

Patent ductus¹ arteriosus in infants and children

A review of 936 operations (1946-69)

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Nine hundred and thirty-six consecutive cases of closure of a patent ductus arteriosus in infants and children are reported. Among 789 without any other cardiac anomalies there were 11 deaths, seven of these with severe congenital anomalies other than cardiovascular. There was one incomplete closure. The deaths in this series were mostly associated with additional congenital cardiac anomalies. Forty-eight of the 59 who died had additional cardiac anomalies. Forty-seven of the deaths were in infants. For 691 patients over the age of 1 year the hospital mortality rate was less than 0.5%.

Ligation of the ductus using two ligatures of thick plaited silk (1.2 mm diameter) was the technique used in 99% of these cases. There were four cases of recanalization or inadequate ligation but all four survived. This technique seems an acceptable one for the closure of a patent ductus arteriosus.

We present an experience of 936 consecutive cases of patent ductus arteriosus operated upon at this hospital between April 1946 and May 1969.

The ductus arteriosus was first described by Galen (born 131 A.D.); Fallopi (1561) and Arantius (1564) also observed the structure (Franklin, 1941). Harvey (1628) demonstrated its physiological importance in the fetal circulation (Gilchrist, 1945; Harvey, 1964; Skinner, 1961).

Botallo has been credited with being the first to describe the ductus but this was the result of a misunderstanding. In 1660 van Horne published a collected edition of the works of Botallo (which had been written in 1564). Van Horne mis-translated Botallo's text and introduced a drawing showing the ductus arteriosus which was not in Botallo's text (Franklin, 1941). Following this the ductus arteriosus became known as the 'ductus Botalli'. However, Botallo had made no mention of the ductus arteriosus.

Munro (1907) first suggested surgical obliteration of the ductus. In 1888 he demonstrated in an infant cadaver that the patent ductus arteriosus could be ligated. Although Gibson, in 1898, had clearly described the characteristic murmur of the patent ductus arteriosus and emphasized its diagnostic significance (Gibson, 1900), it was not until 1937 that Strieder made the first attempt to close a patent ductus arteriosus. The closure was incomplete and the patient died (Graybiel, Strieder, and Boyer, 1938).

Gross, on 26 August 1938, successfully closed a patent ductus arteriosus in a 7-year-old girl, and thus began the modern era of cardiac surgery (Gross and Hubbard, 1939).

Gilchrist (1945) published a comprehensive review of the many anatomical, embryological, and experimental observations that have been contributed to the literature.

PATIENT MATERIAL

More than 1,000 cases of patent ductus arteriosus have been operated upon at this hospital from April 1946 to May 1969. Nine hundred and thirty-six had a primary operation on the ductus (Fig. 1). These cases are presented in this series.

We have not included

(a) 21 patients who survived following closure of the ductus performed at the time of an open heart operation;

¹The word 'ductus' is used here with the definition given by most dictionaries to mean a tube, canal or passage with well-defined walls. We support the definition given by *Dorland's Medical Dictionary* (1965) which distinguishes a ductus arteriosus (the presence of the vessel) from a patent ductus arteriosus (the vessel with a persistently open lumen). Any ductus is persistent if it was present in the fetus, but it will allow the passage of blood only if it is patent. 'Patent ductus arteriosus' is, therefore, a correctly descriptive term and should be preferred to 'persistent ductus arteriosus' or 'ductus arteriosus'.

