The Patent Ductus Arteriosus
Observations from 412 Surgically Treated Cases

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A patent ductus arteriosus can be recognized with a high degree of accuracy by auscultation and simple office examination. Electrocardiographic and fluoroscopic studies are helpful, but it is rarely necessary to employ more elaborate and expensive forms of investigation. While the condition seldom causes serious incapacitation in early life, it is apt to be accompanied by a very high percentage of serious complications in later life. These facts give strong backing to the conviction that it is desirable to operate upon all children possessing a patent ductus—even though they are asymptomatic at the time—because it is technically much easier to perform a surgical closure of the vessel in this period. Ligation or suture-ligation is successful in a high proportion of cases, but a complete division of the vessel is the ideal method of therapy. In a consecutive series of 369 cases of division there have been no deaths from hemorrhage. The total mortality rate has been 2.1 per cent. For patients who had no complications prior to surgery, the mortality rate was under one-half of one per cent.

There have been many recent therapeutic advances in the fields of cardiology and surgery, among which is the fascinating chapter of cooperation between medical man and surgeon in the recognition of and the treatment of the patent ductus arteriosus and its various complications. During the past 11 or 12 years many articles have been written about various aspects of these problems, but no attempt will be made here to summarize in detail all of this material. Our purpose is merely to set forth for those interested in the subject a few comprehensive statements regarding the detection of the anomaly, the prognosis in untreated cases, the methods which are available for surgical correction, and the results of such operative procedures.

The Clinical Picture

When a ductus arteriosus remains open beyond the neonatal period, the individual has a shunt which is similar to an arteriovenous fistula. Such a communication may be tolerated extremely well if the possessor is fortunate enough to escape superimposed infection and if the shunt is a small one. Under such circumstances humans have had little or no incapacitation, and indeed have lived to advanced age. Unfortunately, such a favorable outcome is not encountered in a high percentage of cases; there are certain hazards which occur rather frequently: (1) The shunt may divert so much blood from the aorta that the peripheral circulation is robbed and the individual has a retarded physical development.
(2) The heart may increase its output, attempting to maintain the peripheral flow at a satisfactory level; while accomplishing this an exceedingly large amount of blood is passed back through the ductus. The individual may be well developed, and indeed be entirely normal in appearance, but the heart will come to embarrassment or failure. (3) Bacterial infection may be superimposed upon the vascular abnormality, the causative organism commonly being the *Streptococcus viridans*. In patients who have been followed over sufficiently long periods of time, the incidence of this complication is probably 25 per cent. (4) There are more rare complications such as aneurysmal dilatation or rupture. The first of the above-named complications appears in childhood, whereas the others are more apt to be problems of adult life, particularly of the third and fourth decades.

An excellent study of the prognosis for the adult with an untreated patent ductus arteriosus has been made by Keys and Shapiro. They point out that subjects who are alive at 17 years of age with an open ductus have a life expectancy which averages only half that of the general population. While a patent ductus usually seems to be an innocuous affair when seen in children, long-term observations show that commonly the outlook is serious because of the likelihood of late incapacitation and shortening of life.

Individuals with a patent ductus arteriosus may have little or no evidence of cardiac embarrassment, or conversely, they may have marked invalidism, depending upon the age of the person and the size of the leak which exists. In general, the abnormality is tolerated well in childhood and decompensation is rare in that period. As a rule, youngsters have endless energy, can indulge in strenuous sports, and are thought to be entirely normal by their parents. In some instances, there is slight to moderate limitation of physical activity; extensive exercise is followed by dyspnea, palpitation, and excessive fatigue. Patients in middle life often have moderate cardiac embarrassment, less commonly they have all of the classical findings of failure. Adults frequently observe that they cannot maintain former levels of work, that fatigue is marked, or that long periods of rest are required. We are increasingly impressed by the number of individuals who present themselves in their thirties or forties, who have had no frank signs or symptoms of cardiac failure, but who have lost their pep and who drag about in their daily existence with no exuberance. While such people are by no means invalids in the common sense of the term, they are nevertheless incapacitated and are limited in their effectiveness and usefulness.

In an important percentage of cases, but by no means in the majority of them, the general physical development is somewhat retarded. When compared with normal children of the same age, the height and particularly the weight are distinctly less than the average normal; in some cases these findings are very striking. In no instance have we seen lack of mental development which could be rightfully ascribed to the presence of an open ductus.

