SURGICAL ASPECTS OF PATENT DUCTUS ARTERIOSUS*

A REVIEW OF 228 CASES

BY

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Three years ago Hay and Ward (1956) reviewed the results of surgery for 108 cases of patent ductus arteriosus treated at the Royal Liverpool Children's Hospital. The object of this communication is to review the present position at the same hospital from the purely surgical point of view. A further 120 cases have received surgical treatment up to December 31, 1958, making a total of 228 cases available for review, with a minimum follow-up period of five months.

Surgery of patent ductus arteriosus comes of age this year as on August 26, 1938, Gross performed the first ligation operation (Gross and Hubbard, 1939). But the literature on the surgery of patent ductus arteriosus is not very large, considering that the abnormality is such a common one. In fact the contributions of Gross and Hubbard (1939) and Gross (1952) mark the only real major landmarks in the surgery of the condition, reporting the technique of simple ligation and of division respectively. In this second paper Gross reports the extraordinary number of 482 divisions of the patent ductus with 10 deaths. Shapiro and Johnson (1947), reporting 626 operations for patent ductus performed by 48 surgeons, record a mortality of 4.9% and a recanalization figure of 8.7%. They report 172 divisions of their own with no fatality and no recanalization. They state categorically that the operation of ligation is obsolete and should only be done when division is impracticable. Yet even now many surgeons, the present writer among them, have felt a natural hesitancy in substituting the technically more difficult procedure of division for the rather easy one of ligation.

Since Hay and Ward's first report, two other large series of operations for patent ductus arteriosus have appeared in the English literature. Nicks and Molloy (1956) describe a series of 155 cases from New Zealand with 138 operations. In all but five

cases the surgical method used was double ligation with silk, and there were only three recurrences in the 80 cases which had adequate follow-up details. The overall mortality was 2%. Mozen (1957) reviewed 143 cases operated on in Dr. Claude S. Beck's clinic in Cleveland, Ohio. The overall mortality was 2.14%. The surgical method used for closure was ligation and suture in 53 cases, division in 88 and exploration alone in two. Only one example of recanalization is mentioned as having taken place in the whole series, though follow-up details may be incomplete.

The fact that division may be proved statistically to be safe should not be allowed to obscure the fact that the division of a large blood vessel must carry with it an appreciable risk from accident. Nor can it be said categorically at the present time that a suture line in such a major vessel as the aorta or the left pulmonary artery is free from the risk of development of a weakness at some future date. Nevertheless the review made by Hay and Ward (1956) shows that the results of the simple ligation operations are far from perfect. Although there was only one death in 108 cases (a case in which the ductus was not tied because a reversed shunt was found) there was in fact failure to secure closure of the ductus in 10 cases, while a further four showed evidence of recanalization during a period of observation varying from one to 12 months. In addition, operation was abandoned on one occasion because friability of the ductus led to difficulty in dissection and to haemorrhage, which was controlled only with difficulty. Even if the case with the reversed shunt is excluded, together with two of the early recanalizations which appeared to close spontaneously, we are left with the uncomfortable fact that the object of the surgical procedure was not completely successful in 13 of the 107 'eligible' cases (a failure rate of 12%). Here one must say that there was evidence of reduction of the shunt in all these cases. The 'gross' failure rate for all cases was 14% (16 in 108 cases). In the ensuing discussion this series of cases

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will be referred to as Series 1, the newly reported group as Series 2.

The Technical Problem

When the causes of failure to close the ductus were considered, it immediately became apparent, as Hay and Ward pointed out, that there was a close relationship between the success of the operation, then performed entirely by the method of double ligature, and the diameter of the ductus. In 53 cases in which the diameter was 7 mm. or less there was not a single recanalization, whereas this process was observed in no fewer than 16 of the 55 cases in which the ductus had a diameter of 8 mm. or more. In fact only eight of the 20 cases in which the diameter was in excess of 10 mm. were permanently closed by ligature (Table 1).

