LIGATION OF PATENT DUCTUS ARTERIOSUS IN PREMATURE INFANTS

M. LIPPMANN, R. J. NELSON, G. C. EMMANOUILIDES, J. DISKIN AND D. W. THIBEAULT

SUMMARY
Twenty-four neonates, at 25-34 weeks' gestation with a weight range of 570-1530 g underwent ligation of patent ductus arteriosus (PDA). The infants had mild to severe respiratory distress syndrome at birth and later developed signs of heart failure as a result of left-to-right shunting through a PDA. Surgical closure of the PDA was performed within 2-31 days after birth. In the period before operation the heart rate was monitored constantly and the arterial blood-gases were assessed frequently. The trachea was intubated and respiration was controlled with a ventilator. Surgery was performed under controlled ventilation and no anaesthesia was used. Care was taken not to overventilate the lungs. Nine infants died. Death was associated with higher peak inspiratory ventilator pressures at the time of operation and with complications occurring during or after the operation. The most common complication was tension pneumomediastinum which appears to be related to excessive ventilator pressures during surgery.

Heart failure secondary to a patent ductus arteriosus (PDA) in premature infants has been recognized increasingly in recent years (Kitterman et al., 1972). Heart failure may be present in the first days of life, often associated with the respiratory distress syndrome (RDS) (Rudolph et al., 1961; Kitterman et al., 1972; Gay et al., 1973; Thibeault et al., 1975). If medical management is inadequate, surgical ligation of the PDA is required. To obtain high survival rates, intensive care of the infant must be employed before, during and after surgery. This communication defines some of the high-risk factors associated with PDA ligation, and describes a method for optimizing the conditions for PDA ligation.

METHODS
Twenty-four infants, 25-34 weeks’ gestation, with a weight range of 570-1530 g (mean 1000 g) had developed the respiratory distress syndrome, (RDS) in varying severity, during the first few hours of life. This was characterized by tachypnoea, intercostal retraction, increased inspired oxygen requirements and a diffuse granular pattern and prominent air bronchograms on chest x-ray. Umbilical artery catheters were inserted for blood sampling and fluid was administered using infusion pumps. The tips of the catheters were placed above the diaphragm at the level of T6 to T10 approximately. RDS was treated conventionally by temperature control, correction of hypoxaemia, parenteral fluid therapy and sodium bicarbonate infusion (Hobel et al., 1972). Blood transfusions were given to replace blood removed for blood-gas analysis. If respiratory failure became worse, the infant received continuous positive airway pressure (CPAP) or intermittent positive pressure ventilation (IPPV).

The infants with RDS were divided arbitrarily into two groups: (a) severe: those infants who required IPPV and more than 20 cm H2O peak inspiratory pressure to maintain $P_{\text{A}}O_2$ in the range 50-70 mm Hg while breathing 100% oxygen, and (b) moderate: those infants who required no IPPV, or IPPV with less than 20 cm H2O peak pressure, or CPAP (less than 10 cm H2O).

In all infants, the patency of the ductus arteriosus was established either by single film retrograde aortography (Thibeault et al., 1975) or by clinical diagnosis with confirmation at the time of surgery. Retrograde aortograms were performed while the infant remained undisturbed in the neonatal intensive care unit (NICU), by injecting 1 ml/kg body weight of a mixture of meglumine diatrizoate and sodium diatrizoate through the umbilical artery catheter. An appropriately timed, single antero-posterior chest x-ray was taken, at the time of injection, with a portable x-ray machine. No adverse clinical side-effects were noted during or after the injection of the contrast medium.
Clinical criteria for diagnosis of PDA included a systolic heart murmur, a heaving precordium and bounding femoral pulses. If massive cardiomegaly and pulmonary oedema were seen on the chest x-ray, heart failure was diagnosed also.

Heart failure and pulmonary oedema were treated with digitalis and diuretics or continuous assisted ventilation, or both. The decision to undertake surgical ligation of the PDA was based on an absence of clinical improvement following vigorous medical management and a need for increasing the ventilator peak inspiratory pressures.

**Preparation for surgery**

If the trachea had not been intubated previously this was done before leaving the NICU. Intubation may be associated with significant reflex bradycardia and hypoxia in infants with heart failure. If the tube is placed inadvertently in the right bronchus and positive pressure is applied for a few breaths, interstitial emphysema of the right lower lobe may result (Thibeault et al., 1973). The position of the endotracheal tube was confirmed by chest x-ray. Immediately after intubation, ventilation was controlled with a transport ventilator—a modified Bird Mark VIII infant ventilator. The machine manometer was connected by a polyvinyl catheter to the proximal end of the endotracheal tube via a right-angle connector and thus registered proximal airway pressure. Cylinders were of the "E" type which have a floating check ball allowing cylinder changing without interfering with the ventilator function. A Burnett single-stage regulator with an on-off lever regulates the beginning of ventilator action. Attached to the ventilator was a Bird Q-circle circuit with a 500-ml in-line nebulizer.

