

Surgical Strategy for Transposition of the Great Arteries with Intact Ventricular Septum After the Neonatal Period

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Objective

To assess the surgical results in patients with transposition of the great arteries and intact ventricular septum undergoing surgery after the neonatal period.

Methods

From January 1998 to March 2004, 121 children with transposition of the great arteries with intact ventricular septum were treated, 29 (24%) of whom after the neonatal period. Selection for surgical treatment was based on echocardiographic assessment by use of the calculation of left ventricular mass and configuration of the ventricular septum. Of the 29 children, 12 were selected for primary anatomic correction, 12 for 2-stage correction after surgical preparation of the left ventricle, and 5 underwent atrial correction.

Results

In the group undergoing primary anatomic correction, one (8.3%) patient died at the hospital due to sepsis. In the group undergoing 2-stage correction, 5 patients underwent slow preparation with correction 3-6 months after the first stage, 4 of whom died after the first stage. This fact caused a change in our protocol, with adoption of the rapid preparation technique in the other 7 patients, of whom all achieved the second stage. Of the 8 children undergoing the second stage, one died at the hospital and another died later. Late clinical evolution of the children in both groups is excellent.

Conclusion

The echocardiographic selection allowed a safe choice of the best surgical approach for patients with transposition of the great arteries and intact ventricular septum after the neonatal period.

Key words

transposition of the great arteries, intact ventricular septum, anatomic correction, ventricular preparation

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The Jatene's anatomic or surgical correction¹ in the neonatal period is the surgical technique of choice for the treatment of transposition of the great arteries (TGA) with intact ventricular septum (IVS). The operation should be performed until the 15th day of life, and this period may be extended with relative safety until the end of the first month². After that period, the progressive drop in pulmonary vascular resistance reconditions the performance of the left ventricle (LV) to a low-pressure circuit with progressive reduction in its muscle mass³. Surgical correction in such circumstance may precipitate a significant ventricular decompensation in the immediate postoperative period because of the incapacity of the LV to acutely assume systemic circulation. The exact determination of that moment is very important, because, we often approach children referred for correction of transposition of the great arteries after the first month of life. Such patients should be selected through an echocardiographic study for a still possible primary anatomic correction or for another type of correction (atrial or 2-stage anatomic), if the left ventricle is not adequate to assume the systemic function.

In this study, we analyzed our experience in approaching children with transposition of the great arteries and intact ventricular septum after the neonatal period.

Methods

The protocol of primary anatomic correction for transposition of the great arteries with intact ventricular septum was systematically implanted in our service from January 1998 onwards. Two years later, we initiated the process of 2-stage anatomic correction after ventricular preparation, accepted by the committee on ethics of the Biocor Institute in March 1999. From January 1998 to March 2004, 121 children with transposition of the great arteries and intact ventricular septum were treated. Of the 121 children, 92 (76%) were assessed still in their first month of life, and all of them underwent Jatene's primary correction. The other 29 (24%) children were referred to our service after their first month of life due to complications in the neonatal period or even a delay in their diagnosis. After clinical and echocardiographic evaluation, they were selected for surgical treatment. Twelve children with a mean age of 45.4 days were referred for primary anatomic correction, and 12 others with a mean age of 3.3 months were referred for 2-stage correction after ventricular preparation. The other five children,

who were treated before the introduction of the 2-stage correction, underwent atrial correction according to the Senning's technique. Our initial strategy in cases of 2-stage correction included slow ventricular preparation, according to Yacoub et al⁴, with late anatomic correction, usually between 2 and 6 months after hospital discharge. This procedure was used in 5 children. Later this technique was replaced by that of rapid preparation recommended by Jonas⁵ with definitive correction performed during the same period of hospitalization, and was used in our other 7 patients. The major demographic data observed in the primary correction group and in the 2-stage correction group are shown in table I. Significant differences were only identified in the mean age at the time of the first surgical procedure and in the mean weight of patients at that occasion. The classification by Yacoub et al⁴ was used for describing the coronary anatomy.

