

Successful Ligation of the Patent Ductus Arteriosus in a 1,710-gram Premature Baby with RDS, and the Review of the Literature

by

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Abbreviation used

PDA : patent ductus arteriosus

(I) RDS : (idiopathic) respiratory distress syndrome

BPD : bronchopulmonary dysplasia

FiO₂ : fraction of oxygen in the inspired gas

CHF : congestive heart failure

Although very infrequently, patent ductus arteriosus in premature babies may cause congestive heart failure, which requires a surgical intervention when it does not respond to the vigorous medical treatment. IRDS (idiopathic respiratory distress syndrome) or RDS (respiratory distress syndrome) accompanying such cases makes the postoperative care quite different from that in older children. In the premature babies the weaning from the respirator would be quite difficult if the adequate timing of extubation is missed. Sporadic reports on the surgical repair of PDA in premature babies have appeared, however, in Japan there have been very few reports on the ligation of PDA in a premature baby at the time of the body weight of less than 2,500 grams. The purpose of this paper is to report a case of successful ligation of PDA in a 1,710-gram. 53-day-old baby complicated by mild RDS and intractable heart failure.

case report. M. K.

The mother did not suffer from rubella during the pregnancy of the baby. The baby girl, the third child, was born at the gestational age of 29 weeks and 6 days with premature rupture of the amniotic membrane. The body weight at the birth was 1,200 grams. There were severe asphyxia and cyanosis at the birth (APGAR score 5), and the baby showed respiratory retraction of the supraclavicular notch, intercostal spaces, and infraxiphoidal portion (SILVERMAN's retraction score 2 out of 10). There was also noted tachypnea of 50-65/min. Moderate Jaundice appeared on the second day and total bilirubin gradually increased to 16 mg/dl on the fifth day for which phototherapy was performed with good result. The blood sugar level was within normal limits (45 mg/dl) on the third day of life, and on the same day episode of apnea lasting 5-10 seconds appeared. On the 12th day transystolic murmur (LEVINE 3 out of 6 grade) with the maximum intensity in the 3rd-4th intercostal spaces at the left sternal border was first noted, raising the suspicion of PDA. The return of the body weight to the level at the birth took 16 days. Blood transfusion was performed on Oct. 10th for moderate anemia. On Oct. 16th (38th day) the fine moist rales were first heard at the right upper lung field associated with slight dyspnea. Chest roentgenogram showed moderate cardiomegaly (cardiothoracic ratio 0.66) and increased pulmonary vascularity (Fig. 1). Electrocardiogram showed biventricular hypertrophy (Fig. 8). The liver was 2 cm palpable at the costal margin, and the femoral pulse was bounding. On Oct. 17th (39th day) the baby suddenly developed apnea lasting for 5 minutes at the time

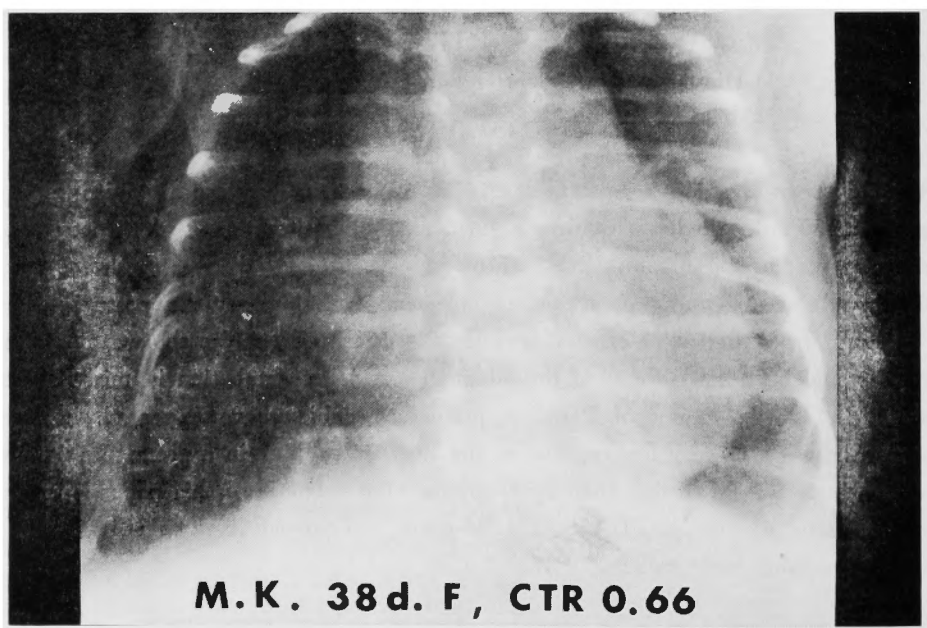


Fig. 1. Preoperative chest roentgenogram, showing cardiomegaly and pulmonary hypervascularity

of tube feeding, which was associated with bradycardia (heart rate decreasing from 140-170/min. to 40-50/min.), fine moist rales, grunting, and increased transsystolic murmur (LEVINE 4 out of 6 grade) with thrill. It was recognized as congestive heart failure, and Digoxin[®]* 0.04 mg/day and Lasix[®]** 0.5 mg/day were started. The blood gas analysis at that time was pO₂ 63 mm. Hg, pCO₂ 48 mm. Hg, and pH 7.295 on room air. Tube feeding was stopped and intravenous administration of the fluid was started. For the subsequent several days the dyspnea improved but the frequent episodes of apnea persisted in the absence of the improvement of the general condition. On Oct. 25th (47th day) there occurred frequent episodes of bradycardia and cyanosis lasting for 15 minutes each time. Blood gas analysis showed lowered pO₂ (56 mm. Hg on room air, saturation 87.4%), and high pCO₂ (65 mm. Hg). Cardiac catheterization was scheduled to rule out a combined ventricular septal defect in terms of the surgical intervention. On Oct. 31, 1974 (53rd day, body weight 1,710 grams) cardiac catheterization was performed under the general anesthesia of GOF using an orotracheal tube (Fig. 2). At the beginning of the procedure the baby

Cardiac Catheterization
Oct. 31, 1974 (at age of 53 days)

	Pressures	O ₂ (vol.%)
IVC	5	
RA	6	
RVi		7.03
mPA	74/35	49
rPA	43/25	33
Ao (desc.)	84/39	53
		7.83

(under GOF anesthesia)

Fig. 2. Preoperative cardiac catheterization

suddenly developed bradycardia of 60/min. which was relieved by the external cardiac massage of 15 minutes. The catheter inserted via the femoral vein passed through the patent ductus arteriosus quite easily. Sufficient blood sampling was almost impossible due to the small size of the catheter (French size No. 4 Cournand catheter) ; blood samples were obtained only from the right ventricle and the aorta. Small amount of the blood transfusion was done due to the low hematocrit of 14-18 %.

Injection of the contrast material was performed in the right ventricle and the pulmonary artery (biplane serial films) which revealed reflux of the contrast material into the aorta probably due to the injection technique, and the increased pulmonary vascularity indicating the high flow through the lungs. Association of a ventricular septal defect could not be ruled out fully. Emergency ligation of the ductus was indicated. The baby was moved to the operating room immediately after the catheterization study with the endotracheal tube in place.

operation and postoperative courses

Anesthesia was conducted with GO and F. The chest was opened by the left posterolateral thoracotomy in the 4th intercostal space. Just before the pleura was opened, bradycardia occurred which was found to be due to the malventilation of the left lung. It was relieved by the reintubation and the cardiac massage of 13 minutes. The lungs were

* Digoxin, Chusai Pharmaceutical Co. Ltd., Japan

** Furosemide, Hoechst Pharmaceutical Co. Ltd., Japan

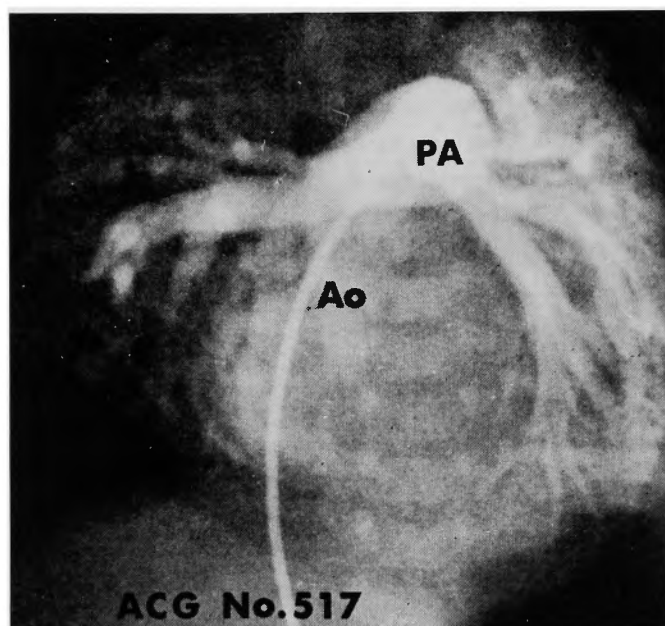


Fig. 3. Preoperative pulmonary arteriography, showing reflux of the contrast material into the aorta, and marked pulmonary vascularity