Superimposed *Streptococcus viridans* infection is rarely found in childhood, though we have seen it as early as 4 years. The highest incidence of endocarditis or pulmonary endarteritis is in the third and fourth decades, following which time the frequency diminishes. The complaints include fever, persistent sweating, anorexia, weight loss, chest pain, and phenomena in various parts of the body suggesting arterial embolism. The latter almost certainly indicate that vegetations are not limited to the ductus region, but that they have also developed on the mitral or aortic valves. Blood cultures provide direct evidence of blood-stream infection, and they probably give some information regarding the severity of the invasion.

The physical findings in a case of uncomplicated patent ductus arteriosus are clear-cut. It is important to emphasize that simple examination (with stress upon an intelligent auscultation) can lead to a rapid and accurate recognition of this congenital abnormality in more than 95 per cent of the cases.

The color of the skin and the mucous membranes is normal in most instances, but some pallor is present in others. Cyanosis is never found, unless there is frank cardiac failure and a reversal of blood flow through the ductus. The nails are not clubbed. The heart is normal
or slightly increased in size; great enlargements are rare. The cardiac activity may be within normal limits, but if the ductus is large, there is an increased forcefulness of the impulse and there is a heaving pulsation over the neck vessels. These findings are more apparent in thin subjects than in heavy-set ones. By auscultation a very characteristic murmur is heard in the second or third intercostal space to the left of the sternum. It is continuous, is accentuated during systole, and dies off during diastole; it usually has a rumbling quality. The pulmonic sounds may be replaced by the murmur, or the second sound may be quite accentuated. The murmur has been well described as a "machinery" one, and the physician who has heard it several times should always be able to recognize it thereafter. It may be widely transmitted over the precordium, into the left axilla, up into the neck, or over the back particularly to the left of the spine. While all of the murmur might be transmitted, it is more common to have only the louder systolic portion carried to the cardiac apex, to the neck, or to the back. A ductus murmur is generally one of considerable intensity, and it is accompanied by a thrill in about one half of the cases. The thrill may be continuous or it may be limited to systole; it is most intense over the pulmonic region, and it is seldom felt far from this area.

On theoretic grounds—and from observations in a few patients—it is possible for a tiny ductus to produce a murmur which is limited to systole; under such circumstances the systolic murmur is always of very low intensity. In contrast, any moderate or loud systolic murmur (unaccompanied by a diastolic element) almost certainly arises from some other cardiac abnormality such as a septal defect or a pure pulmonary stenosis. Since 97 or 98 per cent of all ductuses have continuous murmurs, it is an excellent working rule to avoid making the diagnosis of a patent ductus arteriosus unless such a murmur is present.

It is well to bear in mind that the classical sounds of an open ductus may not be found if one is examining a patient (usually an adult) in failure. At that time the pulmonary artery pressure may be exceedingly high, so that a near-equalization between it and the aortic tension gives a reduced ductus flow, no flow at all, or even a reversal of flow. Such conditions will give, respectively, a murmur limited to systole, no murmur, or a variable murmur associated with intermittent cyanosis. A good description of such a case has been presented by Johnson and associates.8

Parents are often disturbed by the fact that a cardiovascular abnormality was not recognized by their physician in the first few years of life. It is important to restore confidence in their doctor by pointing out that it is often impossible to detect this anomaly in infancy. While it is true that some babies with a ductus have a continuous and easily detectable machinery murmur from birth, it is extremely common to find the following series of events. In the early months the aortic pressure is low and the pulmonary pressure is normally high; there is no appreciable flow through the ductus and there is no murmur. In the subsequent year or so the aortic pressure rises and the pulmonary pressure falls; there is some ductus flow which gives a systolic murmur. By the third year the aortic pressure is high and the pulmonary pressure is low; there is now a considerable ductus flow and a typical continuous murmur. From these facts it is obvious that the best of physicians might not have been able to hear an abnormality in early life. Furthermore, it is clear that if one hears a systolic murmur in the first year or two of life, it is not possible to exclude the presence of a ductus; under such circumstances it is well to examine the child again at 3 or 4 years of age, because if a continuous ductus murmur is ever to develop it will surely be present by that time.

While it is not necessary to discuss here all the important differential diagnoses, it is worthwhile to point out a small group of patients who have high interventricular septal defects which lie in such a position that the medial cusp of the aortic valve is incompletely supported, and hence collapses from time to time and gives aortic valve regurgitation. We have seen 10 such cases (about 1 to every 40 ductus patients). The murmur is most intense in the pulmonary area, but it does not have a
truly continuous quality. It is more properly described as a "to-and-fro" murmur, which on occasions is exceedingly difficult to differentiate from the continuous murmur of an open ductus. Patients with these high septal defects have a very low diastolic pressure (because of the aortic valve insufficiency), important A-V conduction defects by electrocardiographic tracings, and greatly increased pulsations of the aortic arch and pulmonary arteries by fluoroscopic study.