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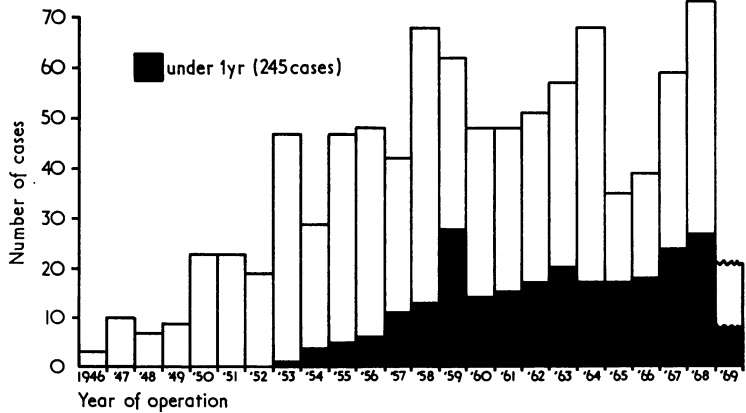


FIG. 1. Annual number of cases operated upon and number of infants.

(b) 32 patients who survived following closure of a medium or large sized ductus at the time of pulmonary artery constriction (banding); and

(c) 11 patients who had an associated vascular ring. We have not included an additional 158 patients, who survived operation for resection of coarctation of the aorta and division of a patent ductus arteriosus (Tawes, Aberdeen, Waterston, and Bonham Carter, 1969).

The age at operation ranged from 3 days to 13 years. Two hundred and forty-five patients (26.1%) were infants, that is, below 1 year of age (Fig. 2).

Females predominated, in a ratio of 1.6:1 (587 females and 349 males).

Nineteen patients were twins (2.2%).

Maternal rubella occurred in 61 patients (6.5%), and 17 additional patients possibly had been associated with maternal rubella.

ADDITIONAL ANOMALIES A patent ductus arteriosus was associated with other cardiovascular anomalies in

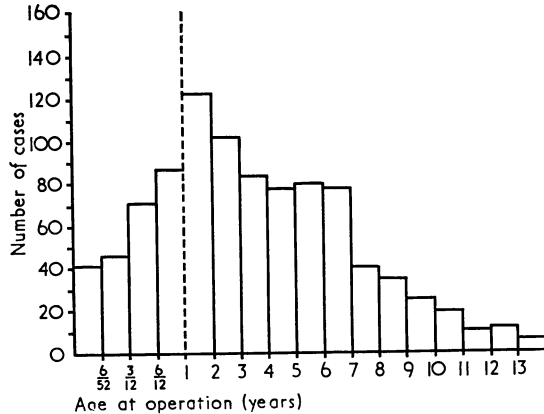


FIG. 2. Age at operation and number of cases.

197 patients (21%) (Fig. 3 and Table I). Seven patients had anomalies of systems other than cardiovascular as the only additional lesion. Therefore, a total of 204 patients (21.7%) had additional congenital anomalies of all types.

Twenty-four patients (12.1%) of the 197 with multiple cardiovascular anomalies had congenital

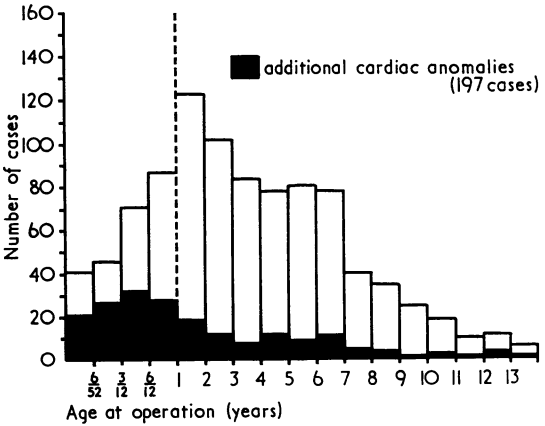


FIG. 3. Additional cardiac anomalies compared with age at operation.

TABLE I
ADDITIONAL HEART LESIONS

V.S.D.	65
V.S.D. + A.S.D.	14
A.S.D.	9
Aortic valve disease	31
Mitral valve disease	13
Pulmonary stenosis	10
Transposed great arteries	14
Other (16 diagnoses)	41
Total	197

anomalies of the alimentary or respiratory systems as well.