The echocardiographic assessment performed in children admitted during the neonatal period did not influence our management, because in all such cases we recommended systematic primary anatomic correction. However, in the group treated after the neonatal period, the echocardiogram was the major factor determining the surgical treatment. On hospital admission, 2-dimensional echocardiography was performed by a single observer (ATL device, HDI-3500 model), and the following parameters were considered: left ventricular end-diastolic diameter (EDD); LV posterior wall thickness (LVPW); and ventricular septum thickness (VS). Left ventricular myocardial mass was calculated by using the parameters just cited and the formula recommended by the American Society of Echocardiography³, and was later corrected for body surface⁶. The parasternal and subcostal views were used for assessing the configuration of the VS, which was classified into the following 3 types: type I = VS bulging into the RV; type II = straightened VS; and type III = VS bulging into the LV (banana-shape). In addition, we observed the presence of blood flow in the ductus arteriosus and obstructions in the LV outflow tract. A ventricular mass index of 35 g/m² was considered the lower limit for indicating primary anatomic correction, in association with the configuration of the ventricular septum (types I or II). In the 2-stage correction group, the mean left ventricular mass was 31.3+0.926 g/m² (median=31.2), 66.7% of the children had type III septum (banana shape), and the remaining had type II septum. After undergoing the first stage of ventricular preparation,

the patients underwent daily echocardiographic evaluation and the following parameters were reanalyzed: ventricular mass, LV systolic function, configuration of the VS, and determination of the gradient through pulmonary artery (PA) banding. Indication for anatomic correction (second stage) was confirmed after acquisition of a significant ventricular mass and complete straightening of the VS.

The first stage was performed through left posterolateral thoracotomy in the fourth intercostal space. The systemic-pulmonary anastomosis was performed with a 5 mm PTFE prosthesis interposed between the left subclavian artery and the PA, and this anastomosis was performed in the intrapericardial portion of the PA, after sectioning the ligamentum arteriosum and resecting its base. With this technical diversion, we facilitated the approach of the prosthesis on the second surgical time and avoided distortions and adherences close to the left branch of the PA, which requires wide mobilization during the definitive correction. Then PA banding was performed with a PTFE band, the systemic and left ventricular systolic pressures were simultaneously monitored, and a LV systolic pressure/systemic pressure ratio close to 0.7 was established as a parameter. The systematic use of milrinone and epinephrine was established during the peri- and immediate postoperative periods, and transition to oral vasodilator occurred after 48 hours. The postoperative evolution is almost always complicated by low-output syndrome, hypoxemia, and oliguria due to a sudden increase in the afterload imposed to the LV. This lasts approximately 48 hours and requires critical care during that period. After that phase, a progressive improvement in ventricular performance is observed and should be daily followed up with echocardiographic assessment until the parameters required for indication of the second stage are achieved.

The technique of anatomic correction, primary or second stage (Jatene's surgery)⁷, has already been cited. Extracorporeal circulation (ECC) with moderate hypothermia (28° C) was basically used in association with vasodilation with sodium nitroprusside in a regimen of arterial normal flow. Myocardial protection was performed with a single dose of blood cardioplegia. The Lecompte maneuver was used in all patients, and then the neoaorta was reconstructed. Coronary transference was performed after identifying the site of implantation, determined with the aorta distended by the arterial flow. Button reimplantation is usually used, and trap-

Table I - Demographic data of the children selected for primary correction and for 2-stage correction

Primary anatomic correction					2-stage correction				
N	Sex	Age (days)	Weight (kg)	Coron anat*	N	Sex	Age (days)	Weight (kg)	Coron anat*
1	M	60	3.45	IA	1	F	82	5.10	?
2	M	34	3.65	IA	2	F	151	6.35	?
3	M	48	3.70	IIB	3	F	265	7.10	?
4	F	38	3.20	IIC	4	M	97	5.20	?
5	M	40	3.30	IA	5	M	76	5.00	IA
6	F	55	4.10	IA	6	M	84	5.50	IA
7	M	45	3.30	IA	7	M	109	6.40	IA
8	M	61	3.50	IA	8	M	32	3.60	IA
9	M	30	3.00	IIID	9	F	54	4.20	IA
10	M	45	4.35	IIID	10	M	92	4.10	IIID
11	M	58	3.30	IIB	11	M	166	5.40	IA
12	M	32	4.00	IA	12	F	206	7.00	IIB
Mean age=45.5±11.0 days					Mean age=117.8±67.2				
Mean weight=3.6±0.4					Mean weight=5.4±1.1				