M. K. 53 Days, F.



2 LIS



Fig. 4. Preoperative phonocardiogram, showing the transsystolic murmur

beefy-red and very stiff, showing marked reduction in compliance. The ductus was in the usual position and measured 7 mm. in the outer diameter and 8 mm. in the length; the size of the ductus was as large as that of the descending aorta. The ductus was triple ligated using two thick silk sutures (1-0 braided silk) at each end and one 4-0 Tevdeck transfixing suture in center. The thrill disappeared completely and the existence of a ventricular septal defect was ruled out. The rectal temperature was monitored continuously throughout the procedure and it was kept above 37°C by an electric heat lamp and a warm blanket. Twenty-five ml. of whole blood was transfused during the procedure for the low hematocrit of 23%. The duration of the operation was 70 minutes including the interrupted period due to the cardiac massage. Immediately after the baby was returned to the Premature Baby Unit, the endotracheal tube was removed for the trial. However, due to the bradycardia and bradypnea it was reintubated and was connected to a volume-controlled ventilator (BOURNS respirator*). Blood gas analysis showed pO_2 55 mm. Hg, pCO_2 63 mm. Hg, and pH 7.34 on FiO_2 0.6. Intravenous fluid was given at the rate of 5 ml/hr. Frequent suctioning was necessary for the massive bronchial secretion which caused apnea and bradycardia on each occasion. On the evening pO_2 was 42 mm. Hg on FiO_2 of 0.6. Next morning around nine o'clock blood gases showed pO_2 65 mm. Hg, pCO_2 51.5 mm. Hg and pH 7.44 with saturation of 92.6% on FiO_2 0.7. One hour later the tube was blocked with the secretion and the tube was changed. Chest roentgenogram showed slight pneumomediastinum (Fig. 5). At 2 o'clock in the afternoon (22 hours postoperatively) the

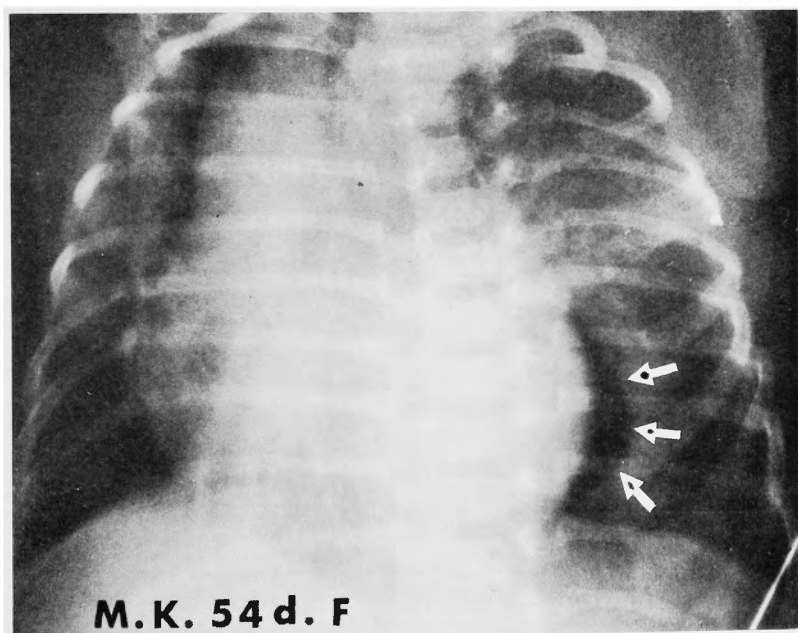


Fig. 5. Chest roentgenogram on the first postoperative day, showing slight pneumomediastinum

* BOURNS Life System, RIVERSIDE CALIFORNIA, U.S.A.

orotracheal tube was removed in the presence of the complete set-up for the emergency intubation. The baby was watched very intensely in the 95% humid 42% O₂ cuvette for the next hours. Although the respiratory rate was 50-65/min. with some retraction immediately after the extubation, the respiration became markedly unlabored with much improvement in the respiratory retraction of the intercostal spaces and suprasternal notch after one hour. On that evening several transient episodes of bradycardia associated with apnea appeared which responded well to the cutaneous stimulation, as in the usual cases of the premature babies whose episodes of apnea responded well to the cutaneous stimulation such as the tickling of the babies' foot. On Nov. 2nd (2nd postoperative day) tube feeding was started, but for the following several days moderate distention of the bowel was noted, and on Nov. 3rd apnea lasting 30 seconds occurred immediately after the tube feeding which was regarded to be of a neurogenic origin characteristic of a premature baby. For the subsequent ten hours there were seven such episodes which required cardiac massage and mechanical ventilation with the infant circle. However, those episodes subsided gradually with the control of the volume of the tube feeding. The baby required blood

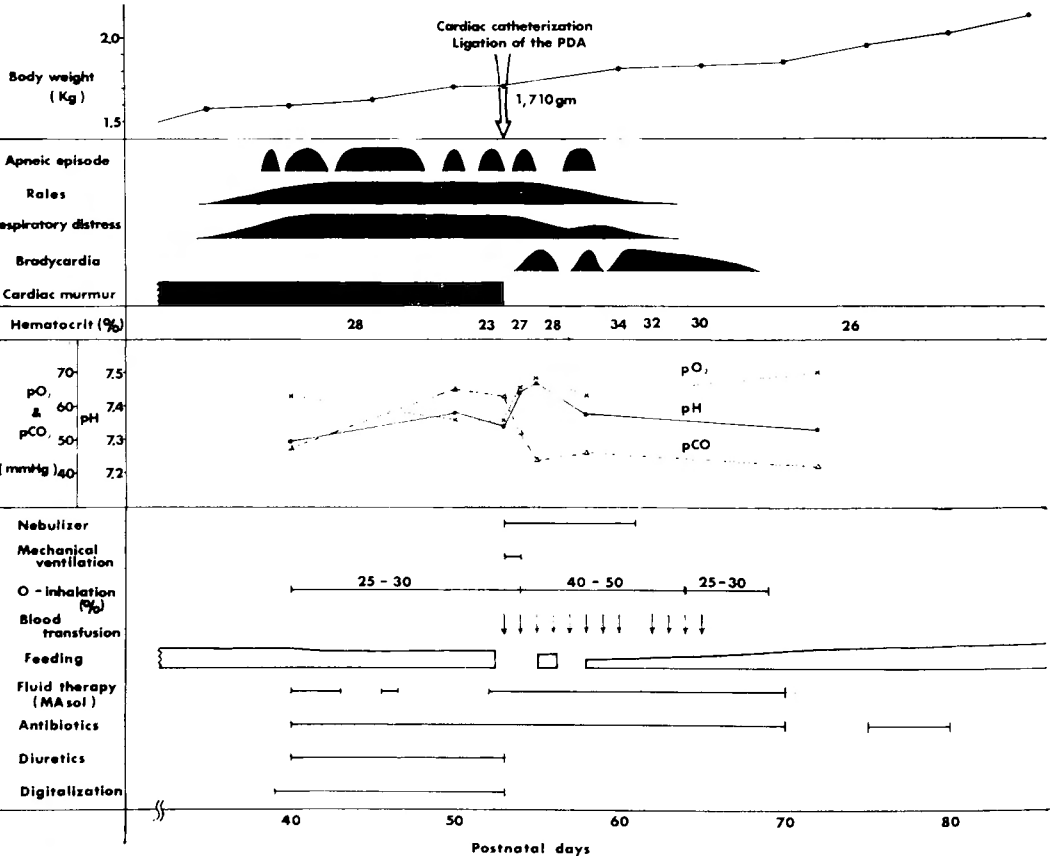


Fig. 6. Pre-and postoperative courses

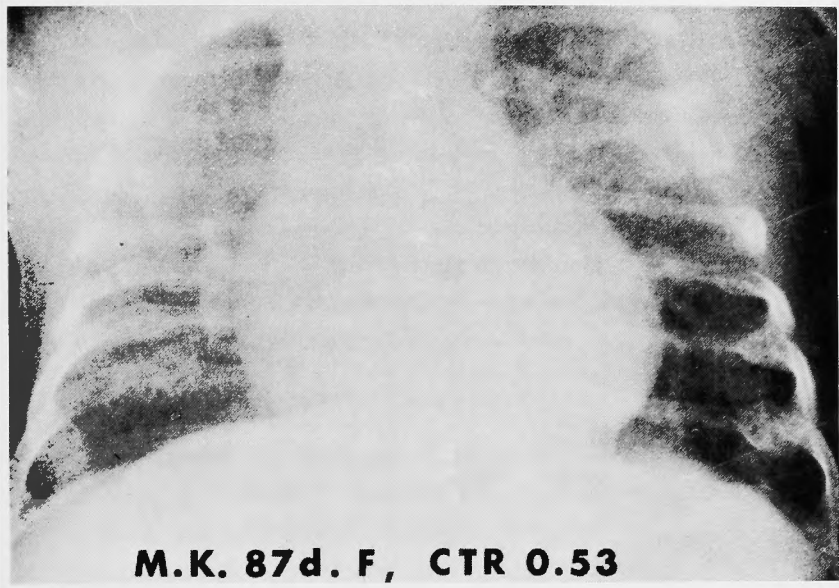


Fig. 7. Postoperative chest roentgenogram, showing marked reduction in CTR.

