

Original Article

Surgical management of congenital cardiac defects in neonates and young infants born with extremely low weight

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Abstract Surgical treatment of cardiac defects in infants born with extremely low weight is sometimes required during the neonatal period. Optimal timing of these operations has yet to be clarified. With this in mind, we reviewed our experience of surgical treatment for 29 infants born with extremely low weight between 1994 and 2001. The main surgical procedures were ligation of a patent arterial duct in 26, a Brock procedure in 2, and ligation of an aorto-pulmonary window in 1 infant. The age at operation ranged from 5 to 57 days, with a median of 30 days, and weighed from 506 to 902 g, with a median of 710 g. There were no deaths. For the 2 infants undergoing the Brock procedure, the reduced systemic blood flow also necessitated closure of the arterial duct. For almost all the 26 infants with a patent arterial duct, indomethacin was given as the initial therapy, but the duct had not closed completely. Increased symptomatology just before the operation due to reduced systemic blood flow, such as decreased cerebral blood flow, decreased urine output, and intestinal ischemia, mandated the earlier surgical ligation ($r = -0.576$, $p = 0.004$). The youngest infant needed an infusion of catecholamines perioperatively to maintain stable hemodynamic conditions ($r = 0.554$, $p = 0.003$). In 4 infants, including the youngest 2, steroids were administered intravenously just after the ligation. Our results suggest that reduced systemic blood flow is the main indication of surgical repair in infants born with extremely low weight. Even for one in whom the supply of pulmonary blood is dependent on the arterial duct, early reconstruction of the pulmonary arterial pathways, using the Brock procedure, followed by ligation of the duct, is required. Acute adrenal insufficiency should not be overlooked just after the surgery, particularly in the youngest patients.

Keywords: Prematurity; patent arterial duct; adrenal insufficiency

ALTHOUGH SOME HAVE RECOMMENDED EARLY total corrective surgical repair of congenital cardiac defects even in patients born with low weight,^{1,2} surgical repair for infants born with extremely low weight, less than 1000 g, may be limited to closed procedures that avoid cardiopulmonary bypass, such as ligation of a patent arterial duct, repair of coarctation, and the Brock procedure. In these patients, the outcome is not so good. The increased

incidence of morbidity³ before surgical ligation of the duct has called into question the timing of the surgical treatment, particularly whether the surgical ligation should or should not be performed as initial therapy, prior to a trial of medical treatment with indomethacin.

We had chosen medical treatment with indomethacin as our first choice for attempted closure of the arterial duct in patients born with low weight. In this paper, we have focussed on the timing of closed heart surgery, in particular, ligation of the arterial duct after medical treatment, and have identified the physiological reaction before and after surgery in a series of infants born with extremely low weight.

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Patients and methods

Patients

We reviewed retrospectively the charts of all infants born with extremely low weight undergoing surgical treatment between 1994 and 2001 during the neonatal and early infantile period for improvement of the hemodynamic conditions. We discovered 39 infants in whom closed procedures had been performed, including ligation of a patent arterial duct in 36, the Brock procedure in 2, and ligation of an aorto-pulmonary window in 1 infant. Of 36 infants who underwent surgical ligation of the duct, 10 had been transferred to our medical center for surgical ligation, and were excluded from our study because they had been managed initially in the referring hospitals, and we did not determine the timing of the ligation. The median age at operation was 45 days, with a range from 14 to 77 days, and in our opinion, in several of these cases, the operative procedure was unduly delayed.

Over the period of study, 449 infants had been delivered in our medical center with extremely low weights. No infants died because of patency of the arterial duct. The duct closed spontaneously in 295 (66%) of these infants. Our first option for attempted closure of the patent arterial duct is medical closure using an infusion of indomethacin. Using this approach, the duct closed after the infusion in 128 (29%) infants. The remaining 26 infants who required surgical ligation, along with another 3 infants who underwent Brock procedure or ligation of an aorto-pulmonary window, formed the object of our study.

