patient, with mild stenosis of the left inferior vein. The remaining 3 (42.9%) patients had the obstructive infradiaphragmatic form, extrinsic at the level of the diaphragm. All surgeries were performed through median sternotomy with hypothermic extracorporeal circulation, and total circulatory arrest was required in 2 patients.

Results - In-hospital death occurred in 1 patient with infradiaphragmatic TAPVD with connection of the inferior vertical vein with the portal vein. The cause of death was related to multisystem organ failure. In 4 (57.1%) patients, the postoperative period was characterized by the presence of low cardiac output and pulmonary hypertension.

Conclusion - The result of the surgical correction of this anomaly is associated with acceptable morbidity and mortality, depending on early referral and surgery, without progression of the pulmonary vascular hypertension findings.

Key words: total anomalous pulmonary venous drainage, congenital heart defect with increased pulmonary blood flow, pulmonary veins

Total anomalous pulmonary venous drainage is a rare congenital anomaly, corresponding to approximately 2% of all congenital heart defects¹. The great variability of anatomical forms results in different clinical presentations, which range from stable settings with balanced pulmonary and systemic flows with mild arterial insaturation to increased pulmonary flow settings with exuberant pulmonary edema.

Morbidity and mortality related to the surgical treatment of total anomalous pulmonary venous drainage have been drastically minimized in the last decade, and several international centers have obtained excellent results²⁻⁷ (tab. I and II). These results are from the earlier diagnosis of the anomaly, essentially due to the advances in echocardiography⁸, with feasible optimization and stabilization of preoperative clinical conditions³. In addition, other relevant factors include advancements in anesthetic techniques, extracorporeal circulation, myocardial protection of surgical techniques, and postoperative management focused on the understanding of the pathophysiology of the anomaly. Early surgical treatment during the neonatal period proved to be essential, because, in the natural history of the defect, a mortality of 50% is found in the first 3 months of life⁹.

Total anomalous pulmonary venous drainage may have different anatomic variants, the supracardiac and cardiac being the most frequent. The infradiaphragmatic and mixed variants correspond to 25% and 5% of the cases, respectively. The latter 2 forms are characterized by their high association with venous obstruction and a higher morbidity and mortality according to some authors^{10,11}.

Despite all the progress cited, an elevated mortality of that anomaly persists in developing countries¹², because the diagnosis and the referral of patients to tertiary centers is delayed, occurring in a phase with varied degrees of pulmonary hypertension, many times associated with infection and malnutrition¹³.

This study aimed at analyzing the in-hospital evolution of patients with the infradiaphragmatic and mixed forms of total anomalous pulmonary venous drainage, who underwent surgical treatment.

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Table I - Results of the surgical treatment for infradiaphragmatic total anomalous pulmonary venous drainage

Author, year	N patients	Incidence* (%)	Obstruction (%)	Mortality (%)
Lupinetti et al. ² , 1993	11	26.8	100	9.1
Raisher et al. ³ , 1992	2	10	100	0
Michielon et al. ⁴ , 2002	16	18	87.5	2.2
Sano et al. ⁵ , 1989	16	36.4	93.8	6.3
Hyde et al. ⁶ , 1999	20	23	85	20

* in regard to the total number of patients with all types of the anomaly.

Table II - Results of the surgical treatment for mixed total anomalous pulmonary venous drainage

Author, year	N patients	Incidence* (%)	Obstruction (%)	Mortality (%)
Lupinetti et al. ² , 1993	2	4.9	50	0
Raisher et al. ³ , 1992	5	25	40	0
Michielon et al. ⁴ , 2002	9	10.1	11.1	1.1
Hyde et al. ⁶ , 1999	8	9	25	0
Delius et al. ⁷ , 1996	20	8.6	15	15

* in regard to the total number of patients with all types of the anomaly.