The proportion of additional anomalies was much higher in the younger infants. Of those under 3 months of age at the time of operation, 55.1% (48 of 87) had additional cardiac anomalies. Figure 4 shows the contrast between those under 6 months, those aged between 6 and 12 months, and those over 12 months at the time of operation.

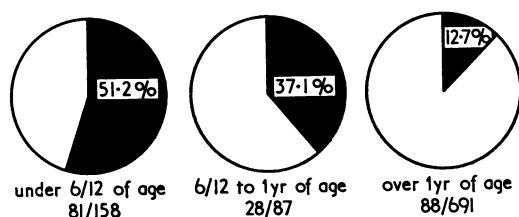


FIG. 4. Proportion of additional heart lesions in three age groups.

Pulmonary hypertension (Campbell, 1955; Ellis, Kirklin, Callahan, and Wood, 1956) (having a pulmonary artery pressure greater than 50 mmHg) was found in 28 patients with isolated patent ductus arteriosus, while another 38 patients with a ductus and additional cardiac anomalies were found to have pulmonary hypertension of this degree. However, many patients did not have cardiac catheterization preoperatively nor were pressure measurements made at operation in the majority of the cases, so the number with pulmonary hypertension is under-reported in this series. When the pulmonary vascular resistance was close to the systemic vascular resistance, pressures were recorded at operation and in five patients the pulmonary artery pressure increased or remained unchanged on trial occlusion of the ductus; therefore the operation was not proceeded with and the ductus was left patent. Nevertheless, in two patients the ductus was ligated later after further catheterization studies. The pulmonary artery pressure at this second attempt was just below the systemic pressure.

Subacute bacterial endocarditis has not been encountered in this series.

Myocardial ischaemia can be a significant associated anomaly and cause of death in infants with congenital heart disease but with normal coronary arteries (Tawes *et al.*, 1969). Its importance has probably been underestimated in the past. Of 25 patients with patent ductus arteriosus who died between 1953 and 1967, three (12%) were found to have evidence of long-standing ischaemia, such as areas of focal necrosis, and focal and interstitial fibrosis, with loss of fibrillar structure with formation of granular hyaline fibres or vacuolation. This was a less common problem in patients with patent ductus arteriosus than in infants dying with coarctation of the aorta, of whom 38% (of 61 cases) had evidence of long-standing ischaemia, and with Fallot's anomaly, of whom 35% (of 17 cases) were affected.

OPERATIVE TECHNIQUE

A left lateral thoracotomy through the third or fourth intercostal space was made, using either a lateral skin incision (80%) or a vertical skin incision in the mid-axillary line (20%) with an opening in the fourth intercostal space, as described by Browne (1952). The axillary incision was used mainly in infants.

The mediastinal pleura was incised longitudinally over the descending aorta and dissection was made down to the aortic wall. The pleura and periaortic connective tissue were then reflected medially, as further dissection was made with scissors close to the aortic wall. The dissection was continued medially over the anterior wall of the ductus. This had the effect of displacing the vagus nerve medially with the pleura and sub-pleural tissues, and also carried the left recurrent laryngeal nerve medially and away from danger (Fig. 5).

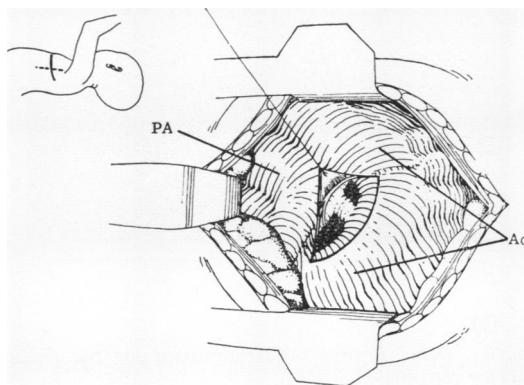
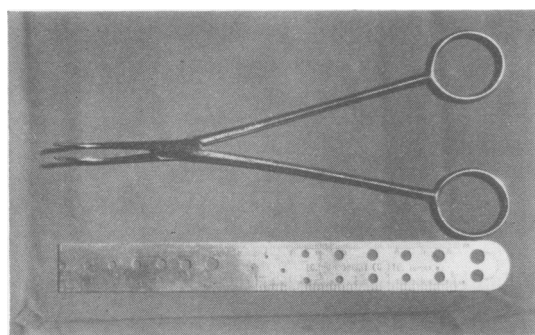