Ductus patients usually have systolic blood pressures which are normal for their respective ages. The diastolic level is normal or depressed, depending upon the size of the ductus. Small fistulas do not give any important change in the diastolic pressure, but large leaks are accompanied by diminutions to 50 or 40 mm. of mercury. When the pulse pressure is high, there may be a Durozies's sign or a visible capillary pulsation in the nail beds.

The femoral pulsations are excellent, the blood pressures in the legs are above those in the arms—points of importance in ruling out a coarctation of the aorta.

In a rough way, it is possible to gain some impression of whether one is dealing with a ductus of small, medium, or large size. If the heart is normal in size or is only slightly enlarged, if the beat is not overly vigorous, if the x-ray changes are minimal, and if the diastolic pressure is only slightly diminished, it is reasonable to assume that the shunt is a relatively small one. On the contrary, if the heart is moderately enlarged, the murmur is intense and is possibly accompanied by a thrill, the diastolic pressure is moderately depressed, and the fluoroscopic findings are those of considerable left-right shunt, one can assume that the ductus is of moderate or average size. In rare cases (possibly 1 out of 40 or 50 patients) the heart is quite enlarged by physical examination, there is a heaving beat which shakes the patient's chest or even the bed on which he lies, there are forceful pulsations in the neck, there are marked fluoroscopic changes, and the diastolic pressure is markedly depressed (though in a few instances the pulmonary pressure may be so high that the peripheral diastolic pressure is not particularly low); one can instantly predict that the shunt is of tremendous size. Under these latter circumstances one is apt to hear additional murmurs which are indicative of a greatly augmented flow through the left side of the heart; the large amount of blood (which may be two or two and a half times normal) will set up murmurs as it rushes through a normal mitral or aortic valve orifice. Therefore, in addition to the continuous murmur in the pulmonary zone, one will hear a separate diastolic murmur in the mitral area, or a separate systolic murmur in the aortic region. It is important to recognize these occasional cases with tremendous shunts so that the patient's family can be informed of the risks which are much higher than those of average cases, and so the surgeon can be adequately prepared to deal with a situation which will present technical difficulties enormously greater than those which are ordinarily encountered.

**Laboratory Findings**

These patients do not have polycythemia.

Electrocardiographic tracings are helpful in a surprisingly small percentage of cases, and we have not depended upon them in more than 1 or 2 per cent of cases to help establish the diagnosis. In the vast majority of cases, particularly in children, electrocardiograms are normal and there is no axis deviation. In some tracings, particularly from adults, there may be left-axis shift, especially in the presence of a shunt of moderate or large size. Fibrillation or indications of myocardial damage may be found in some of the older subjects when the cardiac strain has been excessive. Electrocardiographic study is most valuable as a tool in excluding cases with other cardiac lesions. Particular attention should be given to the presence of any right-axis deviation, the finding of which should make one strongly suspect some other anomaly as a pulmonic stenosis or a tetralogy of Fallot. In only 4 patients have we found right preponderance when there was a pure patent ductus arteriosus; presumably the flow into the pulmonary circuit was very high and the right ventricle hypertrophied because it was pumping against an increased pressure. Whenever a prolonged P-R interval is encountered, one
should suspect that the auriculoventricular conduction apparatus is longer than normal and is probably stretched out around a septal defect.