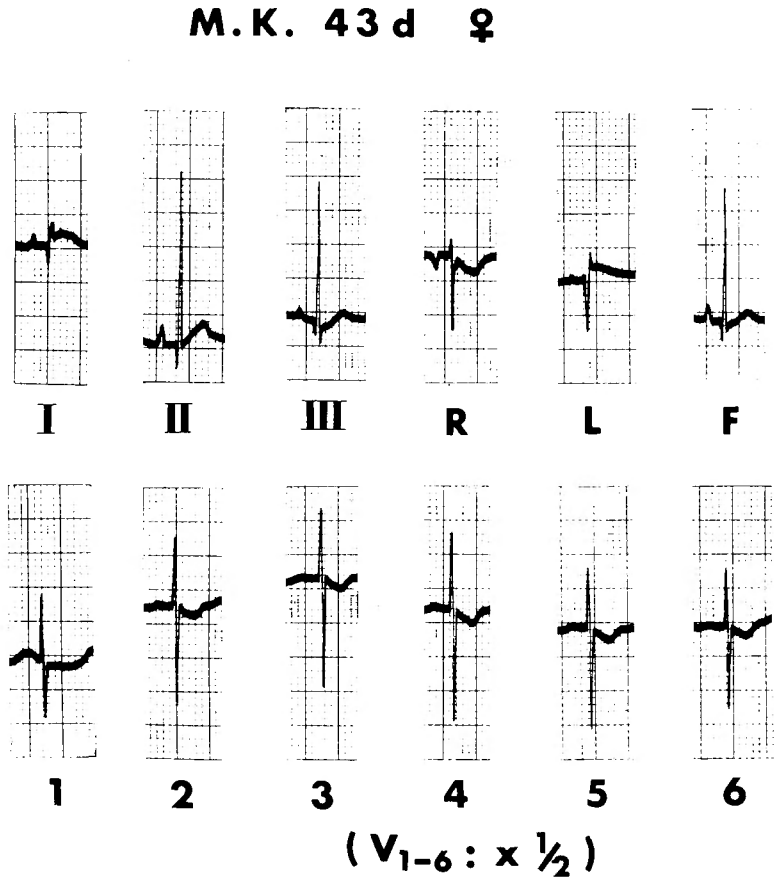


Fig. 8. Preoperative electrocardiogram, showing biventricular hypertrophy.

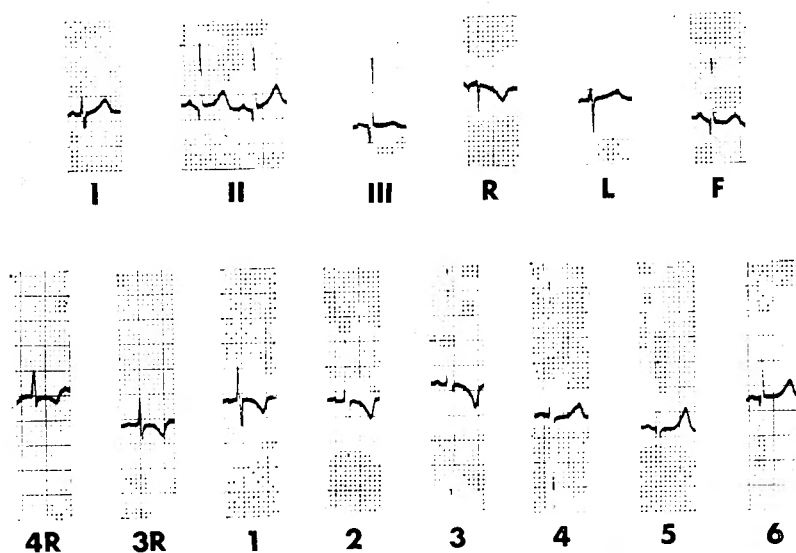
M.K. 100 d, postop PDA

Fig. 9. Postoperative electrocardiogram

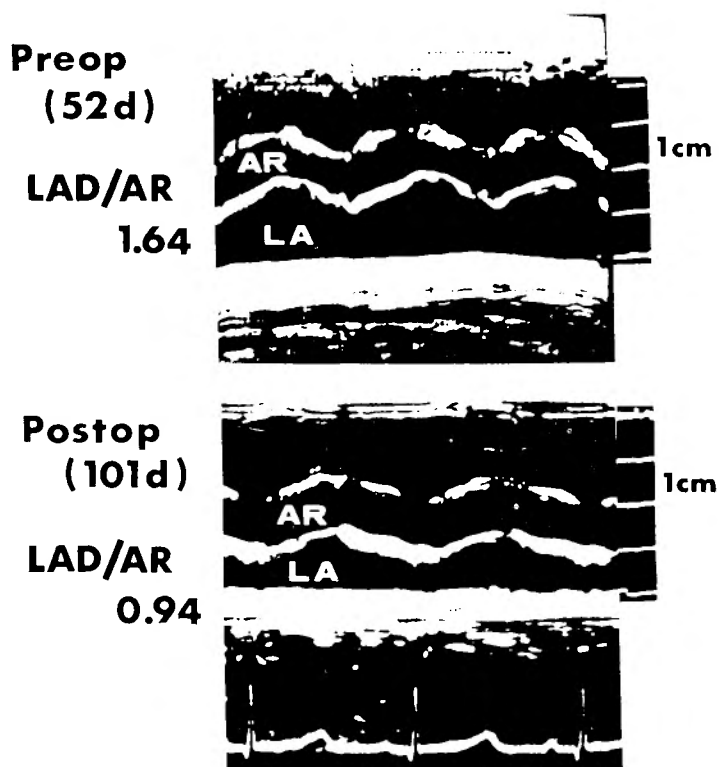


Fig. 10. Echocardiogram, showing marked reduction in the left atrial size postoperatively

transfusion on several occasions to combat the persisting anemia. On Nov. 27th the oral feeding was started. Digitalis was stopped on the 52nd postoperative day. The lungs sounded clear throughout the postoperative period. On the 53rd postoperative day (102nd day of life) the baby was discharged in a good condition. Postoperative course was illustrated in Fig. 6. Chest roentgenogram on 87th day of life (34th postoperative day) showed marked reduction in cardiothoracic ratio from the preoperative 0.66 to 0.53. The baby is now enjoying full activity weighing 10 kgms 22 months after the surgery. Slight retinophthia of the prematurity (OWENS 1st stage) appeared transiently on the 32nd day of life, which subsided spontaneously within 2 weeks without sequelae.

Literature review

POWELL (1963)¹¹ reported the incidence of PDA in premature baby is not different from that in the full-term infants (10 cases of PDA in premature infants in a total of 106 instances of the lesion, the incidence being 9.5%), however, many investigators say that delayed closure of PDA is more commonly seen in the premature babies, the incidence ranging from 7 to 36% (BURNARD, 1959²¹; RUDOLPH, 1961⁸); DECANQ, 1963³); DANILOWICZ, 1966⁴¹; AULD, 1966⁵); SIASSI, 1969⁶); GIRLING, 1971⁷); HOLLIDIE-SMITH, 1972, 7 %, 52 out of 700; BLANCO, 1973⁴²), 36 out of 100; and CLARKSON, 1974²²), 18 out of 100). BURNARD (1959)²¹ noted that the ductus murmur had disappeared by 10 hours of age in most full-term infants but that the murmur persisted in 10% premature infants beyond the second day of life. KITTERMAN et al. (1972)³¹) said that the incidence of PDA among 111 infants weighing less than 1,750 grams at birth was 15.3%. MURPHY et al. (1974)³⁸) reported small number of incidence, 1.07% out of 5,298 babies. BLANCO (1973)⁴²) showed that the incidence increased with the degree of prematurity (the incidences of PDA were 77%, 44% and 23% in babies with gestational ages of 28-30, 31-33 and 34-36 weeks respectively). However, GIRLING and HALLIDIE-SMITH (1971)⁷) showed no correlation between the incidence of PDA and gestational age in 38 premature infants. The increased incidence of PDA in the respiratory distress syndrome, which mainly occurs in the premature infants, has also been documented by several investigators (RUDOLPH, 1961⁸); DANILOWICZ, 1966⁴¹); JEGIER, 1968³⁴); SIASSI, 1969⁶); GIRLING, 1971⁷); KITTERMAN, 1972³¹); GUPTA, 1972³³); and NEAL, 1975²⁶)) BLANCO et al. (1973)⁴²) showed that a clinical diagnosis of RDS was made in 81% of babies with PDA and in only 26% of babies without PDA. In the series of Neal et al. the incidence of 19% (76 PDA out of 396 RDS patients).