Methods

This study retrospectively assessed 7 (10.8%) patients with the mixed and infradiaphragmatic forms of total anomalous pulmonary venous drainage of a total of 65 patients operated on at the Instituto do Coração of the Hospital das Clínicas of the Medical School of the University of São Paulo from December 1993 to March 2002. Patients diagnosed with associated malformations, such as transposition of the great arteries, univentricular atrioventricular connection, atrial isomerisms, atrioventricular septal defects, and hypoplastic left heart, were excluded from the study.

The patients' ages ranged from 5 days to 19 months (mean of 7 months), their weights ranged from 2.4 to 9.5 kg (mean of 5.2 kg), and their heights from 42 to 72 cm (mean of 56.7 cm). Five (71.4%) patients were males. The clinical diagnosis in all patients was confirmed with 2-dimensional echocardiography, and 3 patients also underwent cardiac catheterization aimed at studying in greater detail the pulmonary venous return, at measuring intracavitary pressures, especially in patients suspected of having pulmonary hypertension, in addition to performing balloon atrioseptostomy in the presence of restrictive interatrial septal defect.

Four (57.1%) patients had the mixed form, which was intrinsic obstructive in 1 patient, with mild stenosis of the left inferior vein. Three (42.9%) patients had the obstructive infradiaphragmatic form, extrinsic at the level of the diaphragm, in addition to a restrictive interatrial septal defect. The detailed anatomy of the pulmonary veins and their sites of drainage are shown in table III.

In the preoperative period, 5 (71.4%) patients were in NYHA functional class IV and the remaining 2 (28.6%) were in NYHA functional class III. Three patients had clinical and echocardiographic signs of pulmonary hypertension, 3 had severe protein-calorie malnutrition, 2 had active pulmonary

infection, both using mechanical ventilation, and 2 were in shock, depending on vasoactive drugs with difficult to control metabolic acidosis. The patients were admitted to the intensive care unit to stabilize their cardiorespiratory and metabolic conditions prior to corrective surgery. The most frequently used measures, depending on the individualized analysis of each case, were as follows: the liberal use of vasoactive drugs (dopamine and dobutamine), pulmonary vasodilating agents, mechanical ventilation, diuretics, broad-spectrum antibiotic therapy, and correction of the fluid, electrolytic and acid-base imbalances.

All patients were operated on through a median sternotomy with the aid of hypothermic extracorporeal circulation at 20°C through aortic and bicaval cannulation right after systemic heparinization. The myocardial protection used in most patients was the crystalloid St Thomas Hospital cardioplegia at 4°C, and, in the 2 most recent patients, cold blood cardioplegia via the intermittent antegrade route every 20 minutes was preferred. Two patients required total circulatory arrest and deep hypothermia for connecting the vertical vein and the left atrium. The surgical techniques used in the patients with infradiaphragmatic total anomalous pulmonary venous drainage were the laterolateral transatrial anastomosis between the vertical vein and the left atrial lateroposterior wall towards its auricle, and closure of the interatrial septal defect with a bovine pericardial patch preserved in glutaraldehyde, followed by ligation of the vertical vein close to the diaphragm. In regard to the mixed type of total anomalous pulmonary venous drainage, transatrial anastomosis with closure of the interatrial septal defect was performed in 3 patients, while direct anastomosis was possible in the remaining patients, in addition to correction of the stenosis of the left inferior pulmonary vein with a bovine pericardial patch. The anastomoses were performed with continuous suture with 6- or 7-zero polypropylene thread.

Table III - Anatomic characteristics of the 7 patients with total anomalous pulmonary venous drainage

N	Type	Site of connection	Obstruction	PH	Mortality
1	Mixed	LPV+RIPV » LSVC; rest » VCSD	No	Yes	No
2	Mixed	LPV+RIPV » coronary sinus; rest » LSVC and innominate vein	No	Yes	No
3	Mixed	RPV+LPV » coronary sinus; rest » RSVC	Yes	Yes	No
4	Mixed	RPV » RSVC; LPV » right atrium	No	No	No
5	Infra	PVs » ductus venosus	Yes	Yes	No
6	Infra	PVs » portal vein	Yes	Yes	Yes
7	Infra	PVs » IVC	Yes	Yes	No

IVC- inferior vena cava; LIPV- left inferior pulmonary vein; LPV- left pulmonary veins; LSVC- left superior vena cava; PH - pulmonary hipertension; PVs - pulmonary veins; RIPV- right inferior pulmonary vein; RPV- right pulmonary veins; RSVC- right superior vena cava.