Roentgenologic studies often help in the recognition of a patent ductus arteriosus, and film and fluoroscopic studies are also valuable in ruling out other cardiac abnormalities and rheumatic valvular disease. With a pure patent ductus the findings are indicative of a shunt from the aorta into the pulmonary circuit. The heart is slightly or moderately enlarged, particularly in transverse dimension; marked enlargement is rare. While it may be difficult to tell whether there is enlargement of one or both ventricles, not infrequently it is possible to show that the left chamber is the predominant one. Often the pulmonary artery (frequently incorrectly called the pulmonary conus) is fuller than normal and projects outward from the left border of the cardiac shadow. Likewise, vessels within the lung fields, particularly in the hila, are apt to have increased fullness. In about half of the cases the hilar vessels have a “hilar dance”; this may be quite difficult to observe, and too much reliance should not be placed upon the presence or absence of this point. Left anterior oblique and lateral views give evidence of left auricular enlargement in about half of the cases; this dilatation is best seen as an encroachment on the barium-filled esophagus. Such enlargement is dependent upon an increased flow through the left side of the heart; the left ventricle enlarges somewhat, whereas the thin-walled auricle dilates to a greater degree. Fluoroscopic observation and kymographic tracings generally show an augmented pulsation, particularly of the left ventricle, the aortic knob and the pulmonary artery. It is important to emphasize that roentgenologic findings are not specific for a patent ductus arteriosus; they may be mimicked by certain other lesions. A pure pulmonary stenosis is often accompanied by a considerable dilatation of the pulmonary artery beyond the obstruction. Septal openings are left-right shunts which give findings of an increased pulmonary flow. A fenestra between the first portions of the aorta and pulmonary artery gives roentgenologic pictures exactly like those of an open ductus. When the roentgenologist finds evidence of a left-right shunt, he is presented with the possibility of making several diagnoses. If in addition to an augmented pulmonary flow there is right ventricular enlargement, he should lean toward a diagnosis of interventricular septal defect. If there is associated right auricular enlargement, an interauricular septal defect is suggested. If there is no enlargement of the right side of the heart, he can be reasonably sure that the patient has a patent ductus (or one of the rare fenestras between the first portions of the aorta and pulmonary artery). If a ductus is small, the roentgenologic picture is normal or shows little change therefrom. Conversely, when the ductus is of moderate or large size, the roentgenologic findings are clear-cut and striking.

Cardiac catheterization can give direct measurement of various blood flows, and can give a reasonably accurate idea of the size of the shunt, but it is not necessary as a routine study for average cases. Of course, there are many patients with obscure abnormalities of the heart who should be studied by all means available, including catheterization, but it has been our experience that it is extremely rare to pick from this group a ductus which can come to operation which could not have been recognized by simpler means of roentgenography and cardiac auscultation.

More than 95 per cent of patent ductuses can be recognized with great facility and rapidity. While electrocardiographic studies and roentgenologic observations are helpful, it is well to emphasize that the vast majority of these lesions can be accurately detected in a few moments by intelligent use of the stethoscope. Furthermore, if a characteristic murmur does not exist in a given patient, too much stress should not be laid on laboratory or roentgenologic findings which might suggest the presence of a ductus, because operation under such circumstances will almost certainly lead to the finding of some other cardiovascular defect.

Considerations of Surgical Technic

It is not the purpose of this communication to discuss the details of operative technic; hence, only a few general statements will be made in this regard.

While we formerly employed cyclopropane
anesthesia for these cases, the fact that about half of our fatalities seemed to have been attributable to cardiac arrest or irregularity under this anesthetic has now influenced us to abandon cyclopropane and to employ ether and oxygen as a routine choice. Obviously, the anesthesia must be given with a closed system. An intralaryngeal tube should always be used to ensure an adequate airway at all times and to facilitate the suction-removal of any secretions from the lower respiratory tract. This gives the best chance for maintaining a quiet anesthesia during operation and it tremendously reduces the incidence of postoperative pulmonary complications.

There are some who have advised a posterior thoracic approach, an exposure which seems to us to be unduly complicated and quite unnecessary for the average ductus case. It is a more time-consuming exposure and closure. It certainly does not give the best view of the ductus. Its only possible superiority would be in the rare case with a huge ductus wherein one might want to place a large Potts-Smith-Gibson or a Freeman clamp on the aorta to isolate the ductus area without completely occluding the entire aortic lumen; such an application is impossible or is awkward from the antero-lateral approach. In all of our cases the chest opening has been through a left antero-lateral incision, made below the breast for cosmetic reasons, cutting the third intercostal muscles all the way around to the angle of the ribs. When handling adults, or when dealing with patients with large ductuses in whom maximum exposure is desirable, the cutaneous and latissimus dorsi incisions should be carried well around to the posterior axillary line. These exposures have been so satisfactory that we see little reason for changing them.

When the mediastinum is entered in front of the lung root, it is hardly necessary to emphasize that a thorough knowledge of the local anatomy, and of the congenital abnormalities which are apt to be encountered in this region, is a sine qua non. In so crowded a space a single false step can lead to disaster. Probably the biggest cause of failure in this type of surgery has been the trepidity of those who felt unsure of the exact positions of the large vessels; being fearful of setting up a rousing hemorrhage, they do not adequately free the ductus from its surrounding vestments. Under such circumstances it is almost impossible to tackle the ductus with any assurance of completing a thorough job. Conversely, an accurate anatomic knowledge of the area will allow one to proceed rapidly and without risk, to free the ductus entirely of all its coats, to clean off the adjacent aorta, and to mobilize adequately the nearby pulmonary artery. Only by such an extensive and thorough freeing can one subsequently deal with the ductus in a proper manner.