Positive end-expiratory pressure (PEEP) may be applied by immersing the expiratory tube under water in a retard bottle, kept at the foot of the apparatus. The inspired oxygen fraction ($F_{1O_2}$) was measured with a continuous oxygen analyser (IMI—International Medical Instrument Company) with an electrode placed distal to the water trap. $F_{1O_2}$ could be adjusted in the range 0.21–1.0. A Twin-O-Vac venturi suction allowed suction at any time during the procedure. As a safety feature, a Penlon oxygen bag and mask was always kept with the machine in case of unexpected failure. The machine could be powered with wall oxygen during the procedure if necessary, thereby conserving the cylinder contents. Arterial blood-gases were measured before transportation. We regard the optimum range of arterial pH as 7.30–7.40, $P_{aCO_2}$ 30–45 mm Hg and $P_{aO_2}$ 50–70 mm Hg. The heart rate was monitored electrically during transportation. Although it is desirable to have arterial pressure measurements also we have found that the heart rate was the most useful measurement.

During surgery the infant was placed on a warming pad and the rectal temperature was monitored. Ventilation during the procedure was maintained using the transport ventilator. No premedication was given. Just before the procedure, if necessary, a paralysing dose of suxamethonium 1 mg/kg body wt. was given. No other anaesthetic agent was used. The ductus was ligated with No. 2 silk suture using a transpleural approach through the left fourth intercostal space. During operation, the arterial oxygen tension was maintained in the range 50–70 mm Hg; if there was no arterial cannula, 100% oxygen was used. In the critically ill infant, while the left lung was being retracted to expose the ductus, it was usually necessary to increase the inspired oxygen concentration to 100%. Sometimes it was necessary to increase the inspiratory pressure while the pleural space was open and the lung was retracted. However, excessive pressure may result in interstitial or mediastinal emphysema or a pneumothorax. Occasionally, retraction of the left lung caused profound bradycardia which could be controlled by temporarily releasing the traction on the left lung. Fluids and electrolytes were administered during the surgical procedure, at the same rate as before operation, using an infusion pump. In addition, blood losses during operation were replaced by 2–5-ml increments of whole blood. At the end of the operation, a chest x-ray was obtained to exclude pneumomediastinum or pneumothorax. Occasionally, retraction of the left lung caused profound bradycardia which could be controlled by temporarily releasing the traction on the left lung. Fluids and electrolytes were administered during the surgical procedure, at the same rate as before operation, using an infusion pump. In addition, blood losses during operation were replaced by 2–5-ml increments of whole blood. At the end of the operation, a chest x-ray was obtained to exclude pneumomediastinum or pneumothorax. In later cases, the chest tubes were removed before skin closure. The infant was returned immediately to the NICU where $P_{aO_2}$ was maintained at approximately 50 mm Hg. Oxygen 100% was given and the ventilator pressure was adjusted to maintain $P_{aCO_2}$ between 40 and 50 mm Hg. There is usually a large right-to-left shunt immediately after operation in patients of this type, presumably secondary to a low lung volume in the left lung. Within 5–24 hr following operation, most patients required less than 50% oxygen to maintain an adequate $P_{aO_2}$. When the peak inspiratory pressure required was less than 15 cm H$_2$O and $F_{1O_2}$ was less than 0.5, CPAP (5 cm H$_2$O) was instituted. When the end-expiratory pressure could be reduced to 2 cm H$_2$O, the positive pressure was discontinued; if the blood-gas values remained stable for 2 hr, the endotracheal tube was removed.
LIGATION OF PATENT DUCTUS

Recently we have been using the "Baby Bird" ventilator before and after operation, and the infant is weaned from the ventilator using intermittent "mandatory" ventilation.

RESULTS

Nine infants died during the period in hospital (table I). The following factors did not appear to influence the mortality rate: the gestational age, the birth weight, the age at operation and the number of days of controlled ventilation before operation.

TABLE I. Analysis of factors in premature infants requiring PDA ligation with reference to survival. Mean values are shown with SEM and are compared using Student's t test

<table>
<thead>
<tr>
<th></th>
<th>Survived</th>
<th>Died</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of infants</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Birth weight (g)</td>
<td>1061 ± 55</td>
<td>n.s.</td>
</tr>
<tr>
<td>Surgical weight (g)</td>
<td>962 ± 61</td>
<td>n.s.</td>
</tr>
<tr>
<td>Gestational age (weeks)</td>
<td>28.8 ± 0.4</td>
<td>n.s.</td>
</tr>
<tr>
<td>Age (days)</td>
<td>11.2 ± 1.5</td>
<td>n.s.</td>
</tr>
<tr>
<td>Time on ventilator before surgery (days)</td>
<td>6.2 ± 1.5</td>
<td>n.s.</td>
</tr>
<tr>
<td>Moderate RDS</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Severe RDS</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Ventilator pressure at time of surgery (cm H₂O)</td>
<td>14.6 ± 1.8</td>
<td>P &lt; 0.05</td>
</tr>
</tbody>
</table>

n.s. not significant (P > 0.05).