TABLE 1

EFFICIENCY OF CLOSURE RELATED TO SIZE OF DUCTUS

	Diameter of Ductus (mm.)				Total
	Less than 5	5-7	8-10	More than 10	
Series 1	4 (—)	49*(—)	35 (4)	20†(12)	108 (16)
Series 2	3 (—)	66*(1)	39 (2)	12 (2)	120 (5)
Total	7 (—)	115 (1)	74 (6)	32 (14)	228 (21)

Figures in brackets indicate number of failures

* Includes two cases of 'small' ductus, size not recorded

† Includes five cases of 'wide' ductus, size not recorded

While the magnitude of the failure rate with larger ductuses was not at once appreciated by us, it had for a long time been obvious that the very large ductus was not technically suitable for ligation. One reason for this is that the large ductus usually has a large flow through it with a raised pressure in the pulmonary artery. The very large ductus, in which the diameter is greatly in excess of its length, with its sclerotic walls, presents a formidable surgical problem.

This was at first tackled by attempting ligation by linen thread over a small pad of gauze or lint. This often seemed to result in obliteration of the lumen at the time of operation, but in only one instance (a 14 mm. ductus) was the closure permanent. Next the effect was tried of tying ligatures while the blood pressure was temporarily lowered by the ganglion-blocking agent Arfonad. This again seemed usually to provide satisfactory immediate closure, but the end results were equally disappointing.

With this unsatisfactory situation in mind the methods of closing the ductus were reviewed. First of all a point of anatomy was made which is not

always appreciated. The ductus in the unborn child is virtually a continuation of the pulmonary artery, and has an oblique entry into the aorta which is in most instances maintained even after the pulmonary circulation has been opened up by the establishment of breathing. When the ductus fails to close and the left to right shunt becomes established, the blood has to take a very sharp turn back into the pulmonary artery from the aorta (Fig. 1a). This no doubt

FIG. 1.—Evolution of patent ductus arteriosus (a) in foetal life ; (b) in extra-uterine life.

accounts for the observation frequently made at operation, that the thrill is usually much more obvious in the main trunk of the pulmonary artery than in the left branch. But, in addition, there is a point of impact of the stream on the area of the aortic wall immediately adjacent to the origin of the ductus, but on the distal (caudal) side of the actual orifice. Much as a river erodes its banks on the convexity of a curve, so must this stream of blood, which is often nearly reversed in direction, exert a continual pressure on this area. The common shape of the ductus is conical, with a much wider opening into the aorta than into the pulmonary artery (Fig. 1b). The aorta itself is frequently appreciably wider just below the ductus than above it for the same reason. The ductus has often been described as spindle-shaped or cylindrical, but in the author's experience this is only exceptionally the case. The short, wide, 'high-pressure' ductus may be virtually cylindrical if it can be said to have any length at all, but the average ductus only assumes a spindle shape if traction on it pulls out some of the wall of the pulmonary artery. Firm pressure just in the angle between the aorta and ductus will restore the apparent cylindricity of the

vessel, and indeed a ligature may be tied here without much difficulty. Such a ligature tends, however, to be obliquely placed and is as insecure as if an attempt were made to close a hole in the side of the aorta by ligation (Fig. 2). It is naturally

FIG. 2.—Correct and incorrect ligatures.

pushed towards the narrowest part of the ductus and then will not fully occlude the lumen of the vessel. The truly effective position for an occluding ligature is at the narrowest point of the ductus, and perhaps a single ligature properly placed there will suffice to obliterate the vessel. Many surgeons recommend multiple ligatures on the ductus; yet if further ligatures are to be tied after the ductus has been ligated at each end, there is a real danger of causing a rupture of the ductus, with catastrophic haemorrhage as a result.