mechanism of delayed closure. It is said that the closure of the ductus arteriosus occurs not rapidly but rather gradually (PATTEN, 1931). In 1900 GERALD⁵⁵) suggested that the ductus arteriosus closed in two steps: physiologic and anatomic. The functional closure occurs 10 to 15 hours of age (MOSS, 1963)¹⁶), while the anatomical closure of the ductus may be delayed 1 week to 2 months (JAGER, 1942¹⁸); ELDRIDGE, 1955¹⁹); BURNARD, 1959²¹); MITCHELL, 1957¹⁷); AULD, 1966⁵); DANILOWICZ 1966⁴¹); GIRLING, 1971⁷); KROVETZ, 1972²³); HALLIDIE-SMITH, 1972²¹); and CLARKSON, 1974²²). The functional closure of the ductus is believed to

be the result of the muscular constriction of the ductus precipitated by the first breathing at the birth (KENNEDY, 1942⁹⁾; DAWES, 1955¹³⁾; BORN, 1956¹²⁾; WILSON, 1958¹⁴⁾; and HÖRNBLAD, 1970⁶⁷⁾). DAWES et al.¹³⁾ showed that in the newborn lamb contraction of the ductus began as saturation of the arterial blood with oxygen rose above 60%. KENNEDY (1942)⁹⁾ and BORN (1956)¹²⁾ showed using guinea pigs and lambs respectively that an increase in oxygenation of the systemic blood was accompanied by visible constriction of the ductus arteriosus. Moss et al. (1964)⁶³⁾ demonstrated in 15 normal unanesthetized full-term infants that the left-to-right shunts through the PDA disappeared with administration of 100% oxygen and recurred with 13% oxygen. Similar observations were made by ROWE et al. (1964), GILLMAN et al. (1966), BOR et al. (1970) and KNIGHT et al. (1973)⁶⁸⁾. In the premature babies with or without IRDS delayed closure of the ductus by several weeks or months is often observed due to the following possible reasons; 1) hypoxia (ELDRIDGE, 1955¹⁹⁾; and BURNARD, 1958²¹⁾). LUND found (quoted by POWELL¹⁾) that interference with respiration in the newborn caused a functionally closed ductus to open. HULTGREN (1955, quoted by POWELL¹⁾) showed that breathing low oxygen mixture may reopen the ductus in infants aged under three days, and JOHNSON (quoted by POWELL¹⁾) demonstrated with angiography patency and closure after an incident of atelectasis. It was also noticed by BURNARD et al. (1958)¹⁹⁾ that 71% (15 out of 21) of the asphyxiated babies developed the ductus murmur, as compared with 13% (3 out of 23) when there was no asphyxia, 2) prematurity of the muscular structure of the ductus (DANILOWICZ, 1966⁴⁾), 3) decreased sensitivity of the musculature to the rise in pO_2 (McMURPHY, 1971⁵⁰⁾; and McMURPHY, 1972⁵¹⁾); and 4) reduction in cholinergic innervation of the ductus (ARONSON, 1970⁴³⁾). However, the biggest factor is by all means hypoxia. In the study of the auscultation of the 100 mature babies murmur attributable to the flow through the ductus arteriosus was heard in 37 babies and the majority of them had mild asphyxia (BURNARD, 1958¹⁹⁾). Many investigators observed that most PDA actually closed, although delayed, in the presence of IRDS in the premature babies. In many cases the ductus arteriosus did not close spontaneously until the premature infants reached its full gestational age (POWELL, 1963¹⁾; AULD, 1966⁵⁾; and DANILOWICZ, 1966³⁾). In the animal studies it has been clearly demonstrated that the ductus closed in the presence of high oxygen environment, and some observed the same effect on the clinical cases (POWELL, 1963¹⁾; and DUNN, 1973²⁴⁾). CLARKSON et al. (1974)²²⁾ found a high incidence of ductal murmurs in the small number of infants delivered by cesarean section and suggested the possibility that the physiologic processes involved in the onset and maintenance of normal labor and delivery also played a part in setting the stage for normal ductal closure after birth. Although it is said that the ductus stays open permanently if it does not close by the end of 2 months (MARK and YOUNG, 1963²⁰⁾), HALLEDIE-SMITH (1972)²¹⁾ showed that in premature infants the delayed closure may occur up to 6 months of age, and CLARKSON et al. (1974)²²⁾ described the disappearance of the murmur by 3 to 29 weeks in 15 babies. The relationship between PDA and RDS is not clear since both increase with decreasing gestational age (CORAN, 1975³⁵⁾). IRDS was considered to be present by CLARKSON et al. (1974)²²⁾ when

there was the clinical picture of grunting respiration with sternal or rib recession present during the first three hours of life and persisting beyond six hours, along with typical radiologic findings.

murmur. PDA is usually suspected clinically by the existence of the cardiomegaly, heart murmur, and bounding femoral arterial pulsation (widened pulse pressure). The heart murmur was more commonly systolic or transsystolic (DECANCQ, 1963³¹; GUPTA, 1972³³; HORSLEY, 1973³²; GAY, 1973²⁹; KITTERMAN, 1972³¹, 29 out of 29 (100%); ZACHMAN, 1974³⁰; MURPHY, 1974³²; CORAN, 1975³⁵, 25 out of 30 (84%); and NEAL, 1975²⁶, 48 out of 76 (63%)). Although continuous murmur was heard in all 11 cases of the series of RITTENHOUSE et al. (1976)²⁷ and in all 18 cases of the series of CLARKSON et al. (1974)²², which was very diagnostic in their series, it was rather exceptional in other series (HORSLEY, 1973³², 9 out of 13 (70%); CORAN, 1975³⁵, 5 out of 30 (17%); and NEAL, 1975²⁶, 28 out of 76 (37%)). The murmur is changing rapidly with the state of the pulmonary vascular resistance, and also the necessity of disconnection of the endotracheal tube to hear murmur caused the occasional misevaluation of the murmur (KITTERMAN, 1972³¹; and CORAN, 1975³⁵). The continuous murmur appeared in relationship to congestive heart failure (GUPTA, 1972³³; and ZACHMAN, 1974³⁰). NEAL et al. (1975)²⁶ stated that 14 of 28 patients (50%) with a continuous murmur developed congestive heart failure, whereas only one of the 48 (2%) with only a systolic murmur developed heart failure. THIBEAULT et al. (1975)²⁷ stated that the murmur was not audible in most of their cases (22 out of 27 (75%)), frequently in the presence of massive cardiomegaly and failure, while patency of the ductus arteriosus was demonstrated by the aortogram performed at a mean age of 39 hours. Only five out of 27 infants (18%) had ductal murmur prior to aortography. It was assumed that the PDA was so large that the turbulent flow did not occur (THIBEAULT, 1975²⁷; and NELSON, 1976³⁶). In other series the murmur usually occurred at 7th day of age (ZACHMAN, 1974³⁰), 7th day (DECANCQ, 1963³¹), 5 to 6 days of age (KILMAN, 1974⁴⁰), 3 to 6 days (HORSLEY, 1973³²), birth to 35 days (av. 10.8 days) (MURPHY, 1974³⁸), 3 to 13 (mean 5.7) days (EDMUNDS, 1973³⁹), and during the first two weeks (CLARKSON, 1974)²². KITTERMAN et al. (1972)³¹ stated that the age at onset of the murmur may also be helpful in predicting the subsequent course of infants. The PDA murmur was first heard on the average at 4.7 days (range, three to seven days) among the six infants who underwent operative closure, but the murmur was not heard until an average of 13.3 days (range, two to 28 days) among the 14 who had spontaneous closure, and in only three of these infants was it heard at the age of seven days or before. Typically the murmur appeared as the lung disease seemed to be improving (NEAL, 1975²⁶). The quality of the murmur was described by GAY (1973)²⁹ as a rough, "bag of rocks" one.

congestive heart failure. In certain cases of large left-to-right shunt congestive heart failure occurs. WAGENVOORT et al. (1961)¹¹ showed that the decreased medial thickness of the muscular pulmonary arteries in the premature babies which would cause the large left-to-right shunt through the ductus due to the low pulmonary vascular resistance in the first few days of life. RUDOLPH et al. (1961)⁸, showed by the cardiac catheterization studies that

infants with severe RDS had low pulmonary arterial pressures and evidence of a widely patent ductus arteriosus with a large left-to-right shunt, whereas Moss et al. (1965)⁶⁴⁾ showed in 77 normal premature and 18 infants with IRDS that the mean pulmonary arterial pressure was elevated with severe RDS contrary to the previous several observations. The medial smooth muscle is acquired during the latter part of gestation (RUDOLPH, 1970⁴⁸⁾). A diastolic murmur, bounding pulses, hepatomegaly, apnea and bradycardia were the most frequently associated findings in patients with cardiac failure. Peripheral edema or pulmonary rales were less reliable indications of failure in these patients (ZACHMAN, 1974³⁰⁾). THIBEAULT et al. (1975)²⁷⁾ stated that if massive cardiomegaly and pulmonary edema were seen on chest x-ray, the diagnosis of heart failure was made. He also stated that the lack of clear objective criteria for the diagnosis of persistent heart failure has made the indications for the surgical ligation of PDA uncertain. The incidence of congestive heart failure was 23% (12 out of 52) by HALLIDIE-SMITH (1972)²¹⁾, 1 out of 18 by Clarkson et al. (1974)²²⁾ two-thirds of the patients in the series of ZACHMAN et al. (1974)³⁰⁾ and 20 per cent (15 out of 76) in the series of NEAL et al. (1975)²⁶⁾. In patients without failure, in the series of ZACHMAN et al.³⁰⁾, only 25 per cent had severe RDS, but over half of the failure group had severe RDS and 44 per cent required respiratory therapy. Congestive heart failure was not recognized prior to 10 days of age in any patient in the series of NEAL et al.²⁶⁾. The interval between the onset of the murmur and onset of the failure ranged from less than 1 day to 21 days (NEAL 1975)²⁶⁾.