The mortality rate was associated significantly with the magnitude of the peak inspiratory ventilator pressures at the time of operation (P < 0.05). The higher the pressure the greater was the mortality rate, although there were some infants with high pressures (severe RDS) who survived while others with low pressures (moderate RDS) died. Thus the severity of the lung disease at the time of operation was not the only factor which influenced the outcome.

Table II shows the relationship of the outcome to the complications occurring during operation or shortly thereafter. The most common complications were tension pneumomediastinum and severe metabolic acidosis (table IIa). Tension pneumomediastinum usually began shortly after the operative procedure was complete.

The standard type of intrapleural chest tube was not effective in draining the mediastinal collections of air and attempts at direct aspiration or insertion of a tube to the mediastinum were often unsuccessful. In four instances, the pneumomediastinum persisted for longer than 24 hr. We feel that this complication was caused by excessive ventilator pressures, either during or after the procedure. It occurred only rarely when overinflation was avoided. The removal of the chest tube before skin closure did not result in an increased incidence of pneumothorax or pneumomediastinum.

DISCUSSION

Surgical ligation of PDA has become a relatively common procedure in large centres of neonatal surgery (Kitterman et al., 1972; Edmunds et al., 1973; Horsley et al., 1973; Thibeault et al., 1975). The operation may be required in the first days of life (Gay et al., 1973; Thibeault et al., 1975). In the experience of ourselves and others (Edmunds et al., 1973; Gay et al., 1973), the heart failure may be controlled for days or weeks with ventilator assistance but chronic ventilator lung disease and poor nutrition may complicate a late surgical repair. In this study and in that of Gay and others (1973), weight, immaturity and age were not factors which complicated surgery or its results.

In small premature infants with moderate RDS, the onset of heart failure from PDA occurs gradually over a few days (Thibeault et al., 1975). Surgery may be performed electively, although in infants of 32 weeks gestation or less with severe RDS, heart failure may occur in the first 24 hr of life (Thibeault et al., 1975). The combination of heart failure and RDS necessitates high ventilator pressures and these complicated the surgical procedure (table II). Thus heart failure must be anticipated in the management of severe RDS.
and diagnostic methods should be available at all times. We have found single-film aortography to be very useful in establishing the diagnosis of a ductus arteriosus with a massive left-to-right shunt in the absence of a heart murmur (Thibeault et al., 1975). In our hospital a team has been organized to perform ligation of the PDA within a short period of time. We believe that multidisciplinary intensive care of the infant is an important factor in survival in these procedures.

So far as we are aware, details of perioperative care have not been published previously, but our survival rate (62%) compares favourably with that in the literature (Edmunds et al., 1973; Gay et al., 1973; Horosy et al., 1973).

Attention to detail in endotracheal intubation, transportation, arterial blood-gas and heart rate monitoring, temperature control, the avoidance of overinflation, and the speed of the procedure are important to success. The value of an extrapleural, rather than transpleural, approach to the ductus in minimizing retraction damage to the left lung and therefore decreasing the need for high inspiratory pressures following surgery is being evaluated currently.

We have avoided the use of anaesthetic or analgesic agents which, in our experience, are unnecessary. Moreover, the survival rate of our infants was equal to or better than that reported in the literature, including reports of operations in which anaesthetic drugs were used.

Despite the absence of atropine, the use of suxamethonium was not associated with cardiac arrhythmia. Bradycardia, when it occurred, was associated with retraction of the left lung.

ACKNOWLEDGEMENT

Supported in part by Investigative Groups Support of the Los Angeles County Heart Association 470 1G3.

REFERENCES


LIGATION OF PATENT DUCTUS


LIGACION DEL CONDUCTO ARTERIOSO ABIERTO EN NIÑOS PREMATUROS

SUMARIO
Se practicó la ligación del conducto arterioso abierto (PDA) a veinticuatro recién nacidos, de 25 a 34 semanas de la gestación; tenían un peso que variaba entre 570 a 1530 g. Los niños tenían el síndrome de angustia respiratoria entre suave y severa en el momento del nacimiento y luego desarrollaron síntomas de insuficiencia cardíaca como resultado de una derivación de izquierda a derecha a través de un PDA. Se llevó a cabo un cierre quirúrgico del PDA dentro de los 2-31 días posteriores al nacimiento. En el período anterior a la operación el ritmo cardíaco fue vigilado constantemente y los gases sanguíneos arteriales frecuentemente evaluados. Se entubó la tráquea y se controló la respiración con un ventilador. Se practicó la operación quirúrgica con ventilación controlada y no se usó anestesia. Se tuvo cuidado en no ventilar en demasia los pulmones. Nueve niños murieron. La muerte se consideró en conexión con más elevadas presiones ventilatorias de los picos de inspiración en el momento de la operación y con complicaciones que surgieron durante o antes de la operación. La complicación más corriente fue la tensión neumomediastina que parece estar relacionada con presiones ventilatorias durante la operación.
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