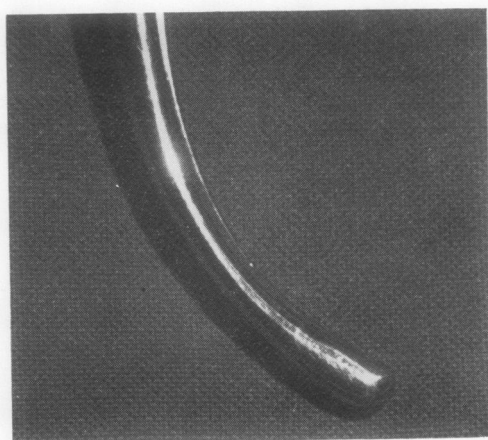
FIG. 5. Diagram of dissected ductus showing left vagus nerve and recurrent laryngeal nerve passing below ductus. Insert shows skin incisions used (PA=pulmonary artery; Ao=aorta).

Dissection was then made below and above the ductus and a careful dissection was made posterior to the ductus with Denis Browne's ductus dissector, an instrument with an olive-shaped dissecting tip which has proved extremely safe in practice (Fig. 6a, b).

Ligation of the ductus using two ligatures of 1.2 mm plaited silk was the method of closure in 99% (Fig. 7). In a few cases where the ductus was wide (as wide as the aorta) and short, division and suture was used to avoid constricting the aorta (Fig. 8).



(a)



(b)

FIG. 6. Denis Browne's dissector used for the ductus, showing the olive-shaped tip.

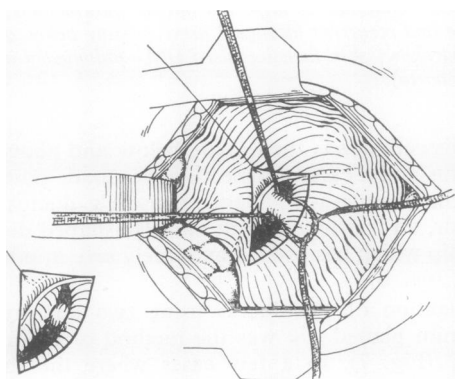


FIG. 7. Diagram of the two ligatures placed around the ductus.

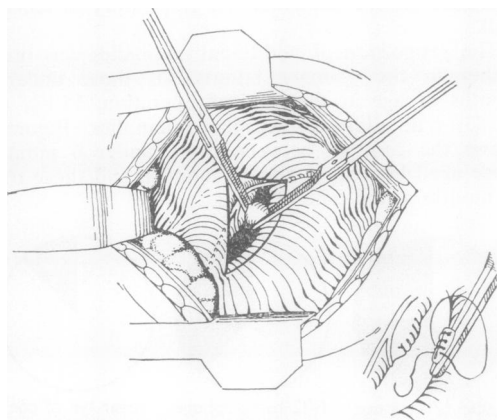


FIG. 8. Diagram of division of ductus.

Hypotension (usually induced with trimetaphan, or a brief period of halothane anaesthesia) was often used for a short period when pulmonary hypertension was present. The tense ductus usually became soft when the systemic arterial pressure was reduced to below 90 mmHg, and the ligature was then easily tied down.

PREOPERATIVE CARE

URGENCY OF OPERATION If the patent ductus arteriosus had resulted in heart failure, heart enlargement or pulmonary hypertension, the operation was performed soon after diagnosis, whatever the age (Adams and Forsyth, 1951; Anderson, 1954). If a symptom-free ductus without evidence of pulmonary hypertension was found in a young child of 1 to 3 years, operation was usually postponed until about 4 to 5 years of age for psychological reasons.