cardiac catheterization. In the mature babies, the cardiac catheterization is mandatory for the preoperative hemodynamic evaluation especially for the detection of the associated cardiac anomalies. However, in premature babies, the cardiac catheterization itself becomes hazardous and the procedure is often not recommended (AULD, 1966⁵⁾; GUPTA, 1972³³⁾; BLANCO, 1973⁴²⁾; GAY, 1973²⁹⁾; ZACHMAN, 1974³⁰⁾; MURPHY, 1974³⁸⁾; KILMAN, 1974⁴⁰⁾; NEAL, 1975²⁶⁾; CORAN, 1975³⁵⁾; and THIBEAULT, 1975²⁷⁾). HORSLEY et al. (1973)³²⁾ performed cardiac catheterization in all but one infants (out of 13 infants) in the light of the surgical intervention, his criteria for the catheterization being the patients above the age of 7 days, with pCO₂ greater than 60 mm. Hg and with cardiac murmur following the failure of the medical management of 3 days' duration. Significant complication occurred in 9 of these 13 patients (70%). KITTERMAN et al. (1972)³¹⁾ performed cineangiogram in all 16 infants and noted complication in 2 patients. RITTENHOUSE et al. (1976)²⁵⁾ did the catheterization in 6 infants without complications and he stated that the information was useful in confirming the diagnosis and quantitating the degree of the shunt but was not essential for the decision to operate. Even though the cardiac catheterization would be indicated in all cases in the light of the hemodynamic assessment in this rather new field of cardiac disorder (RUDOLPH, 1961)⁸⁾, the study itself has some limitation to prevent accurate evaluation of the data. EDMUNDS et al. (1972)⁴¹⁾ and GAY et al. (1973)²⁹⁾ stated that because of difficulties or mere impossibilities in obtaining well mixed blood samples, calculation of the shunts were unreliable. Measurement of pressures and oxygen saturation were not routinely

performed in the series of HORSLEY et al.³²⁾. In avoiding the considerable risk of the cardiac catheterization, none of the 84 infants who underwent ductus ligation in the groups of GAY et al. (1973)²⁹⁾ and ZACHMAN et al. (1974)³⁰⁾ was subjected to catheterization. Association of the other cardiac anomalies was rare; only one of the above 84 infants was subsequently shown to have an associated anomaly, in ZACHMAN's series only 2 (small VSD) out of 44 infants, and in GAY's series only one out of 45 (coarctation and hypoplasia of the aorta). The identification of the PDA and assessment of the magnitude of the shunt through it have lately been performed by dye-dilution (BLANCO, 1973⁴²⁾; MURPHY, 1974³⁸⁾; and CORAN, 1975³⁵⁾), and aortography (KITTERMAN, 1972³¹⁾; EDMUNDS, 1973³⁹⁾; THIBEAULT, 1975²⁷⁾; ZACHMAN, 1974³⁰⁾; RITTENHOUSE, 1976²⁵⁾; and NELSON, 1976³⁶⁾). KITTERMAN et al.³¹⁾ performed cineangiography, and THIBEAULT et al.²⁷⁾ and NELSON et al.³⁶⁾ described the usefulness of the single-film retrograde aortography by hand injection of the contrast material through the catheter placed in the umbilical artery. THIBEAULT et al.²⁷⁾ showed a good correlation between the magnitude of the left-to-right shunt as estimated by aortography and the size of the heart, and also demonstrated the patent ductus in the absence of the heart murmur. They emphasized the importance of the careful day-to-day clinical assessment using this retrograde aortography in NICU. ZACHMAN et al. (1974)³⁰⁾ stated that the size of the PDA was usually as large as that of the aorta in their series. No doubt the clinical findings alone would be sufficient for the consideration of the treatment (ZACHMAN, 1974³⁰⁾; and AULD, 1966⁵⁾), however, hopefully more hemodynamic data could be obtained in the future from the cardiac catheterization to investigate this special problem of PDA in the premature babies with or without RDS, although detailed preoperative catheterization studies have thus far not been helpful in predicting in advance which patients will be benefited by ligation of the PDA (BESSINGER, 1974⁴⁵⁾). The complications encountered in HORSLEY's series³²⁾ were all due to cannulation of the femoral artery, and they later developed the technique of passing a balloon-tipped flow directed catheter via the femoral vein into the arterial system either through the PDA or through a patent foramen ovale. They thus continued to recommend the preoperative cardiac catheterization. PRINTUP (1976)⁴⁹⁾ found that the presence of a PDA was almost assured if there was a very significant backflow detected with a bidirectional Doppler placed over the femoral artery.

Echocardiography Using echocardiography, SILVERMAN et al. (1974)²⁸⁾ have demonstrated the normal diameter of the left atrium and the aortic root and established the ratio of the left atrium-to-aorta to be 0.86 ± 0.10 . In five premature infants with large PDA the ratio was increased to 1.28 ± 0.23 , and all the babies who required surgical ligation of PDA had this ratio above 1.15. Changes in this ratio appeared to correlate well with the effect of medical and surgical therapy. BAYLEN et al. (1975)⁵⁶⁾ studied the effect of the left-to-right shunting upon left ventricular and atrial dimension by means of 129 serial echocardiographic studies in 37 premature infants with PDA. Left cardiac dimensions were enlarged in infants with significant PDA and were greatest in surgically treated infants

(postoperatively they returned rapidly to normal) in contrast with the persistent enlargement observed in some medically treated infants. MEYER (1976)⁴⁶⁾ stated that the ratio of the left atrium to the aorta in a large left-to-right shunt the ratio was greater than 1.3.

indications for surgery In the majority of the premature babies with PDA with or without RDS, the ductus produced no untoward symptoms and did close spontaneously (MURPHY, 40 out of 57 patients, 1974³⁸⁾; and CLARKSON, 16 out of 17, 1974²²⁾). LEES et al. (1967)⁵⁹⁾ demonstrated that increased pulmonary blood flow without heart failure had only a minor effect on gas exchange, the alveolar-arterial oxygen difference on room air and on 100% oxygen is slightly widened, owing to an increase in intrapulmonary right-to-left shunting. However, in certain cases congestive heart failure developed and required therapy (JEGIER, 1968)³⁴⁾. Most of the babies who developed a murmur of patent ductus arteriosus had spontaneous closure (HALLIDIE-SMITH, 1972²¹⁾), even if congestive heart failure developed (AULD, 1966⁵⁾; DANILOWICZ, 1966¹⁾; and GIRLING, 1971⁷⁾). THIBEAULT et al. (1975)²⁷⁾ agreed that in larger infants (body weight greater than 1,000 grams) with late congestive heart failure the ductus would usually close spontaneously. NEAL et al. (1975)²⁶⁾ stated the same opinion, in that the conservative management of infants with RDS, PDA, and CHF would be preferable to surgical intervention. It has been stated that administration of oxygen to these babies may facilitate closure of the ductus (POWELL, 1963¹¹⁾; and DUNN, 1973²⁴⁾), however, the hazards of pulmonary damage and retrolental fibroplasia were great with that form of therapy (GIRLING, 1971⁷⁾). DUNN et al. (1973)²⁴⁾ treated 3 premature babies with PDA with environmental oxygen therapy with good results. They gave 30% oxygen with no effect, followed by 35% oxygen which caused the disappearance of the signs of cardiac failure, and the disappearance of the murmur after 6, 8 and 10 days of oxygen therapy. The highest PaO_2 was 152 mm. Hg and they stated that the risk of retrolental fibroplasia among more mature infants must be extremely low, especially if the PaO_2 is kept below 150-200 mm. Hg. Introduction of acetylcholine (HEYMANN, 1971⁵⁸⁾) or the mechanical stimulation of the ductus by the tip of the catheter at cardiac catheterization was tried with moderate effect. ZIEGLER (1952)⁶¹⁾, Rudolph (1958)⁶²⁾ and JEGIER et al. (1968)³⁴⁾ have indicated that surgical treatment may be life-saving in infants with persisting congestive heart failure due to a PDA. AULD (1966)⁵⁾, HALLIDIE-SMITH (1972)²¹⁾ and CLARKSON (1974)²²⁾ proposed conservative medical treatment because most of these babies developed spontaneous closure although delayed. Even if no spontaneous closure occurred, most of these babies responded well to the usual medical management without requiring ligation of the PDA (GAY, 1973²⁹⁾; and MURPHY, 1974, in cases without RDS³⁸⁾). However, if the relief of the heart failure could not be obtained medically with or without the assistance of mechanical respiratory support, surgical intervention was indicated by many investigators (DECANCQ, 1963³⁾; DANILOWICZ, 1966⁴⁾; CLEVELAND, 1969⁵²⁾; KITTERMAN, 1972³¹⁾; GUPTA, 1972³³⁾; EDMUNDS, 1973³⁹⁾; ZACHMAN, 1974³⁰⁾; MURPHY, 1974³⁸⁾; THIBEAULT, 1975²⁷⁾; CORAN, 1975³⁵⁾; GAY, 1973²⁹⁾; RITTENHOUSE, 1976²⁵⁾; and NELSON, 1976³⁶⁾). THIBEAULT et al. (1975)²⁷⁾ and RITTENHOUSE et al. (1976)²⁵⁾ pointed out