In the earlier part of our work only ligation of the ductus was employed, using various types of material to accomplish this. In a series of 43 cases it was found that 80 per cent of the patients obtained a complete obliteration and a permanent closure of the shunt, 10 per cent had the ligatures cut through and some of the fistula re-established, and the remaining 10 per cent had ligatures which were not put on tightly enough to close the vessel completely. While these over-all results might be considered satisfactory, it is obvious that they were not perfect. These observations are similar to those of Shapiro and Johnson who analyzed (by personal communications with various physicians) 626 patients operated upon by 46 surgeons; the mortality rate in uninfected cases was 4.9 per cent and the incidence of recanalization was at least 8.7 per cent. Blalock has developed a method of "suture-ligation" which is distinctly better than all of the ligation technics which we originally employed; it uses two encircling stitches at either end of the ductus, mattress sutures through the ductus, and an encircling tape of linen. Scott has recently published a series of 161 closures of this type with excellent results. However, it has been widely recognized by vascular surgeons for many decades that closure of any large artery or shunt is most satisfactory when accomplished by a complete severance of the vessel; we believe that this fundamental principle also applies to the treatment of an open ductus for it gives the best assurance that the shunt has been completely closed off and that it will not recur. Complete division certainly seems to be the ideal method of therapy, provided it can be accomplished without assuming a high risk. While complete division
would seem to be fraught with dangers of uncontrollable bleeding, we have now performed 369 complete divisions without the loss of a single patient from hemorrhage at the time of operation or subsequent thereto. Eight of these ductuses were divided in patients who were being operated upon primarily for excision of a coarctation of the aorta. Obviously, the division technic requires more experience and care, yet we have found it possible to turn over a large number of these cases to assistant residents on the thoracic service who have performed a division in every instance without the loss of a single patient from hemorrhage. During the period in which we have divided the ductus in 369 cases, 3 patients have been encountered who had enormous shunts (larger than 1.5 cm. in diameter) from which we withdrew without any attempt to close the vessel; division seemed to be too formidable and risky; certainly any form of ligation or suture-ligation would have been ineffective and possibly fatal because of subsequent erosion and hemorrhage. With these rare shunts of great size some special technic must be developed, such as that suggested by Freeman and more recently by Conklin and Watkins.2

The patient's postoperative course can be made much more comfortable by injection of a local anesthetic in the posterior portions of the upper four or five intercostal nerves while the chest is open. For the last 10 years we have routinely infiltrated Nupercaine (in oil) in or about these structures, producing a regional hypesthesia which lasts for a week or 10 days.

A very careful closure of the chest has much to do with the patient's postoperative comfort and with the minimizing of accumulating fluid within the pleural cavity. In all cases some fluid does collect in the pleural sac, but in only a small percentage of subjects is this of sufficient degree to require postoperative tapping.

While chemotherapy is wholly unnecessary in many cases, there is some justification for using it as a routine prophylactic measure in the hope of avoiding postoperative pulmonary complications. It has long been our custom to give appropriate chemotherapy for 24 hours before operation and to continue it for four or five days thereafter.

Oxygen tents are not necessary during the postoperative period. If the left lung is kept in a state of full or nearly-complete expansion, the respiratory apparatus is functionally satisfactory and an oxygen tent is a needless encumbrance.

Patients can be allowed out of bed on the fourth or fifth day and can be ambulatory shortly after that. Routinely, they are discharged from the hospital on the eighth or ninth postoperative day. They are allowed increasing physical activity for the subsequent week or two, and ordinarily are back to complete and unrestricted activity or employment one month after operation.

**Selection of Cases for Operation**

From an intense interest for 12 years in the surgical therapy of ductus cases, the following general policies have been developed and adopted:

Certainly, there can be no disagreement with the recommendation that operation be undertaken for all patients with retarded physical development which cannot be accounted for on some other basis. Likewise, it is generally agreed that cardiac fatigue or failure demands operative closure of the shunt, so that the mechanical burden on the heart can be immediately reduced. Operation is also desirable for those subjects—mostly in the third and fourth decades—who do not show ordinary signs of cardiac failure but who nevertheless drag about with fatigue, a reduced activity, and a definite knowledge that it is becoming increasingly difficult to carry on the job of life. Such patients are more numerous than are those with classical findings of cardiac failure; to operate upon them is extremely satisfying, because they can be restored to normal life and vigor.