Management of the patent arterial duct

When significant left-to-right shunting was detected through a patent arterial duct by ultrasonic echocardiography, medical treatment was started, initially by restriction of fluids. Indomethacin was administered intravenously at 12-hour intervals in three doses of 0.2 mg/kg. One to four sets of three doses of indomethacin were given before proceeding to surgical ligation of the duct. Of the 26 patients who underwent surgical ligation of the duct, 2 required emergency ligation without the trial of indomethacin because they had renal insufficiency, which was deemed to be a contraindication to treatment with indomethacin. Mechanical ventilation was started in all patients within 10 min of birth, except in 2, who were intubated within 30 min of birth. Catecholamines were given continuously if the systolic blood pressure was below 35 mm of mercury, and were continued in 7 patients until ligation of the duct. Injections of steroids to close the duct,⁴ or to treat combined respiratory distress syndrome,⁵ were needed in 13 patients.

Surgical management

Ligation of the duct was performed in the operating room through a left posterolateral thoracotomy, using a hemoclip in 23 or a silk tie in the other three. A chest tube was not required following the operation. The median age at operation was 31 days, with a range from 7 to 57 days, and the patients weighed 743 g, with a range from 506 to 902 g. The weight at birth had ranged from 500 to 1000 g, with a median of 800 g, and the gestational age ranged from 23 to 37 weeks, with a median of 34 weeks. The diameter of the duct as judged by preoperative ultrasound ranged from 0.9 to 3.5 mm, with a median of 2.05 mm. The outer diameter measured at the repair ranged from 3 to 7 mm, with a median of 4 mm. Indomethacin had had no effect on the duct in 3 infants.

In one infant, an aorto-pulmonary window was ligated as an emergency, using a hemoclip placed through a left posterolateral thoracotomy on the 5th day of life.⁶ The window was located between the ascending aorta and the pulmonary trunk just above the sinus of Valsalva. The weight at repair was 678 g. Severely reduced cerebral blood flow had been revealed by echography, and there was renal insufficiency. She weighed 758 g at birth, and had been born following a gestation of 30 weeks and 5 days.

In two neonates, we performed a Brock procedure. The first patient had critical pulmonary stenosis, having been born weighing 878 g. The second patient was born with pulmonary atresia with intact ventricular septum, weighing 752 g. In the first patient, anterior cerebral blood flow decreased subsequent to her 6th day of life, despite continuous infusion of prostaglandin E1. We performed a Brock procedure on her 10th day. We used a special dilator (Geister Medizintechnik GmbH, Tuttlingen, Germany) inserted through the midportion of the anterior wall of the right ventricle. The dilator consists of a round shaft surmounted by a triangular pyramid. In the second patient, reversed abdominal aortic blood flow had been detected on the third day of life despite continuing infusion of prostaglandin E1. Peritoneal drainage was performed on her 8th day because of intestinal perforation. The Brock procedure was performed on the 11th day. After perforating the pulmonary valve with the dilator, a Hegar dilator of larger size was passed through the valvar orifice.

Analysis of data

Perioperative variables analyzed for correlation with the age at operation for the infants undergoing ligation of the patent arterial duct included gestational age at birth, weight at operation, diameter of the duct as judged by preoperative ultrasound, preoperative symptoms due to reduced systemic output,

and perioperative requirement for steroids. Linear regression analysis, or the Spearman rank-order analysis, were used to test for correlation.

Results

Early results

The duct was ligated without any death, and all the infants were discharged well. The postoperative course of the neonate with an aorto-pulmonary window was similarly uneventful, without any distortion of either the aorta or the pulmonary trunk subsequent to clipping.⁶

After the Brock procedure performed on the 10th day in our first patient, it was possible to discontinue the infusion of prostaglandin E1. The diameter of her arterial duct had been measured at 2.0 mm using ultrasound. On the 14th day, reversed diastolic blood flow was detected in the anterior cerebral, renal, and mesenteric arteries, and systolic supply through these arteries was thought to be decreasing. Mefenamic acid given on the 16th day, and indomethacin infusions on the 25th and 43rd days, induced spontaneous closure of the duct. In the second patient, having performed the Brock procedure on the 11th day, an infusion of indomethacin had no effect on her arterial duct, the diameter of the duct being measured at 3.3 mm using ultrasound. To maintain systemic flow, we ligated the duct on the 13th day. Both patients discharged well, without any complications, after the treatment needed to close the duct.

Timing of surgical ligation of the arterial duct

No correlation existed between the age at the repair and gestational age at birth, weight at the operation, and diameter of the duct as measured using preoperative ultrasound.