door flaps are indicated in the presence of single coronary ostium or of coronary arteries with retropulmonary trajectory. The neopulmonary artery was reconstructed with 2 flaps of autologous pericardium. The secondary closure of the sternum was indicated in situations of ventricular dysfunction or increased bleeding.

The Student *t* test was used to compare the groups in regard to qualitative data. Data were expressed as median or mean \pm standard deviation. The significance level adopted for analysis was 5%.

Results

Of the 12 children undergoing primary anatomic correction, only one died, and in-hospital mortality was 8.3%. That child was 34 days old and had type IA coronary anatomy (Yacoub). The child had significant hemodynamic instability accompanied by total atrioventricular block (TAVB) right after sternotomy, which required the installation of extracorporeal circulation under unfavorable conditions. After correction, the child was kept in the protocol of secondary sternorhaphy and evolved with a significant low-output syndrome, requiring high doses of inotropic agents. After hemodynamic stabilization, sternorhaphy was performed on the third postoperative day (POD), and the cardiovascular evolution was good. However, pulmonary infection occurred, being followed by sepsis and death on the eighth POD.

The mean intensive care unit length of stay (ICULOS) of the other patients was 5.9 days, and a prolonged ICULOS was related to pulmonary problems or the need for pharmacological adjustments, such as the transition from intravenous amines to oral vasodilating drugs. One patient required reoperation for hemostasia revision. Another patient required secondary sternorhaphy, with re-approximation on the second POD. After hospital discharge, all 11 survivors had an uneventful evolution, being in excellent clinical conditions.

Of the 5 patients undergoing slow preparation, 4 died after the first stage, before completing the definitive correction. One of those deaths occurred during the in-hospital phase and 3 after discharge. Those deaths occurred during the initial phase. The first patient who died was evolving well, but had a sudden clinical worsening and severe hypoxemia on the first POD. The patient underwent hemodynamic study that showed migration of the PA band and obstruction of the right branch of the PA. Reoperation was performed under critical conditions, and the child died during reoperation. Of the 3 deaths occurring after hospital discharge, 2 occurred suddenly in the second and third postoperative months. The other child was readmitted to the hospital with severe pulmonary infection in the second postoperative month, and died after 48 hours. Of the 7 children undergoing rapid preparation, all completed the protocol, and anatomic correction was performed during the same period of hospitalization. Pulmonary complications were observed in 2 patients, but a good clinical resolution occurred. Another child required reoperation for revising the systemic-pulmonary anastomosis, which had a thrombus close to the subclavian artery.

Left ventricular mass acquisition was approximately 1.6 g/day, and such gain did not exceed 4.6 g/day, with a maximum peak of myocardial hypertrophy occurring around the second POD and prolonging until the end of the first week (tab. II). At that time, mean ventricular mass was 43.7 ± 1.1 gm/m² (median=44.2). The mean LV ejection fraction, which was $63.5\% \pm 10.9\%$ (median=66.5%) in the preoperative period, had a significant

drop in the first 2 days after preparation, decreased to $37.0\% \pm 6.3\%$ (median=39.2%), and gradually returned to normal values at the end of one week. The mean maximum LV/PT gradient observed throughout the first week was 55.7 ± 5.1 mmHg. The configuration of the VS already showed changes on the first POD, and, after the fifth day, 72.7% of the cases showed type II VS. At the end of one week, 81.8% had type I VS, and 18.2% had type II VS, always accompanied by a significant gain in ventricular mass (fig. 1). Briefly, ventricular preparation caused significant hemodynamic and structural alterations in the LV, which was adequate to anatomic correction around the tenth POD.