Regarding the possible benefits of surgery for patients who have blood stream infection with *Streptococcus viridans*, thinking has taken several turns during the past 10 years. During 1938 and 1939 when this serious malady could not be cured in more than 5 or 10 per cent of cases with the sulfonamides and other measures which were available, there seemed to be little theoretic reason why surgical closure of a shunt should be of much benefit. However, in
1940 Touroff and Vesell\textsuperscript{10} showed in a dramatic way that such infection could be cured by obliteration of the ductus unaccompanied by sulfonamide therapy. In more extended observations, Touroff demonstrated that the cure rate could be raised to about 75 per cent by surgical means. We corroborated this with 9 recoveries in 12 infected cases which were surgically treated in the pre-penicillin era. By the mid-forties such recovery rates could be obtained, or even bettered, by penicillin therapy alone. This might seem to indicate that the infected patient should now be treated solely by penicillin, aureomycin, chloromycetin or one of the newer chemotherapeutic agents, but two additional factors should be taken into account. First, it must be borne in mind that subsequent attacks are not uncommon and it is possible that a second infection might come from an organism which is resistant to therapy. Second, while it is possible to cure infections in a high percentage of cases by appropriate chemotherapy, this does not necessarily mean that the entire cardiac mechanism can be returned to normal. There are many studies of patients whose infection has been dispelled but who in an appreciable percentage of cases are left as cardiac invalids because of the damage or scarring which remains in the myocardium. Obviously, the degree of such injury to the cardiac musculature depends upon such considerations as the duration and severity of the infection; it is known to vary greatly from case to case. The possibility that such pathologic change can reside in the musculature makes it desirable to reduce the mechanical load of the heart by surgically closing the open ductus. It is our present-day opinion that (1) Infected patients should be intensively treated by chemotherapeutic means for an appropriate length of time. If the blood stream cannot be sterilized by this alone, operation should be added during the active stage. (2) If it is possible to sterilize the blood stream by drugs alone—which can be accomplished in four-fifths of the cases—operation can be deferred for several months. This delay in operation has several advantages. In some cases it allows inflammatory reactions in the ductus wall to subside and thus lessens the technical difficulties of surgery. It allows the patient to recoup somewhat from the financial onslaught of an attenuated illness. It permits him to get out of the hospital for a period and to convalesce satisfactorily before undertaking a major operation. In summary, all infected cases should be treated by drug therapy plus surgery, the latter being either early or delayed, depending upon the efficacy of the drug therapy.

After a consideration of the above three categories (the physically retarded youngster, the patient with cardiac failure or fatigue, and the subject with superimposed infection) one is left with a large number of patients—particularly in the childhood ages—who have no important symptomatology and who repeatedly raise the question of whether or not operation should be advised. The answer to this query depends almost entirely upon the fatality rates and the promise of a permanent ductus closure which can be offered by the surgeon. Obviously, if surgical complications or mortality rates are high in a given institution, it is preferable to leave these young subjects alone. Conversely, in a large series of such patients we have been able to demonstrate that permanent closure can be assured by division of the ductus, that complications are almost nil, and that fatalities are distinctly less than 0.5 per cent. With this record, we feel fully justified in advising surgical closure of the ductus for all children and young adults, even though they are symptom-free at the moment. Without doubt, this approach will mean the subjection to operation of an occasional individual who admittedly might be fortunate enough to go through a long life with no important troubles from a small, open ductus. However, when considering the group as a whole, there can be no question about the fact that many future complications (such as cardiac fatigue and endarteritis) can be prevented and that the surgical risks are far less than is the risk of leaving such subjects untreated. Some clinicians still feel that it is preferable to avoid surgery for all who are asymptomatic, employing it only with those who develop complications in future years. This attitude certainly increases the surgeon’s difficulties. Ductus operations in the young can be performed with relative facility, whereas
those in older individuals give much anxiety because the approach into the mediastinum is deeper, the regional vessels are more rigid and difficult to deal with, and the cardiac reserve is reduced. We are strongly impressed by the number of patients who had been entirely asymptomatic in childhood and in their teens, but who then present themselves in their twenties or thirties with symptoms which physicians would universally agree call for operative intervention. Operations on these older people do not carry higher fatality rates in our series but they certainly can tax the surgeon’s ingenuity. A few experiences of this kind certainly indicate that it is far wiser and easier to operate upon patients in earlier years of life when the operative exposure is shorter, the cardiac reserve is greater, and the regional vessels are softer, elastic, and much easier to work upon. In summary, we believe that it is good “prophylaxis,” which can be obtained at a negligible mortality rate, to advise surgical closure of the ductus for all children and young adults even though they are symptom-free.