The symptoms noted prior to the surgical ligation are summarized in Table 1. The major indications for surgical ligation reflected the reduced systemic blood supply, which was detected as decreased cerebral blood flow with Doppler examination, decreased urine output, and intestinal ischemia. It was the greater number of symptoms noted just before the surgery that precipitated the earlier operation ($r = -0.576$, $p = 0.004$, Fig. 1). Of our 26 patients, only 3 showed pulmonary bleeding as a symptom of increased pulmonary blood flow. In 8 infants, the duct was ligated in the absence of any preoperative symptoms (Fig. 1). These patients were well controlled by means of restricted fluid infusion, ventilatory support, and indomethacin therapy. Their duct, however, did not close completely. The restricted infusion of fluids prevented circulatory insufficiency,

Table 1. Preoperative symptoms.

Symptom	Number
Reduced cerebral blood flow	18 (69%)
Reversed flow in diastole	10 (38%)
Interrupted flow in diastole	8 (31%)
Reduced urine output	11 (42%)
Intestinal ischemia	4 (15%)
Intestinal perforation	1 (4%)
Pulmonary bleeding	3 (12%)

Decreased urine output was defined as almost anuria and was mainly due to a side effect of indomethacin infusion. Intestinal ischemia was detected with poor bowel movement and interrupted mesenteric blood flow

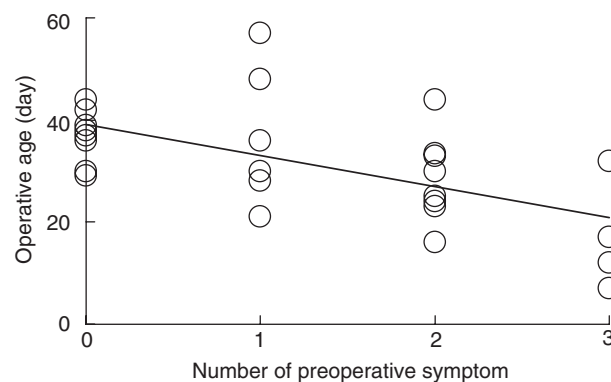


Figure 1.

The correlation between the number of preoperative symptoms and the age at operation in days ($r = -0.576$, $p = 0.004$).

but further restriction was contraindicated because of the nutritional requirements of the infants, and hence we ligated the duct surgically.

Even in the patient with an aorto-pulmonary window, and the 2 infants who needed a Brock procedure, the closure of the window or the arterial duct was indicated because of symptoms due to reduced systemic blood supply.

Perioperative management

Infusions of catecholamines were required both pre- and post-operatively in 7 infants, but postoperatively in only 5 of the 26 patients with a patent arterial duct. The youngest patient at the time of repair needed an infusion of catecholamines to maintain the stability of the hemodynamic conditions ($r = 0.554$, $p = 0.003$, Fig. 2). Furthermore, in 4 of 12 patients needing infusions of catecholamines, injections of steroids were also required to maintain systolic blood pressure a few hours after the operation. Of these, 2 were the youngest among the 26 patients requiring ligation of a patent arterial duct (Fig. 2).

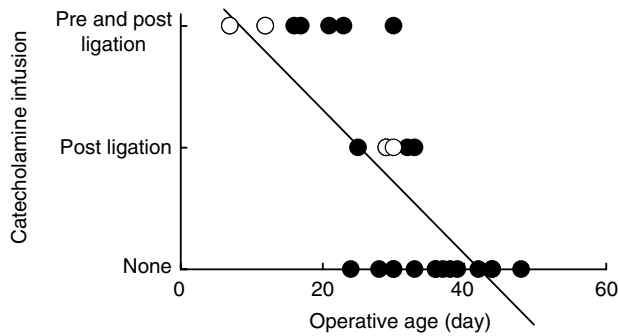


Figure 2.

The youngest patients at the time of repair needed infusions of catecholamines to keep stable the hemodynamic conditions ($r = 0.554$, $p = 0.003$). Of 12 patients who needed an infusion of catecholamines, 4 also required injections of steroids (○) a few hours after the ligation of the patent duct.