The interval between the first and second stages in the only patient who achieved anatomic correction in the slow preparation group was 104 days. In the 7 patients undergoing anatomic correction during the same period of hospitalization, the interval between the 2 stages ranged from 14 to 36 days (mean=21.3 days). The longest 36-day interval occurred in a child who had undergone tracheostomy before the first stage, and only underwent the second stage after resolution of the tracheostomy. Four patients, even with an adequate LV preparation already demonstrated on echocardiography, required an extension of the interval between the procedures for resolving other clinical problems, most of them of pulmonary origin. In regard to in-hospital mortality, of the 8 patients reaching the second stage, one (12.5%), who belonged to the rapid preparation group, died. This child had a classic

Table II - Daily evolution of ventricular mass gain after the first stage

1	day 1	day 2	day 3	day 4	day 5	day 6	day 7	day 8
2	2.9 g	4.6 g	4.2 g	4.1 g	3.9 g	4.0 g	3.9 g	1.3 g
3	3.0 g	4.5 g	4.0 g	3.9 g	4.0 g	4.0 g	4.1 g	1.2 g
4	4.1 g	4.4 g	4.0 g	3.7 g	3.8 g	3.9 g	4.0 g	0.9 g
5	4.0 g	4.5 g	4.2 g	4.0 g	4.1 g	4.1 g	3.9 g	0.8 g
6	3.9 g	4.4 g	4.1 g	3.9 g	3.8 g	3.9 g	3.7 g	0.5 g
7	4.0 g	4.5 g	4.0 g	4.0 g	3.7 g	3.8 g	3.7 g	0.7 g
8	3.8 g	4.6 g	3.9 g	3.8 g	4.0 g	3.7 g	3.8 g	0.5 g
9	3.9 g	4.4 g	4.1 g	3.9 g	3.9 g	3.7 g	3.6 g	0.5 g
10	3.9 g	4.3 g	4.0 g	3.8 g	3.9 g	4.0 g	3.9 g	1.3 g
11	4.0 g	4.5 g	4.2 g	4.1 g	3.7 g	4.0 g	4.1 g	1.2 g
12	3.7 g	4.5 g	4.4 g	4.2 g	4.3 g	3.9 g	4.0 g	0.9 g

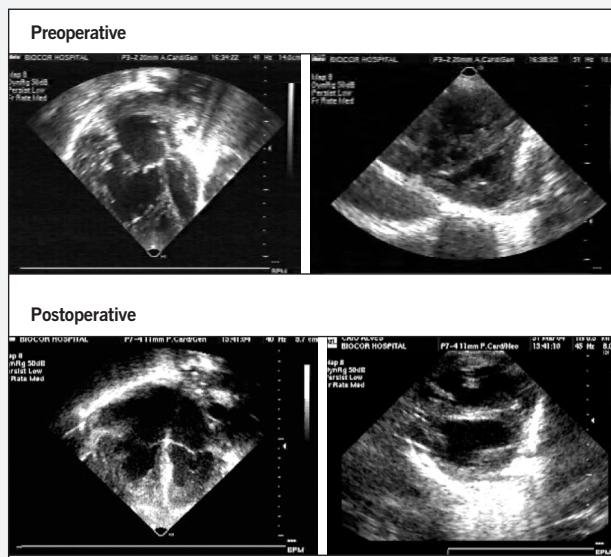


Fig. 1 - Echocardiographic evolution after the first stage (ventricular preparation).

pattern coronary anatomy (type IA of Yacoub), the interval between the 2 procedures was 18 days, and the surgery was uneventful. However, at the ICU, the child had TAVB and acute ventricular failure with a significant hemodynamic repercussion, which suggested a coronary problem. Sternal reopening was performed, but the child remained with a significant ventricular dysfunction and died on the second POD. The mean ICU length of stay among the survivors was 4.4 days, and the prolonged ICULOS was also due to pulmonary problems. One patient died after hospital discharge in the second postoperative month, after requiring prolonged antibacterial treatment and experiencing secondary fungal infection. The 6 children who remain under clinical control have no echocardiographic alterations regarding ventricular function, aortic regurgitation, or stenosis of the RV outflow tract. All of them are in excellent clinical conditions.