that the lack of clear-cut objective criteria for the diagnosis of persistent heart failure has made the indications for the surgical ligation of PDA uncertain, sometimes causing unnecessary ductus ligation or needless delay in patients who ultimately required operation. In the series of MURPHY et al. (1974)³⁸⁾ there were 3 sudden deaths before the decision of surgery was made. They stated that if the duct murmur remained and there was no improvement in the status of the infants after 3 to 4 days, surgery should be performed. HORSLEY et al. (1973)³²⁾ stated that when a premature infants with RDS and a large PDA needs continuous ventilatory support, ligation of the PDA should be used in preference, because all the late deaths were related to the need for preoperative ventilatory support. Deterioration of the respiratory function (decreased lung compliance, decreased pO_2 ²⁵⁾³⁸⁾⁴⁶⁾, increased pCO_2 ²⁵⁾³⁸⁾⁴²⁾) in spite of the adequate mechanical ventilation was regarded as definite indication for ligation of the PDA by several investigators (EDMUNDS, 1972⁴¹⁾; GAY, 1973²⁹⁾; MURPHY, 1974³⁸⁾; THIBEAULT, 1975²⁷⁾; RITTENHOUSE, 1976²⁵⁾; and NELSON, 1976³⁶⁾). Hypercarbia was regarded as distinct indication for ligation of the ductus by several people²⁵⁾³⁸⁾⁴⁶⁾. The level of pCO_2 for the indication varied; pCO_2 greater than 60mm. Hg (RITTENHOUSE, 1976²⁵⁾; and MEYER, 1976⁴³⁾, pCO_2 greater than 85mm. Hg (EDMUNDS, 1972⁴¹⁾), etc. In the series of RITTENHOUSE et al. (1976)²⁵⁾ arterial hypoxia was a clear indication, but they said that oxygenation was usually well maintained (pO_2 53 to 62 mm. Hg) with a fraction of inspired oxygen (FiO_2) of 0.40. Although the importance of performing operation early in premature infants with continued respiratory distress was emphasized by several investigators (SIASSI, 1969⁶⁾; GUPTA, 1972³³⁾; GAY, 1973²⁹⁾; KILMAN, 1974⁴⁰⁾; and CORAN, 1975³⁵⁾) in order to avoid chronic pulmonary changes (bronchopulmonary dysplasia, BPD) which was supposed to develop after 150 hours (NORTHWAY, 1967⁴⁷⁾) or 4 days (GAY, 1973²⁹⁾) of mechanical ventilation, the question of whether this earlier surgery may prevent pulmonary damage remains unanswered (RITTENHOUSE, 1976²⁵⁾). NASH et al. (1967)⁶⁵⁾ studied 70 patients (adults) who died after prolonged artificial ventilation that the morphologic changes were unrelated to the duration of the artificial ventilation, per se, but they were correlated with the prolonged use of the ventilator delivering a high concentration of inspired oxygen, and BECKER et al. (1969)⁶⁶⁾ emphasized the importance of the inspired pressures and also stated that intermittent positive pressure respiration may interfere with the natural course of hyaline membrane disease in such a way that the reparative process is accentuated. ROBERTSON (1974)⁶⁹⁾ successfully treated two premature babies with pulmonary edema with prolonged continuous positive airways pressure for 29 and 12.5 days without sequelae. As far as the timing of operation is concerned, early operation was suggested by other people also (JEGIER, 1968³⁴⁾; CLEVELAND, 1969⁵²⁾; KITTERMANN, 1972³¹⁾; ZACHMAN, 1974³⁰⁾; and NELSON, 1976³⁶⁾). Although HORSLEY, BAHNSON (1973)³²⁾ and EDMUNDS (1972)⁴¹⁾ have shown that surgical closure of the ductus will control the congestive heart failure produced in premature infants with RDS, it is important to assess the degree of contribution of PDA to respiratory insufficiency (RITTENHOUSE, 1976²⁵⁾). Infants with small left-to-right shunt associated with RDS cannot be benefited from ligation of the ductus. Babies with large left-to-right shunt shown by aortogram (THIBEAULT, 1975²⁷⁾) or dye-dilution

(more than 50% of the pulmonary blood flow, CORAN, 1975³⁵⁾) were indicated for surgical intervention. RITTENHOUSE et al.²⁵⁾ lost two babies who were operated upon in the first week of life in an attempt to improve their severe respiratory failure. They stated that the heart was not greatly enlarged on chest x-ray films, which underscored the importance of cardiomegaly in predicting the contribution of the patent ductus to respiratory insufficiency.

operation The preoperative preparation of the infants is particularly important in this situation. Infants without an endotracheal tube were intubated prior to operation in the nursery (GAY, 1973²⁹⁾; RITTENHOUSE, 1976²⁵⁾; and NELSON, 1976³⁶⁾), and the blood gases were corrected to as near normal as possible (KILMAN, 1974⁴⁰⁾; and NELSON, 1976³⁶⁾) and acidosis was corrected (HORSLEY, 1973³²⁾). In order to shorten the transit and operative room time every possible effort should be paid. For that purpose MCGROUGH (1976)⁵³⁾ operated in the neonatal ICU: "bringing the operating room to the infants rather than to take the infant to operating room". During the transit and also during operation the careful monitoring of the rectal temperature and its maintenance using overhead radiant lamp, warm blanket, etc. MURPHY et al. (1974)³⁸⁾ warmed the theater before bringing the patient in. Certain special attentions were paid by several people. In ZACHMAN's series³⁰⁾ most patients received a continuous infusion of isoproterenol (5 to 10 μ g per kilogram per hour) during and following the operation to obviate problems with bradycardia. Patient occasionally received atropine to offset bradycardia due to vagal stimulation³⁰⁾. NELSON et al. (1976)³⁶⁾ in their early series attempted to expand the areas of atelectatic lung and found that they had a high incidence of pneumomediastinum and occasionally substernal pneumothorax, and now they are avoiding overzealous attempts to expand the atelectatic lung. They also used infusion pump for fluids administration. Anesthesia was conducted with N₂O-O₂ (KILMAN, 1974⁴⁰⁾; and ZACHMAN, 1974³⁰⁾), Halothane (EDMUNDS, 1973³⁹⁾; and ZACHMAN, 1974³⁰⁾), fluoroxene or ketamine (EDMUNDS, 1973³⁹⁾), morphine plus curare (MURPHY, 1974³⁸⁾), N₂O and curare (CORAN, 1975³⁵⁾), only occasional muscle relaxant (NELSON, 1976³⁶⁾), curare and local anesthesia (MCGROUGH, 1976⁵³⁾), and little or no anesthesia (MEYER, 1976⁴⁶⁾). PDA was approached by several ways; transpleurally or extrapleurally (KILMAN, 1974⁴⁰⁾, and COOLEY, 1973⁴⁴⁾), through anterolateral (HORSLEY, 1973³²⁾), lateral (MURPHY, 1974³⁸⁾; CORAN, 1975³⁵⁾), posterolateral (EDMUNDS, 1973³⁹⁾, KILMAN, 1974⁴⁰⁾, RITTENHOUSE, 1976²⁵⁾; and NELSON, 1976³⁶⁾) or vertical thoracotomy (Murphy, 1974³⁸⁾), in the third (HORSLEY, 1973³²⁾) or fourth intercostal spaces (KILMAN, 1974⁴⁰⁾ and CORAN, 1975³⁵⁾). Almost all ducti were ligated except for a few cases in the RITTENHOUSE's²⁵⁾ and EDMUNDS' series³⁴⁾. HORSLEY et al. (1973)³²⁾ placed a purse string suture of 5-0 silk at each end and a mattress suture between them, KILMAN et al.⁴⁰⁾ did triple ligation with 5-0 Dacron sutures, the center one having a mattress suture, EDMUNDS et al.³⁹⁾ doubly ligated with zero or number one gauge silk, MURPHY et al.³⁸⁾ used single 0-0 silk suture, and Printup used hemoclip at each end of the ductus. Printup⁴⁹⁾ stressed each end of the ductus because one of the infants who died died from a thrombosis of the left pulmonary artery which originated in the cul-de-sac of a single-ligated ductus early in his series. HORSLEY et al. (1973)³²⁾ stated that they were not aware of unusual friability