PREOPERATIVE INVESTIGATIONS When multiple cardiac defects were anticipated, and especially in the first months of life, cardiac catheterization and angiocardiology were usually performed. The clinical diagnosis of patent ductus arteriosus can be extremely reliable, even in infants, if an experienced paediatric cardiologist is available (Bonham Carter and Walker, 1955).

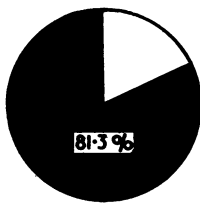
RESULTS

DEATHS Fifty-one patients died in hospital. Another eight died 11 months to 12 years after operation.

Seven hundred and thirty-nine patients had a patent ductus arteriosus without any other cardiac anomalies. All were treated by ligation, and of these 11 died. Seven of these 11 had other systemic non-cardiac anomalies. Four of these died in hospital and three later. Only four deaths (0.5%) occurred in patients with no other major congenital anomaly.⁴ Of the 197 with additional cardiac anomalies, 48 died. Forty-three died in hospital and five died later (Fig. 9).

Forty-seven of the 59 who died were infants (Fig. 10). Figure 11 shows the mortality rate of the whole group related to age at operation (Table II).

Among the 66 patients known to have pulmonary hypertension, there were 10 deaths. In addition, three children have died some years (as many as 10 years) after operation as a consequence of severe and increasing pulmonary vascular



59 died - 48 had additional cardiac anomalies*
* 11 died without additional cardiac anomalies
7 of these had additional systemic anomalies

FIG. 9. Proportion of deaths in those with additional anomalies compared with those without anomalies.

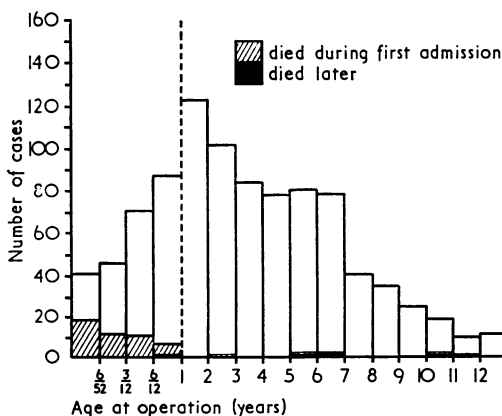


FIG. 10. Deaths compared with age at operation.

⁴Since the completion of this series one child with an uncomplicated ductus has died following ligation as a result of a large abscess around the ductus.

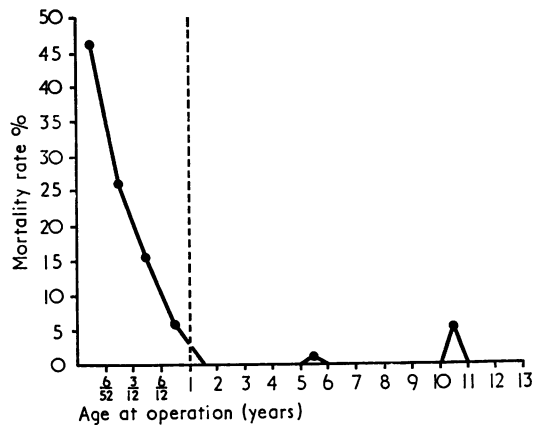


FIG. 11. Mortality rate (early and late) compared with age at operation.

TABLE II
AN OUTLINE OF TOTAL MORTALITY RATE
(EARLY AND LATE)

	Hospital Deaths	Late Deaths
Other cardiac anomalies	43	5
No cardiac anomalies but severe other anomalies	4	3
No other anomalies	4	—
No cardiac anomalies	51	8

disease. In one child the murmur of pulmonary incompetence was such that recurrence of the patency of the ductus was thought possible, but necropsy showed that the ductus had been completely obliterated.