The mean times of extracorporeal circulation and aortic cross-clamping were 84.1 minutes and 49 minutes, respectively. The total circulatory arrest used in 2 patients lasted 9 and 15 minutes.

In the postoperative period, all patients remained under mechanical ventilation for at least 48 hours and sedated with fentanyl and midazolam, sometimes requiring curarization. The patients were maintained under pressure-controlled ventilation with positive end-airway pressure and a slightly increased minute volume, to maintain the partial carbon dioxide pressure around 30 to 35 mmHg. The use of inotropic agents was systematic, especially dobutamine, dopamine, and milrinone, depending on the hemodynamic evolution. Vasodilating agents were prioritized in cases of pulmonary hypertension, sodium nitroprusside and nitroglycerine being used, and, in refractory cases, prostaglandin E1 and inhaled nitric oxide were chosen. Response to treatment was monitored mainly with the aid of 2-dimensional echocardiography, and diuretics were programmed to maintain the fluid balance close to zero or even slightly negative. Early peritoneal dialysis was recommended when oliguria or anuria occurred.

Results

One patient with infradiaphragmatic total anomalous pulmonary venous drainage with connection of the inferior vertical vein to the portal vein died (in-hospital mortality of 14.3%), and the cause of death was related to multisystem organ failure. In the preoperative period, the patient was in poor general and nutritional condition with pulmonary hypertension, evolving to cardiogenic shock, acute renal failure, and septicemia due to mediastinitis in the postoperative period.

The postoperative complications were as follows: low cardiac output in 4 (57.1%) patients; pulmonary hypertension in 4 (57.1%); transient atrioventricular block, which required a transient pacemaker for more than 24 hours, in 3 (42.9%); supraventricular arrhythmias in 3 (42.9%); prolonged mechanical ventilation for more than 7 days in 3 (42.9%); acute renal failure, which required peritoneal dialysis, in 2 (28.6%); and bronchopneumonia in 2 (28.6%) patients. Two (28.6%) patients experienced cardiorespiratory arrest, due to low cardiac output in 1 and to hypoxia in another. Two patients remained with their chests opened on the first postoperative days due to hemodynamic instability, one of whom evolved with me-

diastinitis and required reoperation for exploratory thoracotomy and resuture of the sternum.

The duration of mechanical ventilation ranged from 9 hours to 28 days (mean of 7.5 days). The mean length of stay in the intensive care unit and in the hospital was 10.5 days and 18.2 days, respectively.

Discussion

Total anomalous pulmonary venous drainage is a congenital cardiac anomaly characterized by pulmonary venous return through the pulmonary veins to the systemic venous system. The distribution of blood flow inside the cardiac cavities depends on the size of the interatrial septal defect. If restrictive, a smaller amount of blood will flow to the left atrium, resulting in elevated right intra-atrial pressures, and, consequently, a drop in cardiac output. In most patients, the interatrial septal defect is not restrictive; the blood flow depends on the compliance of each ventricular cavity and on the relation between the pulmonary and systemic vascular resistances.

With the physiological decrease in pulmonary vascular resistance during the neonatal period, a progressive increase in pulmonary flow occurs, resulting in a relation between the pulmonary and systemic flows of around 5 or more. Pulmonary vascular changes and pulmonary hypertension may occur if this process continues. Yamaki et al¹⁴ have postulated that pulmonary hypertension results from an interaction between the hypertrophy of the media layer of the pulmonary arteries and veins. In patients with obstruction, the elevated pulmonary venous pressures lead to pulmonary capillary edema. In addition, reflex pulmonary vasoconstriction occurs, aggravating the pulmonary hypertension with supra-systemic right ventricular pressures. These patients rapidly develop cyanosis and low cardiac output, which may result in multisystem organ dysfunction.