Table 1. Literature review of premature infants undergoing surgery for closure of patent ductus arteriosus

author	No. of cases	No. of cases ̄ or ̄ RDS	average gest. age (wk.)	birth weight (Gm.) (range)	surgery		deaths	
					average age (day) (range)	average weight (Gm.) (range)	No.	per cent
Powell (1963) ¹⁾	1	̄ RDS	1	26	1,195	150	—	0 0
Decancq (1963) ³⁾	1	̄ RDS	1	32	1,077	54	1,417	0 0
Gupta et al. ³³⁾ (1972)	4	̄ RDS	4	30	1,400	31 (7-58)	1,000 (1,000-1,700)	1 25
Horsley et al. ³²⁾ (1973)	9	̄ RDS	9	29	1,200	29 (14-49)	1,342 (1,000-1,800)	4 44
Gay et al. ²⁹⁾ (1973)	45	̄ RDS ̄ RDS	30 15	— —	1,400 (680-2,500)	15 (5-36) (5-69)	1,300 (650-2,200) (680-2,150)	14 47 1 6.8
Kilman et al. ⁴⁰⁾ (1974)	12	̄ RDS	12	29	—	(14-56)	1,246 (1,025-2,600)	3 25
Edmunds et al. ³⁹⁾ (1973)	21	RDS ̄ RDS	6 15	30	1,181	25 (16-44) (5-35)		0 0 10 66 (48%)
Murphy et al. ³⁸⁾ (1974)	14	̄ RDS ̄ RDS others	2 10 2	30	—	—	1,442	0 0 5 50 0 0
Zachman et al. ³⁰⁾ (1974)	27	̄ IRDS	22	30	1,400	15	(567-2,013)	9 33
Toriyama, Ogawa ⁵⁹⁾ et al. (1974)	2	̄ RDS	2	32	1,590	46 (35-56)	—	1 50
Yokota, Muraoka ^{60,54)} et al (1975)	1	̄ RDS	1	29	1,200	53	1,710	0 0
Baylen et al. ³⁷⁾ (1975)	9	̄ pulm. disease other	8 1	—	—	—	—	0 0 0 0
Neal et al. ²⁶⁾ (1975)	5	̄ RDS	5	—	1,260	50	—	2 40
Coran et al. ³⁵⁾ (1975)	30	Group I* Group II**	21 9	30 30	1,312 1,182	21 28	1,363 1,303	7 33 0 0
Nelson et al. ³⁶⁾ (1976)	32	̄ mild-to-moderate RDS	21	—	—	14.8 (6-33)	—	8 37
		̄ severe RDS	11	—	—	7.5 (2-15)	—	5 45
Rittenhouse et al. ²⁵⁾ (1976)	11	̄ RDS ̄ RDS	4 7	31	1,325	42	1,925	0 0 2 18
" (1976)	13	—	—	—	—	—	—	2 23
Meyer (1976)	16	—	—	—	—	—	—	2 13
McGrough (1976)	15	̄ RDS	15	—	—	—	—	2 13
Koh et al. (1976)	1	̄ RDS	6	12	840	27	840	0 0
Total	269							70 26

(̄ : with, ̄ : without, *, **See the text

previous reports from the same institution were included in the latest reports ; reports from SIASSI⁶⁾ and CLEVELAND⁵²⁾ into CORAN's report³⁵⁾, from JEGIER's³⁴⁾ into MURPHY's³⁸⁾, from KITTERMAN's³¹⁾ into EDMUND's, and from THIBEAULT's²⁷⁾ into NELSON's³⁶⁾)

of the duct, but many observed the friable ducti and stressed the gentle handling (EDMUNDS, 1973³⁹); CORAN, 1975³⁵); NELSON, 1976³⁶); MEYER, 1976⁴⁶); and PRINTUP, 1976⁴⁹). COOLEY⁴⁴) stated that proper illumination and magnification helped greatly, and is using three-powered magnifier routinely. Size of the ductus was generally two-thirds the diameter of the aorta (HORSLEY, 1973³²), as large as the aorta (DECANCQ, 1966³), or equal or larger than the aorta (EDMUNDS, 1973³⁹); and CORAN, 1975³⁵). The chest tube drainage was kept to the minimum; none at all (CORAN, 1975³⁵), removed at the end of the procedure (NELSON, 1976³⁶); and MCGROUGH, 1976⁵³) and five to 24 hours after the operation (KITTERMAN, 1972³¹). Operating time reported was 15-25 min. (KILMAN, 1974⁴⁰), 20-30 min. (MEYER, 1976⁴⁶), average 17 min. (MCGROUGH, 1976⁵³) and 30 min. (RITTENHOUSE, 1976²⁵).

operative results. NELSON et al. (1976)³⁶) stated that in analysing the results one must pay attention to the fact that each group is non-homogenous and be very careful to note what sort of infants was included in the series. Recently RITTENHOUSE et al. (1976)²⁵) reviewed the cases reported in the literature; 168 cases including their own 11 cases. The average gestational age ranged from 26 to 35 weeks. The average birth weight ranged from 1,181 to 1,400 grams in the seven series in which the information was given. The idiopathic respiratory distress syndrome was the most common clinical feature seen in 50 to 100 per cent of patients in the larger series. Surgery was usually performed within 6 weeks of birth and the average weight at the time of surgery ranged 1,000 to 1,925 grams. Fifty-nine of the 168 did for an over-all mortality rate of 35 per cent. The cases reported in the literature were summarized in the Table 1 by the authors. Over-all mortality rate was 26% (70 out of 269 infants). The cases of the deaths in the literature were also reviewed by RITTENHOUSE et al. (1976)²⁵) (Table 2). Nearly two-thirds of the infants died from pulmonary complications. Bronchopulmonary dysplasia with progressive respiratory insufficiency was the most common cause, and intracranial hemorrhage was also a frequent cause of death and occurred in 10 per cent of the reported cases. In the series of ZACHMAN et al. (1974)³⁰) 6 deaths out of 9 postoperative deaths were due to BPD, and there were three deaths which

Table 2. Causes of death among 168 premature infants undergoing surgical closure of PDA

cause	deaths	
	No.	per cent
progressive respiratory insufficiency	38	65
intracranial hemorrhage	6	10
management complications	5	8
miscellaneous	4	7
gastrointestinal complications	3	5
sepsis	3	5
Total	59	

(from Rittenhouse, E. A. et al. J. Thorac. Cariovasc. Surg. 71 : 187, 1976)

were related to the endotracheal tube; 2 due to hypoxia from endotracheal tube displacement and 1 due to atelectasis from mucus plugs. In many series no death occurred during the operative procedure (JEGIER, 1968³⁴); GUPTA, 1972³³); KITTERMAN, 1972³¹); EDMUNDS, 1973³⁹); GAY, 1973²⁹); and ZACHMAN, 1974³⁰). The over-all mortality appeared to be closely related to the degree of reversibility of pulmonary insufficiency (RITTENHOUSE, 1976)²⁵). Reviewing the cases reported in the literature (Table 1) in which the information was given, the mortality rate of the cases with RDS (35.6%, 64 out of 180) was much higher than that for the cases without RDS (3.4%, 1 out of 29). In the series of NELSON et al. (1976)³⁶), the survival rate of the severe RDS group was 55 percent, while that for the mild-to-moderate group was 63 per cent. They also stated that the mean age at operation of the severe RDS group (7.5 days) was significantly different from the mean age at operation of the mild-to-moderate RDS group (14.8 days). In the latter group ligation of PDA was performed as early as 2 days of age with one survival. Out of 12 infants, in the series of THIBEAULT et al. (1975)²⁷), with severe RDS, PDA, and massive cardiomegaly, five survived; whereas none of the five who were medically managed survived. In the mild-to-moderate RDS, eight of 14 surgically treated survived whereas 10 of 13 medically managed survived. CORAN et al. (1975)³⁵) divided their 30 infants (all with RDS) into two groups: Group I with premature infants with RDS requiring assisted ventilation shortly after birth and Group II with those with RDS requiring assisted ventilation because of apnea during the later neonatal period. The operative mortality rate for the Group I was 33 per cent (7 out of 21), and that for the Group II was 0 per cent out of 9. GAY et al. (1973)²⁹) stressed the significance of the preoperative mechanical ventilation and the appearance of the lungs at operation upon the operative results. Among 30 infants who required mechanical ventilation preoperatively in their series, 10 developed severe BPD; nine died. There were 14 infants who did not require mechanical ventilation preoperatively and none of these developed severe BPD. All were alive. They stated that if the lungs were found to be firm, "liver-like", or "cobble-stoned", death always occurred. On the other hand, infants with stiff, poorly ventilated lungs had a good prognosis when lung compliance improved at the moment of PDA ligation. CORAN et al. (1975)³⁵) observed that there was a significant difference in the number of hours of mechanical ventilation with a greater than 60 per cent inspired oxygen concentration prior to operation between the survivors and non-survivors; 57 hours in the survivors and 184 hours in the non-survivors. Effect of the ligation was frequently dramatic; marked decrease in the heart size (RITTENHOUSE, 1976²⁵), easy management of blood gases (KILMAN, 1974)⁴⁰), immediate improvement in pCO₂ (RITTENHOUSE, 1976²⁵), marked improvement of the pulmonary edema and heart size within 48 hours (THIBEAULT, 1975)²⁷), significant reduction in the oxygen requirements (CORAN, 1975³⁸), etc. In the RITTENHOUSE's series²⁵) the cardiothoracic ratio averaging 0.65 (0.57 to 0.71) preoperatively decreased to an average of 0.57 (0.52 to 0.63) approximately six weeks after the surgery. Mechanical ventilatory support was required for varying periods of time postoperatively in 11 of 15 patients (MURPHY, 1974)³⁸), 8 out of 12 cases as long as 16 weeks