POSTOPERATIVE COMPLICATIONS Recanalization of the ductus occurred in four cases, 0.4% of the series (Table III), none of which proved fatal.

TABLE III
POST-OPERATIVE COMPLICATIONS

Recanalization or inadequate ligation ..	4
Ligation of left pulmonary artery ..	1
Coarctation after ligation ..	3
after division ..	1
Atelectasis ..	37
Wound infection ..	18
Pleural effusion ..	12
Chylothorax ..	4
Recurrent laryngeal nerve paresis (not permanent) ..	11
Haemothorax ..	2
	93 (9.9%)

The first patient, aged 8 months, was ligated in 1958 with a single ligature because the ductus was so short. She later was shown to have coarctation of the aorta and a narrow recanalization of the ductus. Both defects were successfully repaired by operation.

The second patient (aged 12 years) had a large hypertensive ductus doubly ligated and bled 350 ml of blood from the chest drain about 24 hours after operation. The significance of this was not appreciated until almost four years later when a ventricular septal defect was being repaired with heart-lung bypass at another hospital. Closure of the ductus was required to control the bleeding from the pulmonary artery. Presumably a pseudoaneurysm had developed after the duct ligation. She has subsequently done well.⁵

The third patient was a 12-year-old girl in whom a large hypertensive ductus was ligated with a very large size (1.7 mm diameter) plaited silk ligature. A ductus murmur could still be heard after operation; the ductus was therefore re-explored. The second operation was complicated by haemorrhage from the ductus region, so heart-lung bypass was used and the ductus was effectively double ligated. Presumably the ductus had not been effectively closed, using the larger (1.7 mm) plaited silk ligature. This size was used in only a few cases and is not used now.

The fourth patient, a 7-year-old child, had an uncomplicated ductus double ligated in the usual way. A ductus murmur was heard in the early postoperative period, and investigation confirmed a small persistent patent ductus. Complete closure has not yet been performed.

The left pulmonary artery was ligated in error in an 8-year-old child who was one of the early cases in the series. This was later recognized and the ductus was ligated.

Coarctation of the aorta after ductus ligation was produced in four patients (Table III). In a 5½-year-old child a large and hypertensive duct was double ligated. Three and a half years later, before treatment of his multiple ventricular septal defects, a gradient of 30 mmHg was found at the level of the previously ligated ductus arteriosus. All lesions were successfully corrected by operation.

A second case of coarctation followed division and suture of the ductus arteriosus in a 5-year-old child. Successful resection was performed two years later.

The third patient, aged 8 months, had a large hypertensive ductus which was closed with a single

ligature. Subsequently the development of coarctation and recanalization of the ductus were demonstrated (as mentioned above) and both complications were successfully corrected at the age of 6 years.

The fourth patient, aged 14 months, had a hypoplastic and kinked aorta. Duct ligation produced an aortic pressure gradient which was recognized and corrected at the same operation by aortic end-to-side anastomosis and aortic end-to-end anastomosis with aortoplasty.

Atelectasis was the commonest postoperative complication (37 cases, 3.9%) and the left lower lobe was the commonest site (19 cases).

Wound infection was recorded in 18 patients (1.9%) but this may have been under-reported.

A small pleural effusion occurred in 12 patients. This was treated with aspiration and physiotherapy.

Some chylothorax developed in four patients but in all it was successfully treated by a chest drain and a low-fat diet.

Hoarseness, suggesting a recurrent laryngeal nerve injury, was observed temporarily in 19 patients (1.1%). No permanent recurrent laryngeal nerve injury occurred.

Haemothorax was noted in two patients, both having had a hypertensive patent ductus arteriosus. One patient was subsequently found to have a recurrence of the ductus, as discussed above, and presumably the bleeding was from the site of the ductus ligation.

LONG-TERM OBSERVATION

Of the 877 survivors, all except 22 have been re-examined six months or more after operation.

Of the 153 with a ductus and additional lesions, all have been re-examined, and 123 have been recatheterized and/or had another cardiovascular operation.