Blalock (1946) met this difficulty by applying an encircling suture at each end of the ductus, transfixing the ductus in the middle and tying another ligature over it. Such an encircling suture at the aortic end would tend to come under excessive tension and might not be truly effective in maintaining permanent closure. A simpler method, which has been used more recently in our cases, is to ligate the ductus near the aortic end and then to close the lumen by a multiple transfixion suture of 3/0 arterial silk placed at the narrowest portion of the ductus (Fig. 3). A second ligature, which was passed but not tied before applying the stitch, is then tied over the narrowest portion of the ductus, that is, near the pulmonary end.

It is probably important to use correct ligature material but there is some difference of opinion among surgeons as to which is best for the purpose. We had formerly used a rather fine (No. 35 or 40) linen thread but latterly changed to the stronger No. 25 thread and feel that this is more satisfactory. Linen thread is stronger than silk and holds a knot very securely: it seems likely that a very thick strong ligature, e.g. the 'umbilical tape' of American

authors, will give a less satisfactory closure than a medium sized thread.

Finally, division of the ductus has been undertaken in cases when it is large or unusually thick-walled. The method we favour is one learned from Professor

FIG. 3.—Ligatures and transfixion suture of patent ductus arteriosus.

A. G. Brom of Leiden, in which Potts' aortic clamps are applied from the lateral aspect of the ductus, which gives more room than if they are placed in the long axis of the descending aorta. The vessel may be progressively divided and sutured, usually without undue difficulty. Clamps similar to Potts' aortic clamps but bent at a right-angle (designed by Miss I. Forshall for neonatal oesophageal surgery)* are very satisfactory when applied to a patent ductus and provide more room for manipulation. The first row of interrupted sutures is covered by a continuous suture on each vessel. It is important if the ductus is wide and short to dissect out and mobilize the aorta above and below the ductus as if for resection of a coarctation. If the ductus is very large it is wise also to open the pericardium in front of the vagus nerve in order to have the left pulmonary artery under direct observation and control in the event of difficulty.

Review of Surgical Material

In Hay and Ward's original series (1956) there were 108 cases and a further 120 are reported here, making a total of 228 cases of patent ductus arteriosus dealt with surgically. There were two deaths in the

* Manufactured by Messrs. Charles F. Thackeray & Sons, Ltd., of Leeds.

whole series, one being the case reported in the first series, where a reversed shunt was found to be present at operation (left to right shunt at previous catheterization) and the ductus was not tied. The second death occurred in the second series and was in a 13-year-old boy with a ductus 14 mm. in diameter and with considerable pulmonary hypertension. Division was successfully accomplished but convalescence was marked by a persistent systemic hypertension, the significance of which was not properly appreciated. He was readmitted 12 weeks after operation and died of uncontrollable haemorrhage during attempted surgical cure of an aneurysm at the site of resection. Autopsy showed that there was a coarctation of the aorta which had been outwardly marked only by a slight curvature of the vessel. This had been noted at the original operation but had not been thought to indicate any significant narrowing of the lumen. If the true situation had been understood it might have been possible to resect the coarctation at the original operation, but because the collateral circulation was undeveloped this may well have proved hazardous.

Other deaths have occurred after ligation of a patent ductus but only when the ductus was one of a group of complicated cardiac abnormalities. Only cases in which the patent ductus was the dominant lesion are included in the present series.

Table 1 gives the composition of the two series grouped according to the size of the ductus and also indicates the failure rate in each group. All cases in which the diameter of the ductus was 7 mm. or less were treated by ligation with or without transfixion suture. In our second series of 120 cases there were 69 in this group and the only failure was in an infant with a ductus 6.5 mm. in diameter and with exceptionally thin walls. Recanalization followed this operation and it may be that the sutures slowly cut through the thin vessel walls. Of 51 cases with a diameter of 8 mm. or more there were four recanalizations and three further cases have murmurs which are suggestive, though not diagnostic, of recanalization. The cases with definite recanalization had ductuses with original diameters of 9 mm. (two cases), 14 mm. and 15 mm.; those in which recanalization was suspected had diameters of 8 mm., 9 mm. and 11 mm. Although recanalization represents failure to achieve the aim of the operation, in all cases the condition of the patient had improved and the shunt appeared to be much smaller than before operation.