(KILMAN, 1974)⁴⁰⁾, and 20 out of 27 for one hour to several days (ZACHMAN, 1974)³⁰⁾. MURPHY et al. (1974)³⁸⁾ stated that weaning from the respirator was often tedious. Postoperative complications were frequently related to the mechanical ventilation. Pneumothorax and pneumomediastinum were the most common complications (NELSON, 1976³⁶⁾; MURPHY, 1974³⁸⁾; and ZACHMAN, 1974³⁰⁾, and NELSON et al. (1976)³⁶⁾ stated that the overzealous attempts to expand the atelectatic lungs were hazardous. The long-term value of PDA ligation in the premature infants with RDS has been questioned (EDMUNDS, 1973).³⁹⁾ In the series of EDMUNDS' et al. six (40%) of 15 infants with RDS and ligation of PDA were discharged from the hospital. One of them died with a respiratory infection in a fibrotic lung, and the others except for one had hydrocephalus with severe retardation, and significant slowing of psychomotor development. There was only one baby who was doing well after ligation. In the GAY's series²⁹⁾ 16 infants with severe RDS (defined as requiring mechanical ventilation) survived the operation, but only three of them were doing well, and 7 of the survivors had mild-to-severe BPD. Whereas, among 15 infants without severe RDS, only one died and ten were doing well. Much improved results were reported by NELSON et al. (1976)³⁶⁾ recently. Six (54%) of 11 patients with severe RDS requiring inspiratory pressure greater than 20 cm H₂O were discharged from the hospital. Five of these survivors were doing normally. Thirteen (62%) of 21 patients with mild-to-moderate RDS were discharged from the hospital, and 11 of these were doing well. They stated that ductal ligation in the premature infants weighing less than 1,500 grams could be safely performed in controlling heart failure due to the large left-to-right shunts and that a significant number (50%) of infants, even with severe RDS, survived and appeared to be doing well, and that the management of infants requiring intubation and respiratory support for BPD remained as unsolved problem. In Japan there are still very few reports on the ligation of PDA in premature infants^{54),56),59),60)}, TORIYAMA, OGAWA et al. (1974)⁵⁹⁾ reported on 3 cases of ligation of PDA with RDS in early infancy; 2 out of them were prematurely born; one survived the operation at the 56th day of life at the body weight of 2.8 kilograms.

Discussion

Among 400 premature babies who were admitted to the premature baby unit of Kyoto University Hospital, 80 patients had heart murmur audible immediately after the birth, and 10 of these were suspected of having patent ductus arteriosus clinically, and only 2 out of these 10 developed congestive heart failure. Namely, the incidence of the clinically diagnosed PDA among the premature babies was 2.5 per cent, and that of the heart failure in the patients with PDA was 20 per cent. The incidence would be smaller, if no-murmur-PDA as described by THIBEAULT et al.²⁷⁾ would be included.

In this case the cardiac catheterization was performed in an attempt to rule out the associated cardiac anomaly, however, it was impossible to rule out a combined VSD nor was it possible to calculate the magnitude of the left-to-right shunt. Indication for surgery

was medically uncontrollable congestive heart failure due to the large left-to-right shunt. Operative and postoperative courses were complicated by the episodes of apnea and bradycardia caused by the small size (French size No. 14, internal diameter 3 mm.) of the orotracheal tube which was often blocked with bronchial secretion. Tube was removed 22nd postoperative hour. It was felt that the principle we are holding for the postoperative respiratory care⁵⁴⁾⁷⁰⁾ could also be applied to this premature baby; that is, to avoid unnecessary delay in extubation and to keep the patient in a high humid (100%) warm (28°C) atmosphere in order to keep the bronchial cilia in a good functioning condition. Echocardiogram turned out to be a valuable means to assess the effect of ligation and the postoperative hemodynamic status. The enlargement of the left atrium was not observed any more on the 48th postoperative day (the ratio of the left atrium to the aorta decreased from the preoperative value of 1.64 to 0.94 postoperatively).

Summary

A successful ligation of PDA in a 1,710-gram, 53-day-old premature baby with RDS in an attempt to treat the medically uncontrollable congestive heart failure was reported. The baby is doing well. Literature was reviewed and was described in detail.

(This case was reported at the 11th meeting of the Society of the Japanese Pediatric Surgeons held on June 30-July 2, 1974 at Tokyo.)

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和文抄録

呼吸障害 (RDS) を伴う体重 1,710 グラムの未熟児
動脈管開存症の手術治験例, 及び文献考察.

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未熟児の動脈管開存症の手術報告例はまだ吾国では極めて少ない⁵⁴⁾⁵⁶⁾⁵⁹⁾⁶⁰⁾⁷⁰⁾. われわれは体重 1,710 グラム, 生後 53 日目の未熟児に対する動脈管結紮術に成功したので報告する.

症例 患児 (M. K. 女児) は在胎 29 週で出産, 生下時体重 1,200 グラム. 生下時, 鎖骨上窩, 剣状突起下, 肋間の呼吸性陥凹, 多呼吸などを示していた.

(Apgar score 5, Silverman's retraction score 2/10) 生後 12 日目, 収縮期性心雑音を聴取, 動脈管開存症が疑われた. 生後 38 日目軽い呼吸困難と共に肺野にラ音を聴取, 翌日突然無呼吸発作が頻発し, 心雑音は増強 (Levine 4/6 度), スリルを伴った. 心不全と判断し, ジギタリス剤の投与を開始したが症状の改善をみないため, 53 日目 (昭和 49 年 10 月 31 日) 気管内挿管全身麻酔下に心カテーテル検査, 心血管造影を施行 (PA 圧 74, Aorta 84 mm. Hg) 動脈管開存症と診断した. 心カテーテル検査開始直後, 徐脈発作を来したが, 15 分間の心マッサージで回復した. 心室中隔欠損症の合併を完全に除外できないまま, 直ちに緊急手術を施行した. G. O. F. の麻酔下に左側第 4 肋間 Posterolateral thoracotomy にて開胸下行胸部大動脈と同じ太さの PDA (外径 7 mm) を三重結紮した. この開胸直前に, 再び徐脈発作を来し, 15 分間の心マッサージを余儀なくされた. この徐脈発作は, 気管内チューブの位置不良による左側肺の呼吸不全に起因していた. 術後は十分な換気が得られないため呼吸器を使用した, 気管内チューブが気道分泌物により閉塞され, 徐脈発作を来し, チューブ交換, 心マッサージにより回復せしめ得た. 術後 22 時間目に抜管に成功した. 抜管前の血液ガス分析は, FiO_2 0.7 で, PO_2 65 mm. Hg, PCO_2 51.5 mm. Hg, pH 7.44 (Saturation

92.6%) であった. 抜管後は, 気道分泌物は著明に減少し, 安静な呼吸状態となり, 一般状態も改善したが, 術後 4 日目より開始した鼻注の度毎に, 徐脈を伴う無呼吸発作が出現, その多くは, 皮膚刺激で回復したが, 時にはマスクによる補助呼吸を必要とした. 鼻注量調節により, 未熟児特有の反射性無呼吸発作は漸減, 術後 16 日目酸素吸入中止, 20 日目にクベースから出せた. 術後 50 日目 (日令 102 日), 無事退院し, 術後 22 ヶ月の現在体重 10 kg と元気である.

考察 本症例に超音波による検索を応用したが, 術前認められた左房の拡大 (左房径 — 大動脈径比 1.64) が, 術後 48 日目ですでに消失 (同上比 0.94 — 正常 1.0 以下) していることを証明し, 未熟児 PDA の診断, 術後検討に有用な検査法であることを知った.

これまで京都大学病院未熟児センターに入院した 400 名中, 生直後より心雑音を聴取したものが 80 名あり, この中, 臨床的に PDA と判断されたものが, 10 名あった. そしてこの 10 名中, 2 例に心不全を発生した. 即ち, 未熟児全体の PDA 発生頻度は 2.5 % であり, 心不全発生率は, PDA 中 20% であった. この頻度は, Thibeault 等²⁷⁾ の言う様に心雑音を聴取しない PDA 例を含めると更に低くなる.

心カテーテル検査は危険として施行されない場合が多く未熟児 PDA 又は RDS with or without PDA の血行力学的検索がなされた症例の報告が極めて少ないため, その手術適応を血行力学的データより客観的に決定することが困難な現状である. 本例では, 心カテーテル検査を施行したが短絡量の算出は不可能であった. 心カテーテル検査時, 術中, 及び術後で特記すべきことは, 気管内挿管による trouble である. 内径 3 mm という細いチューブ (French Size No. 14)

は容易に気管内分泌物で閉塞され重篤なる合併症を招来する。文献上にも同様の合併症による死亡例を認めた³⁰⁾。本例では、他の報告例に比して、早期に(術後22時間目)抜管しえたが、可能な限り早期に抜管する努力をする(とくに幼小児では上述の如く、チューブの位置不良、分泌物による閉塞を防ぐ意味でも)、そのあと気管纖毛上皮の生理的活動を保つ様に湿度100%、28~30℃の高温環境とするという、従来吾々の主張して来た開心術後呼吸管理法が^{54), 56), 60)}、未熟児

の本例にも適用され、極めて有効であったことを強調したい。

文献的考察 文献考察は、出来るだけ数字のデータをあけて詳述した。

(注) 本症例の概略は、第12回小児外科学会総会(昭和50年6月31日~7月2日、東京)において発表した。