Figure 2 shows the results of the entire case series.

Discussion

Neonatal correction of transposition of the great arteries with intact ventricular septum according to the Jatene's technique became the main treatment for the condition. That approach was initially proposed by Paul Ebert in 1980 and became a definitive option of treatment after the report by Castaneda et al⁸ in 1984.

The latter was based on the left ventricular capacity of assuming the systemic circulation during that period of life, after which, the LV progressively loses its muscle mass, which makes primary anatomic correction unfeasible. Exactly when the left ventricle loses its capacity to sustain the systemic function cannot be defined, but the following factors may influence it: the drop in pulmonary arteriolar resistance; the presence of blood flow in the ductus arteriosus; the size of the atrial septal defect; and the presence of obstruction in the LV outflow tract. Because a significant number of children are referred for correction of transposition of the great arteries in a late phase, due to both difficulties in the early diagnosis and complications in the neonatal period, the best management for such patients must be determined. This assessment should define whether the primary anatomic correction is still feasible, or whether the 2-stage correction, or even the atrial correction, will be required. The importance of such fact could be confirmed in our study, carried out for more than 6 years, because 24% of the children with transposition of the great arteries and intact ventricular septum were beyond the neonatal period. Other studies have reported percentages ranging from 3.1%⁹ to 7.6%¹⁰, which are much lower than ours.

Echocardiographic selection is the major method for defining the surgical treatment after the neonatal period¹¹. With that examination, in addition to assessing the size of the atrial septal