Of the 732 patients with an isolated patent ductus arteriosus the postoperative progress has been less fully recorded. Three hundred and two patients (41.2%) have been reviewed five years after operation, an additional 138 (17.4%) three and a half years after, and 149 (20.3%) two years after operation.

Aneurysm of the ligated ductus was not observed in this series (Rosenkrantz, Kelminson, Paton, and Vogel, 1967; Ross, Feder, and Spencer, 1961). However, since only about half of the patients who had been operated on more than five years ago had a chest radiograph performed five years or more after operation, this complication has not been completely excluded from all cases in this series.

⁵This patient was treated by Mr. Donald Ross, F.R.C.S., at the National Heart Hospital.

DISCUSSION

The natural history of untreated patent ductus arteriosus is now difficult to assess because most children with patent ductus have the ductus closed by operation (Gardiner and Keith, 1951; Macmahon, McKeown, and Record, 1953).

Keys and Shapiro in 1943 estimated that an adolescent with a patent ductus arteriosus had a life expectancy of half the normal for his age.

Four common hazards accompany the patent ductus arteriosus:

- (1) ventricular hypertrophy and failure;
- (2) bacterial endocarditis—which is rare in children but common in adults;
- (3) pulmonary vascular disease;
- (4) poor physical development (Adams and Forsyth, 1951).

Two further hazards may develop in later age:

- (1) aneurysmal dilatation of the ductus; and
- (2) calcification.

In complicated cases of patent ductus arteriosus, the additional anomalies determine the prognosis (Campbell, 1955). Additional anomalies also determine the mortality rate in the early months of life as for many other forms of congenital heart disease. The mortality rates for treated coarctation of the aorta, Fallot's anomaly, tricuspid atresia, totally anomalous pulmonary veins, and several other lesions have a surprising similarity to the results of closing a patent ductus arteriosus because it is rare, in our experience, for an infant with a single and isolated congenital cardiac defect to die during operative treatment (Aberdeen, 1968; Tawes *et al.*, 1969).

Bacterial endocarditis is rare in children and did not occur in this series. Should it develop in children with a patent ductus arteriosus, duct closure should be performed (Keele and Tubbs, 1941).

The best operative technique for closure of a patent ductus arteriosus has been much debated (Ekström, 1952; Gross, 1953; Jones, 1965). Both ligation and division-with-suture have given excellent results. As a result of early experience Gross changed from a technique of ligation to one of division and suture (Gross, 1947; Crafoord, 1947; Glenn, Bloomer, and Spear, 1956). Jones (1947) also changed to ductus division after some of his early cases had an unsatisfactory duct ligation. However, ligation techniques continued to be used by others (Blalock, 1946; Clagett, Kirklin, Ellis, and Cooley, 1955), and our data confirm that ligation of a ductus can be a satisfactory technique. The importance of using a wide ligature,

tied with just sufficient tension, to occlude a large artery was well reviewed by Reid in 1934. A narrow ligature was shown to cut through an artery which could recanalize without giving external haemorrhage. This confirmed earlier work by Halsted (1916) and Reid who reported 'the advice to bring broad surfaces in apposition by several continuous coarse ligatures is good. We have found that the finer the ligature the quicker it cuts through the arteries; very fine silk cutting through in a day or two'.

Concerning the tension required for ligation, Reid observed 'The surgeon who has had the experience of cutting the human aorta or some smaller, strongly pulsating artery in two when pulling a ligature tight, has a keen appreciation of the dangers of fracturing the arterial wall. Even if this has not happened it is safe to say that most of us are familiar with that unpleasant crunching sensation which one experiences when the ligature causes a rupture of the media of the vessel wall'. Perhaps whether a ductus is divided and sutured or closed by an effective ligation technique is not so important; what is important is that very few cases are lost from technical causes and that complications are rare whatever technique is used (Wilcox and Peters, 1967).

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