Discussion

Although the optimal treatment of a patent arterial duct in infants born extremely low weight has yet to be decided, several investigators have recently recommended surgical ligation as the initial therapy.^{1,7-10} These reports commented on the increased complications, such as necrotizing enterocolitis, after treatment with indomethacin,³ and emphasized the safety of surgical therapy, with low morbidity and mortality. Cassady et al.¹¹ reported that early prophylactic ligation of the arterial duct in infants less than 1000 g produced a decreased incidence of necrotizing enterocolitis. The superiority of surgical ligation as the preferred initial therapy compared to indomethacin, however, has not been confirmed. Robie et al.,⁸ who preferred surgical ligation as the initial therapy, pointed out that a trial of indomethacin therapy was not associated with increased complications. Ligation was recommended mainly because the risk would increase should surgical therapy be delayed, or in anticipation of an improvement in respiratory outcome.^{7,12} On the other hand, Trus et al.,¹⁰ who also recommended surgical ligation as the initial therapy, denied that early surgical ligation decreased the incidence of pulmonary complications associated with prolonged mechanical ventilation. We chose treatment with indomethacin as our first option knowing that we retained the option of surgical ligation because of our careful follow-up. Our result validated this approach, with a low incidence of complications. In particular, intestinal perforation, which was regarded as an increased complication of indomethacin therapy,³ was encountered in only 1 patient. He recovered from the colitis soon after the surgical ligation of the duct. The most important feature in those born at extremely low weight is not to delay surgical ligation, thus avoiding any increase in morbidity, as reported by Grosfeld et al.³

The factor determining the timing of the surgical ligation was the evidence for low systemic flow of blood. Several symptoms, such as oliguria, reduced bowel movement, and necrotizing enterocolitis, are known to be important as factors indicating low systemic flow of blood. Shortland et al.¹³ reported reduced flow of blood in the middle cerebral artery in premature patients with a patent arterial duct. Other data, such as the diameter of the arterial duct, and the ratio between the left atrium and the aorta on echocardiography,¹⁰ were not available as indications for surgical ligation subsequent to the commencement of indomethacin, because this treatment usually initiated closure of the duct. More studies are needed to clarify the efficacy of these echocardiographic data as predictors of the requirement for surgical therapy, particularly in those born with extremely low weight whose arterial duct closed spontaneously or after initial treatment with indomethacin.

For the infants born with extremely low weight who needed a Brock procedure, low systemic flow of blood was again the main factor indicating the need for surgical ligation of the arterial duct. In cases with sufficient flow of blood through the pulmonary valve after the Brock procedure, ligation of the duct is needed early after the operation. The Brock procedure itself should also be undertaken early, prior to development of any decrease in systemic blood flow, because the flow of blood to the lungs needs to be established before closure of the duct.

In some infants who needed earlier ligation of the arterial duct because of severe symptoms due to low systemic blood flow, perioperative infusions of catecholamines, and postoperative injections of steroids, were needed to maintain stable the hemodynamic conditions. As Scott et al.¹⁴ suggested, the infants who need catecholamines early after birth almost certainly have inadequate adrenal function. Although we did not measure levels of cortisol, the infants to whom we gave steroids were all considered to be in danger of acute adrenal failure. In this respect, Watterberg et al.¹⁵ pointed to the lower levels of cortisol in the first week of life. They showed that early adrenal insufficiency induced pulmonary inflammation in those born with very low weight and a patent arterial duct, concentrations of cortisol decreasing during the course of the first week of life. It is also known that glucocorticoids can affect the patency of the duct.^{9,16} Although suppression of adrenal function as a rebound phenomenon of preoperative steroid therapy has been considered one cause of the need for steroids after the ligation, the reduced perinatal levels of cortisol may be another cause. Adrenal insufficiency in the initial days of life may play some role in the patency of the arterial duct in these infants born with extremely low weight.

In summary, therefore, our retrospective review has indicated that surgical ligation of the arterial duct is required in some infants born with extremely low weight subsequent to a trial of medical treatment with indomethacin when the systemic flow of blood is thought to be decreasing. Should the Brock procedure be needed for such infants with pulmonary atresia with intact ventricular septum or critical pulmonary stenosis, both the Brock procedure itself, and the subsequent closure of the arterial duct, should be performed earlier before there is any decrease in systemic blood flow. In a few infants, acute adrenal insufficiency necessitates infusion of steroids after ligation of the duct, mainly in those with extremely decreased systemic blood flow. Such adrenal insufficiency may play some role in the patency of the arterial duct in these infants with extremely low weight.

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