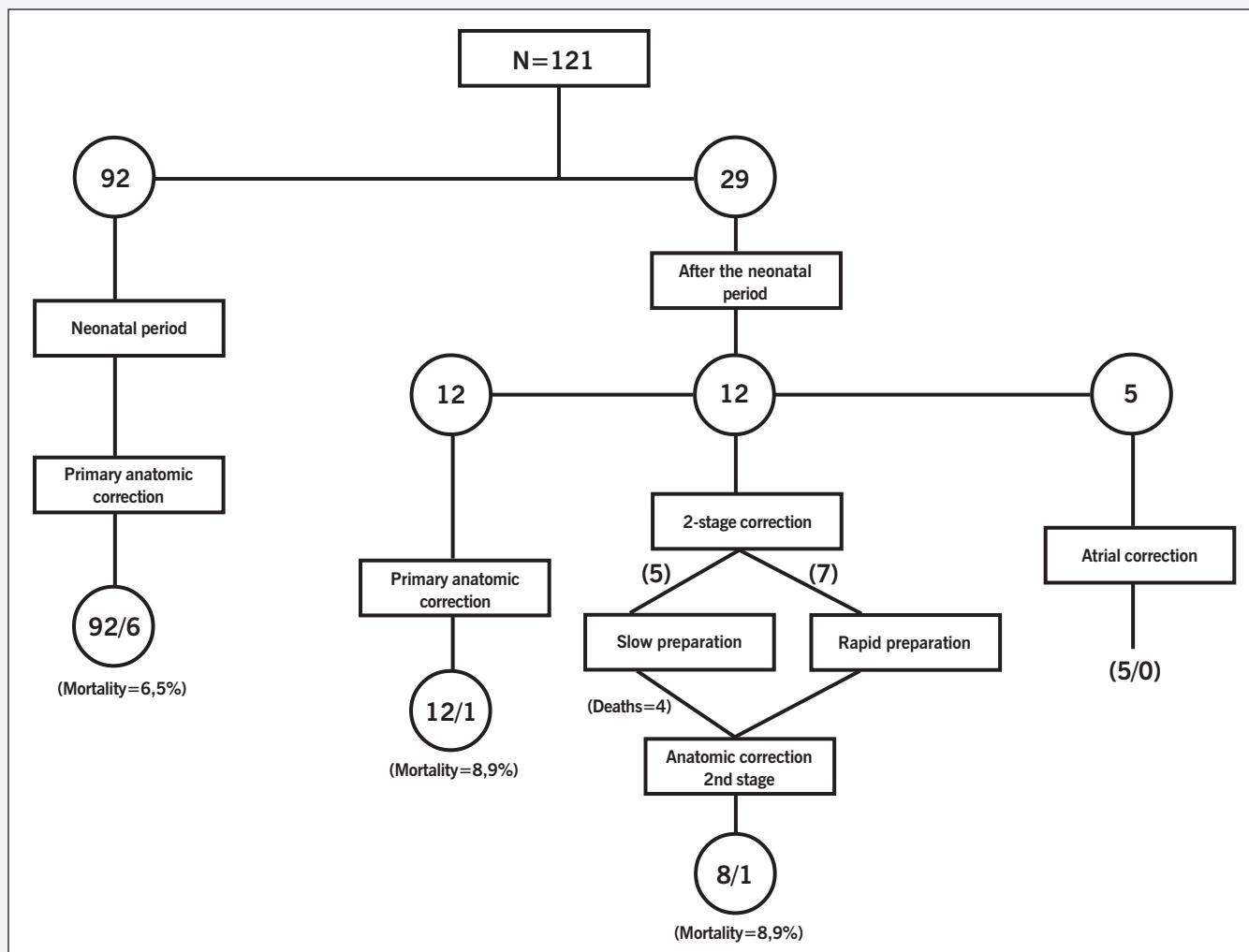


Fig. 2 - Surgical correction of transposition of the great arteries with intact ventricular septum.



defect, the presence and magnitude of the blood flow through the ductus arteriosus, and the obstructions in the LV outflow tract, one may infer the pressure in the left ventricular cavity and its muscular development, which are the major parameters used in our definition. The presence of systolic bulging of the ventricular septum towards the left ventricular cavity (type III or banana-shape septum) indicates a low LV pressure, reflecting the significant pressure gradient between the 2 ventricles. Although that is an important factor in assessing ventricular performance, it has not been used in isolation, because several children within the neonatal period may have a very compressed LV, and may undergo uneventful primary correction.

Determination of ventricular mass was another fundamental point in our preoperative assessment. Despite some limitations related to the method and referring to the LV shape, which may interfere with the final calculation of ventricular mass, that information proved to be effective in practice, not only for surgical indication, but also for ventricular maturation assessment after preparation. A mass of 35 g/m² was used as the lowest limit for indicating anatomical correction, and that parameter should be considered with the configuration of the ventricular septum. The finding of a small muscular mass in association with a type II or III VS in patients beyond the neonatal period is for us an indicator of 2-stage correction. However, in patients with type I or II VS in association with a good ventricular mass index, primary anatomic correction is indicated.

Because we do not know exactly when the LV loses its capacity to assume the systemic circulation, it is difficult to accurately determine the borderline age to perform anatomic correction in cases of transposition of the great arteries with intact ventricular septum. Consensus exists in the literature that primary anatomic correction should be performed until the 15th day of life, and that period may be even safely extended up to the third or fourth week of life, according to most authors^{4,8,10}. However, the approach after the neonatal period is controversial, and only experiences with a small number of patients have been usually reported. Lacourt-Gayet et al¹² and Iyer et al¹¹ have proposed clinical and echocardiographic selection for one- or 2-stage corrections in such cases. Davis et al¹⁰ and Dukan et al¹³ have recommended primary anatomic correction in all patients until the second month of life, based on an aggressive vasodilating therapy and the occasional use of ventricular support in the postoperative period. Our management for patients with transposition of the great arteries with intact ventricular septum was to indicate systematic primary anatomic correction in all patients in the neonatal period and to promote the echocardiographic selection for one- or 2-stage correction in patients treated after the 30th day of life. Therefore, 104 primary anatomic corrections were performed, 92 in the neonatal period, with an in-hospital mortality rate of 6.5%, and 12 after the neonatal period, with a mortality rate of 8.3%; the result has no statistical significance ($P=0.59$). Of the 12 patients undergoing primary anatomic correction beyond the neonatal period, 11 were in the age group between 30 and 60 days of life, and only one was older than 60 days. Therefore, our experience confirms that primary anatomic correction may be performed in most children until the second month of life, with a mortality rate similar to that observed in the neonatal period. Only one patient in that age group, who had unfavorable echocardiographic parameters,

was referred for 2-stage correction, our option in that circumstance, because we do not have devices for prolonged ventricular support, which may be required for postoperative control.