According to the anatomic level of the connection of the pulmonary veins with the systemic circulation, Darling et al¹⁵ classified total anomalous pulmonary venous drainage into 4 types. The supracardiac and cardiac are the most frequent types, with lower preoperative severity and better evolution after surgical correction. The infracardiac or infradiaphragmatic type, found in approximately 25% of the cases of total anomalous pulmonary venous drainage¹⁶, is characterized by pulmonary venous drainage through the diaphragm most commonly to the portal vein or ductus ve-

nosus, and less frequently to the inferior vena cava, left hepatic vein, or gastric vein. This type has the greatest incidence of venous obstruction, this being an independent factor of mortality risk¹⁷. The mixed type (5% of the cases), unlike the others, is characterized by the lack of confluence of the pulmonary veins into a vertical collecting vein, this being a particularity in regard to the echocardiographic diagnosis and surgical planning.

The infradiaphragmatic type shows an elevated association with venous obstruction, which may be due either to the elevated resistance to the venous return, or to the extrinsic compression of the collecting vein at the level of the diaphragm, or even to an obstruction at the junction of the pulmonary vein with the collecting vein. However, van Son et al¹⁸ considered that the most important mechanism of obstruction is the elevated vascular resistance in the collecting veins, especially if the connection occurs in the ductus venosus or in the portal vein, due to the passage through the hepatic parenchyma or the postnatal obliteration, respectively. In our case series, the 3 patients with the infradiaphragmatic type had venous obstruction. One of them, with connection of the inferior vertical vein to the portal vein, underwent surgery on an emergency basis due to pulmonary hypertension and cardiogenic shock. This patient had an eventful postoperative period with acute renal failure, mediastinal infection, and septicemia, evolving to death. The other 2 patients with the infradiaphragmatic type and connections to the ductus venosus and inferior vena cava also underwent surgery on an emergency basis, but had a better outcome. This experience shows that the presence of venous obstruction is important for defining the ideal moment of surgical indication¹⁸.

Based on this, infradiaphragmatic total anomalous pulmonary venous drainage associated with venous obstruction has been considered a surgical emergency. In the cases with connection to the portal vein or the ductus venosus, a preoperative clinical stabilization period should not be waited for, regardless of the surgical risk. Considering the patients who are hemodynamically stable and have no echocardiographic signs of venous obstruction, the semi-elective indication is allowed in the cases with connection with the inferior vena cava or the hepatic vein¹⁸.

The mixed type of total anomalous pulmonary venous drainage results from embryonic alterations that lead to atresia of the confluence of the pulmonary veins. In most cases, drainage of both lungs occurs separately, the veins of one lung more frequently draining at the cardiac level, and those of the other lung at the supracardiac level, facilitating its recognition¹⁹. However, this fact is not always true²⁰, which makes the descriptive echocardiographic diagnosis of the anatomy of the pulmonary veins fundamental for surgical planning. In any case, the intraoperative identification of the 4 pulmonary veins is mandatory.

Delius et al⁷ defined the type of surgery classifying the mixed type of anomalous pulmonary venous drainage into the following 2 groups: 1) 3+1, in which 3 veins drain at the cardiac level or in the vertical vein, and the other in ano-

ther site; and 2) 2+2, in which the veins in each lung drain in different sites. In the first group, 3 veins usually drain in the coronary sinus, and correction is obtained through a communication of the latter with the atrial septal defect, followed by closure of the resulting defect with an autologous or bovine pericardial patch. Correction of the remaining vein should be individualized. In case of obstruction, its connection with the left atrium is mandatory. If the vein is not obstructed, it may be left without correction with persistence of a small inconvenient left-to-right shunt, which, in some patients, may evolve to obstructive pulmonary vascular disease²¹, and even require pulmonary lobectomy²². On the other hand, in the second group, the surgical treatment does not cause greater difficulties due to the frequent presence of a venous confluence, which facilitates the anastomosis with the left atrium.