Method of Closure

In the first series the only method of closure employed was double ligation. Table 2 shows the

TABLE 2
OPERATIVE PROCEDURES FOR PATENT DUCTUS ARTERIOSUS, 1954-58 (SERIES 2)

Operation	Cases (No.)	Recanalization
Simple ligation	70	5 (+3?)
Ligation and transfixion suture	40	0
Division	10	0
Total	120	5 (+3?)

methods of closure adopted in Series 2. Simple ligation was employed 70 times with five certain and three doubtful recanalizations, ligation and transfixion suture in 40 cases with no recanalization, and division in 10 cases with no recanalization.

Taking the series of 228 cases as a whole it is clear that the risk of recanalization after simple ligation is very small indeed if the ductus is 7 mm. in diameter or less. There was only one example in 122 cases of this size treated in this way.

One hundred and six cases had a patent ductus 8 mm. in diameter or larger, and the situation with regard to these is shown in Table 3. It will be seen

TABLE 3
PATENT DUCTUS ARTERIOSUS OVER 8 MM. IN DIAMETER (COMBINED SERIES)

Operation	Size of Ductus (mm.)	Cases (no.)	Failure to Close	Re-canalization
Simple ligation	8-10 Over 10	62 22	2 8	4 (+2?) 4 (+1?)
Ligation and transfixion suture	8-10 Over 10	9 2	— —	— —
Division	8-10 Over 10	3 6	— —	— —
Operation abandoned	8-10 Over 10	— 2	— 2	— —
Total		106	12	8

that 18 of these cases were not permanently closed after operation, a failure rate of 16%. All these failures were in cases treated by simple ligation. As before mentioned, the failure rate was especially high when the ductus was more than 10 mm. in diameter. Fewer than one in three of these cases (eight out of 22) could be closed by ligation, and recanalization followed in four others. Thus, simple ligation gave permanent closure in less than half of this group of 22 children with a large ductus treated by this method. In the intermediate size of 8 to 10 mm. six out of 66 cases (9%) were not permanently closed.

By contrast there were no failures and no recanalizations in 11 cases treated by ligation and

transfixion alone. The numbers are small and may not be really significant but they suggest that this technique may possibly give better results.

Nine cases in this group of large patent ductus were treated by division with a successful outcome in all except the one death from a hidden coarctation recorded above.

In our last 91 cases there have been no certain recanalizations, although the three doubtful examples are to be included among these. Of these 91 cases, 41 were ligated simply, 40 had an additional transfixion suture as described and 10 were divided. For what it is worth the doubtful recanalizations were all in the group of simple ligations.

Conclusion

Simple ligation is a safe and easy method of obliteration of the patent ductus when the diameter is 7 mm. or less. It may be even more secure if a transfixion suture is employed in addition. Above 8 mm. it seems clear that division should be the method of choice. Our second series of cases covers a transition period in our surgical policy but the failure rate of 4% (five in 120 cases) compares favourably with the previous figure of 14% (16 in 108 cases). Further reduction of the failure rate is probably dependent on more extensive use of division of the medium sized ductus. The overall mortality was 0.9% (two deaths in 228 cases).

Summary

Two hundred and twenty-eight cases of patent ductus arteriosus treated surgically are reviewed.

In 122 cases the ductus was 7 mm. or less in diameter; all were ligated with or without transfixion suture and there was only one recanalization.

In 106 cases the ductus was 8 mm. or more in diameter. In 18 (16%) cases closure was either not complete or not permanent. All failures occurred after simple ligation.

Simple ligation, preferably with a multiple transfixion suture, gives satisfactory closure of the small patent ductus (7 mm. or less in diameter).

Where the patent ductus is 8 mm. or more in diameter permanent closure can only be ensured by dividing it.

Most of the cases reported in this paper were under the care of Professor John D. Hay, and it is a great pleasure to record my indebtedness to him for his stimulating help, both in the clinical work involved and in the preparation of this report.

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