The indication for 2-stage correction or for atrial correction prevailed in the group of children referred after the 60th day of life, and only one out of 16 children treated during that period underwent primary correction. For 2-stage correction, our initial protocol predicted a late anatomic correction, in which the interval between the 2 stages ranged from 2 to 6 months. Our result with this management was not satisfactory; one patient died in the immediate postoperative period due to technical problems (migration of the PA band), and 3 others died after hospital discharge, 2 of whom suddenly and the third patient due to pulmonary infection. In 1980, Yacoub et al⁴ reported the cases of 20 patients undergoing late staging, with an immediate mortality of 3 patients; later, 14 patients underwent the second stage, with 4 deaths (29%). The major advantage of slow preparation can be related to better conditioning of the LV, which provides better results in the long run, a fact that still requires further observation. On the other hand, the long interval between the stages may be the source of problems related to the presence of PA banding, such as distortions in the pulmonary trunk and branches, and a greater incidence of late aortic insufficiency^{8,9}. Another complication reported in the slow preparation was the development of ventricular fibroelastosis, a cause of mortality after the second stage¹⁴. In addition to those factors, the difficulty in the appropriate control of some patients after hospital discharge also favors the early correction in rapid preparation. Change to the rapid preparation strategy with the 2 stages being performed in the same hospitalization period significantly improved our results, and the 7 patients treated in such way achieved the second stage. Daily echocardiographic evolution allowed us to accompany the alterations induced by ventricular preparation, safely establishing the ideal point of maturation for definitive correction. The data found in our sample coincide with those of other publications that define the ideal period for the second stage as between the ninth and fifteenth days after preparation. Evidence exists that patients above the age of one year may require a more prolonged interval of preparation to achieve adequate ventricular preparation^{11,15}. In our sample, the oldest patient was 225 days old and underwent the second stage on the 19th POD with excellent echocardiographic parameters. We have followed the recommendation of Ilbawi et al¹⁶, avoiding a very tight pulmonary artery band, which may induce subendocardial ischemia. This detail significantly facilitates manipulation in the postoperative period without negative influence on LV preparation. The possibility of performing adjustable PA banding has been investigated, and may have good applicability, mainly in patients approached later¹⁷.

Although most studies have reported a good clinical evolution in children undergoing correction after rapid LV preparation, it cannot be stated if the quality of the myocardium generated is similar to that of the native. Because after some weeks of life the myocyte loses its mitotic capacity and LV adaptation after preparation results exclusively from hypertrophy without the corresponding coronary proliferation, this fact can limit the long-term result¹⁵. Nevertheless, it seems clear that ventricular preparation, when performed earlier, is more effective in left ventricular remodeling. In children older than 6 months of age, the results obtained with

rapid preparation have not been as consistent as those performed earlier. Few patients older than one year will be approached, and, for them, the best procedure has not yet been defined. Slow preparation with adjustable PA banding should be the most indicated technique in such situation.

In conclusion, our experience shows the importance of establishing a safe surgical approach for children with transposition of the great arteries and intact ventricular septum treated after the neonatal period. Assessment of the ventricular septum and calculation of the LV mass by use of echocardiography is the major method for selecting surgical treatment. In that significant group

of patients, which in our sample corresponded to 24% of the entire group of transposition of the great arteries with intact ventricular septum treated for a period longer than 6 years, primary correction could be performed in the great majority of the patients, when treated until the 60th day of life. From that age onwards, most patients have unfavorable echocardiographic parameters for primary anatomic correction. In such circumstance, the patients should be referred for either atrial or 2-stage anatomic correction. In the 2-stage correction, the rapid preparation technique provided better results when compared with those of slow preparation, and is our current option for such patients.

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