In our case series, of the 4 patients with the mixed type only 1 had a 2+2 type drainage, which characterizes the lack of anatomical uniformity of that anomaly.

Surgical treatment has evolved considerably in recent decades, due to several factors. The evolution of the preoperative management with special emphasis to the more precise and rapid echocardiographic diagnosis, the techniques of surgery, anesthesia, and extracorporeal circulation, and the modern intensive treatment in the postoperative period were responsible for the significant reduction in the indices of operative mortality, with a direct impact in the long run.

Risk factors identified in the past^{10,17} do not seem to be important for characterizing the severity of patients, due to the advances obtained. Therefore, the early age, the anatomical type of total anomalous pulmonary venous drainage, the need for mechanical ventilation and preoperative inotropic support, and emergency surgery no longer appear as risk factors for mortality in the most recent case series²³. Venous obstruction, especially if diffuse and associated with the infradiaphragmatic forms, remains as a risk factor for mortality^{4,24}. In a previous study carried out at our institution, analyzing all types of total anomalous pulmonary venous drainage, Binotto et al¹³ identified age, poor general condition, and preoperative infection as important risk factors for mortality that need to be controlled, and mainly are due to the late referral of patients to tertiary centers.

The surgical treatment of total anomalous pulmonary venous drainage should pursue the reestablishment of a wide and nonrestrictive connection between the left atrium and the collecting vein(s). The surgical aspects involve the knowledge of the different anatomical forms of total anomalous pulmonary venous drainage and the recognition of the importance of alleviating all venous obstructions. The precise surgical technique has been crucial for improving surgical results. Early surgery, the use of deep hypothermia and circulatory arrest, the performance of a wide anastomosis between the confluence of the pulmonary veins and the left atrium, and the precise respect to the geometry of these structures are the factors responsible.

Several technical modifications for the surgical treat-

ment have been proposed with no significant difference between the results in the different maneuvers²⁵⁻²⁸. In addition to the technical details especially involving access to the pulmonary veins, some authors²⁹ consider that the vertical vein should not be ligated when the left atrium is small, with a low compliance to accommodate a sudden increase in volume after surgical correction. Other authors^{5,30} consider that this tactic promotes a more tranquil postoperative period, but postulate that this benefit is transient, because a left-to-right shunt frequently remains, requiring surgical or interventional closure. In our service, we recommend routine ligation of the vertical vein in addition to reconnection of the pulmonary veins to the left atrium.

Pulmonary hypertension continues to be the major postoperative cause of morbidity and mortality in these patients. When present, it is associated with increased mortality, but its clinical treatment is usually effective. The latter is based on optimization of the cardiac output with inotropic agents, a reduction in afterload, volume restric-

tion, and diuretics. The control of pulmonary hypertension crises is extremely important, because they lead to acute hypoxemia, with consequent metabolic acidosis and cardiovascular failure. Its treatment usually includes mechanical ventilatory support under deep sedation and frequent curarization with hyperventilation and the use of pulmonary vasodilators, such as nitroglycerine, milrinone, and nitric oxide³¹. When the clinical diagnosis of pulmonary hypertension crises is difficult, continuous monitoring of pulmonary artery pressure is important, because it allows early treatment and, therefore, a significant improvement in prognosis^{5,24}.

In conclusion, the infradiaphragmatic and mixed types of total anomalous pulmonary venous drainage have particularities in regard to their diagnosis and surgical treatment. Because of the advances in pediatric cardiac surgery in its multidisciplinary aspects, the result of the surgical correction of this anomaly is associated with acceptable morbidity and mortality, depending on early referral and surgical treatment, with no progression of pulmonary vascular hypertension.

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