Total Anomalous Pulmonary Venous Drainage. Surgical Therapy for the Infra-diaphragmatic and Mixed Anatomical Types

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Objective - To study the in-hospital evolution of patients with the infra-diaphragmatic 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 defects. 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 results (tab. I and II). These results are from the earlier diagnosis of the anomaly, essentially due to the advances in echocardiography, with feasible optimization and stabilization of preoperative clinical conditions. 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 life.

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.

Despite all the progress cited, an elevated mortality of that anomaly persists in developing countries, 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 malnutrition.

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.
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 anterograde 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 lateral posterior 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 I - Results of the surgical treatment for infradiaphragmatic total anomalous pulmonary venous drainage

<table>
<thead>
<tr>
<th>Author, year</th>
<th>N patients</th>
<th>Incidence (%)</th>
<th>Obstruction (%)</th>
<th>Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lupinetti et al., 1993</td>
<td>11</td>
<td>26.8</td>
<td>100</td>
<td>9.1</td>
</tr>
<tr>
<td>Raisher et al., 1992</td>
<td>2</td>
<td>10.0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Michielon et al., 2002</td>
<td>16</td>
<td>18</td>
<td>87.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Sano et al., 1989</td>
<td>16</td>
<td>36.4</td>
<td>93.8</td>
<td>6.3</td>
</tr>
<tr>
<td>Hyde et al., 1999</td>
<td>20</td>
<td>23</td>
<td>85</td>
<td>20</td>
</tr>
</tbody>
</table>

* 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

<table>
<thead>
<tr>
<th>Author, year</th>
<th>N patients</th>
<th>Incidence (%)</th>
<th>Obstruction (%)</th>
<th>Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lupinetti et al., 1993</td>
<td>2</td>
<td>4.9</td>
<td>50</td>
<td>0</td>
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<tr>
<td>Raisher et al., 1992</td>
<td>5</td>
<td>25</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>Michielon et al., 2002</td>
<td>9</td>
<td>10.1</td>
<td>11.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Hyde et al., 1999</td>
<td>8</td>
<td>9</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Delius et al., 1996</td>
<td>20</td>
<td>8.6</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

* in regard to the total number of patients with all types of the anomaly.
Table III - Anatomic characteristics of the 7 patients with total anomalous pulmonary venous drainage

<table>
<thead>
<tr>
<th>N</th>
<th>Type</th>
<th>Site of connection</th>
<th>Obstruction</th>
<th>Pulmonary hypertension (PH)</th>
<th>Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mixed</td>
<td>LPV»RIPV » LSVC; rest » VCSD</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Mixed</td>
<td>LPV»RIPV » coronary sinus; rest » LSVC and innominate vein</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Mixed</td>
<td>RPV » coronary sinus; rest » RSVC</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Mixed</td>
<td>RPV » right atrium; LPV » right atrium</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>Intra</td>
<td>PVs » ductus venosus</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Intra</td>
<td>PVs » portal vein</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Intra</td>
<td>PVs » IVC</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

IVC - inferior vena cava; LPV - left pulmonary vein; RIPV - right inferior pulmonary vein; RSVC - right superior vena cava; PH - pulmonary hypertension; 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 nitroglycerin 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 cardiacogenic 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 mediastinitis 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 al. 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 al. 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 drainage, is characterized by pulmonary venous drainage through the diaphragm most commonly to the portal vein or ductus ve-
The cardiac level or in the vertical vein, and the other in ano-
to the following 2 groups: 1) 3+1, in which 3 veins drain at
the mixed type of anomalous pulmonary venous drainage
for surgical planning. In any case, the intraoperative identi-
ty of surgical indication
outcome. This experience shows that the presence of ve-
nections to the ductus venosus and inferior vena cava also
other 2 patients with the infradiaphragmatic type and con-
diaphragm, or even to an obstruction at the junction of the
pulmonary vein with the collecting vein. However, van Son
et al considered that the most important mechanism of
obstruction is the elevated vascular resistance in the collect-
ing 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, respecti-
vically. In our case series, the 3 patients with the infradia-
phragmatic type had venous obstruction. One of them, with
connection of the inferior vertical vein to the portal vein, un-
derwent surgery on an emergency basis due to pulmonary
hypertension and cardiogenic shock. This patient had an
eventful postoperative period with acute renal failure, me-
istiinal infection, and septicemia, evolving to death. The
other 2 patients with the infradiaphragmatic type and con-
nections 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 ve-
nous obstruction is important for defining the ideal moment
of surgical indication.

Based on this, infradiaphragmatic total anomalous
pulmonary venous drainage associated with venous ob-
struction has been considered a surgical emergency. In the
cases with connection to the portal vein or the ductus veno-
sus, 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 vein.

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, facil-
iting its recognition. However, this fact is not always
true, which makes the descriptive echocardiographic diag-
nosis of the anatomy of the pulmonary veins fundamental
for surgical planning. In any case, the intraoperative identi-
fication of the 4 pulmonary veins is mandatory.

Delius et al 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 com-
unication of the latter with the atrial septal defect, followed
by closure of the resulting defect with an autologous or bo-
vine pericardial patch. Correction of the remaining vein
should be individualized. In case of obstruction, its con-
nection with the left atrium is mandatory. If the vein is not
obstructed, it may be left without correction with persisten-
ce of a small inconvenience left-to-right shunt, which, in
some patients, may evolve to obstructive pulmonary vascular di-
sease, and even require pulmonary lobectomy. On the
other hand, in the second group, the surgical treatment
does not cause greater difficulties due to the frequent pre-
sence of a venous confluence, which facilitates the anasto-
mosis 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 preo-
perative management with special emphasis to the more pre-
cise 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 do not seem to be
important for characterizing the severity of patients, due to
the advances obtained. Therefore, the early age, the anato-
mical type of total anomalous pulmonary venous drainage, the
need for mechanical ventilation and preoperative inotro-
pic support, and emergency surgery no longer appear as
risk factors for mortality in the most recent case series. Venous
obstruction, especially if diffuse and associated with the infradiaphragmatic forms, remains as a risk factor for mortality. In a previous study carried out at our in-
stitution, analyzing all types of total anomalous pulmonary
venous drainage, Binotto et al identified age, poor general
condition, and preoperative infection as important risk fac-
tors 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 anom-
alous pulmonary venous drainage and the recognition of the
importance of alleviating all venous obstructions. The pre-
cise surgical technique has been crucial for improving surgi-
cal 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-
Anomalous pulmonary venous drainage. Surgical therapy

References

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