Finally, what advice should be given those rather rare patients one sees in the middle years (35 to 50) or more advanced ages (above 50) who have always been symptom-free. These almost always have moderate-sized or small shunts, the larger ductuses having proved fatal in earlier life; the mechanical burden on the heart is therefore seldom excessive. Furthermore, these people, while not entirely free from the possibility of superimposed bacterial infection, have passed the years of peak incidence of this complication; it is becoming a decreasing menace for them. These considerations, plus the fact that operation in this time of life is certainly not easy, probably make it wise to avoid operation in the middle-aged asymptomatic group and to refuse it entirely in the older group. (This attitude for the asymptomatic middle-aged and elderly subjects should in no way make one hesitate to proceed with operation for anyone who has important symptoms in advanced years. We have operated upon a woman of 51 with marked incapacitation who was tremendously benefited by surgery.)

A consideration of the indications for operation should include some comment regarding the ages during which it is preferable to undertake this form of surgery. In general, if there are pressing indications for operation such as the stunting of physical growth, cardiac embarrassment, or superimposed infection, therapy should be undertaken with complete disregard for the age or size of the patient. We have operated upon an 11 month old baby who weighed but 13 pounds and who had marked physical retardation and also had cardiac failure; at the other end of the scale a woman of 51 was operated upon because of marked pulmonary hypertension and incapacitation. Both of these patients had excellent recoveries. Regarding operation on asymptomatic subjects, operation can be performed within a wide span of years. While it is quite possible to do so, there is seldom need for undertaking such a measure before 3 or 4 years. The surgeon still has excellent vessels to work upon until 15 or 20 years of age, though this limit is by no means a sharp one. In short, for the elective cases, optimum ages run from 3 or 4 years up to 15 or 20 years; the best chances for a smooth and relatively easy surgical procedure are generally provided between the ages of 6 and 12.

The age distribution of 412 patients in our series of surgically treated cases was:

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While many elective thoracic procedures were once thought to be performed most safely during summer months, this limitation no longer exists. There need be no hesitation about conducting ductus operations at any time of the year. During the last nine years we have not recognized any case of postoperative pneumonia, a situation which is attributed to the routine use of antibiotics before and after surgery and to the maintenance of a dry airway during operation.
An associated interventricular or interauricular septal defect is not a contraindication to surgical closure of an open ductus. A ductus does not compensate for either of these anomalies; all three defects are left-right types of shunts. Obviously, operation on a patient with an open ductus and a septal defect will not restore the cardiovascular apparatus to normal, but at least the heart can be considerably improved by taking off some of its mechanical burden. We have operated upon 19 such patients, all of whom survived.

Similarly, rheumatic mitral stenosis is not a contraindication to operative closure of the ductus, provided there is no important rheumatic activity at the time that operation is undertaken. Indeed, an associated rheumatic mitral stenosis is a clear-cut indication for surgical closure of the ductus, because such therapy will reduce the amount of blood which has to flow through the left side of the heart and the narrowed valve. Obviously, under these circumstances the cardiovascular apparatus cannot be made normal, but it can certainly be improved. We have operated upon 4 such individuals, all of whom survived.

The combination of pulmonary stenosis plus a patent ductus is rare; it is not a contraindication to operation on the ductus. A ductus in no way compensates for the bottleneck at the pulmonic valve (this is in contrast to the compensatory effects of a ductus in cases with a tetralogy of Fallot). Operative closure of the ductus is a desirable procedure, even though it will not return the cardiovascular apparatus to normal. We have operated upon 2 children with this combination of abnormalities; both survived. If in future years the pulmonary stenosis is of sufficient degree to produce important symptoms, the pulmonary valve opening can be enlarged by the Brock technique.

A word of caution is necessary regarding individuals who have any cyanosis, and who also have the auscultatory sounds of a patent ductus arteriosus. With these findings, the ductus should never be closed surgically, because it almost certainly is acting as a compensatory mechanism for a complicated cardiovascular defect.

Results of Surgical Therapy

The surgical treatment of a patent ductus arteriosus, while extremely promising since the earliest attempts, has been attended by falling fatality rates and by more satisfactory results. In the present day, these surgical undertakings should seldom be followed by any serious complications and the mortalities should not be more than a few per cent. In our series at the Children’s Hospital and the Peter Bent Brigham Hospital of Boston 412 patients have been operated upon, 43 of whom had some form of ligation and subsequently 369 had complete division. In the latter group there have been 8 fatalities, giving an over-all mortality rate of 2.1 per cent. This series included a considerable number of patients who had some degree of cardiac failure and also 12 who had active infection at the time of operation. In those patients who were asymptomatic prior to operation, the mortality rate has been slightly less than 0.5 per cent. The cause of fatality in our division cases were as follows:

<table>
<thead>
<tr>
<th>Case</th>
<th>Age</th>
<th>Cause of Fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>Mediastinitis and bacteremia (S. aureus).</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>Cardiac dilatation, because of hypoplastic descending aorta.</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Cardiac arrest from cyclopropane anesthesia.</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Collapse immediately following operation, from cyclopropane anesthesia.</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Cardiac arrest after ductus division. Cyclopropane anesthesia. Cerebral anoxia; death 48 hours later.</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>Cardiac arrest, ? cyclopropane death.</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>Cardiac arrest during mediastinal dissection, probably cyclopropane death.</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>Mediastinitis and bacteremia (S. aureus).</td>
</tr>
</tbody>
</table>

In the surviving patients certain changes have been found which will be separately considered as follows:

The diastolic blood pressure rises immediately to normal, the extent of rise varying with the depression which had existed prior to operation. When the leak from the aortic arch has been stopped, the peripheral system is able to maintain the diastolic pressure at normal physiologic levels.
In almost 90 per cent of the cases all murmur has disappeared following division of the ductus. In the remaining patients, the continuous machinery murmur has disappeared but there remains a systolic murmur which is believed to arise from a second cardiovascular defect or is a functional sound. Twenty-eight of these have as residual defects the following:

Septal defects ............................................. 19
Pure pulmonic stenosis .................................. 2
Rheumatic mitral stenosis ................................ 4
Bicuspid aortic valve ..................................... 3

In addition to these 28 with known pathologic lesions, there are a similar number who are left, following surgery, with a grade 1 or 2 soft systolic murmur in the pulmonic area which is not accompanied by any other physical sign, roentgenologic change, or electrocardiographic abnormality; we believe these murmurs to be functional, but it is of course possible that some of these patients do have minor intracardiac anomalies.

The activity of a heart strikingly diminishes after surgical closure of a ductus. This can be appreciated by inspection of the thorax, by noting reduced prominence in pulsations of the neck vessels, and by fluoroscopic or kymographic studies. A heart which before operation had a very heaving, pounding and forceful beat, will be found to have a postoperative activity which in comparison is quiet and much less vigorous. Postoperative diminution in cardiac action is not great if the ductus had been a small one; in contrast, obliteration of a large ductus is followed by a decrease in forcefulness which is quite evident to both physician and patient.

Some change in the over-all size of the heart can often be expected following closure of a shunt. Cardiac enlargement can represent hypertrophy or dilatation, but generally it is a combination of the two. If enlargement is due primarily to dilatation, this will disappear immediately following surgical closure of the ductus. If hypertrophy has existed, the heart apparently has little ability to shrink, but observations in a growing individual will show that the thorax and other body measurements increase during the subsequent year or two, whereas the heart grows very little during this period, at the end of which time a normal cardiothoracic ratio becomes established. When a ductus shunt has been small, there is little diminution in the size of the heart following operation; in contrast, when a fistula of large size has been closed, the over-all dimensions of the heart will decrease markedly. We have seen diminutions in transverse diameters of as much as 1.5 cm.

Individuals who had essentially normal physical development before operation show no important changes following surgery. However, underweight subjects, most of whom are in the childhood group, will exhibit a surprising and gratifying gain in weight to an amazing degree during the year or two subsequent to surgery. Apparently, closure of a shunt increases the peripheral flow of blood to the body and thereby improves the general physical state.

Eppinger, Burwell and Gross and others have accumulated data on the changes in circulation following closure of a patent ductus arteriosus. The figures all clearly indicate that obliteration of the shunt can greatly diminish the output of the left side of the heart and presumably the cardiac reserve is accordingly improved.

In the pre-penicillin era 12 patients were operated upon during infection with Streptococcus viridans. Nine of these survived and were cured, whereas the others went on and eventually died of their infectious disease. Now that penicillin and other chemotherapeutic agents are available, one is not justified in using surgical means alone. We have employed surgery in 6 patients who had been already cured of their infection by penicillin or other drugs. All 6 of these have survived, and while it is not possible to make any objective measurements of gains which might have accrued, it is reasonable to believe that the closure of the shunt was of value in the rehabilitation of these subjects.

For those children and young adults who have been operated upon for "preventive" reasons there is universal agreement that they or their families feel better on psychologic grounds for having had the anomaly corrected. Many of these people had previously
harbored a fear that something disastrous was hanging over their heads, and they were much relieved when this anxiety was removed—a consideration of no small significance. While no objective measurements can be made of what has been accomplished, it is quite reasonable to believe that some of these individuals have been kept free of complications which might otherwise have developed. The majority of patients in our series have been operated upon for prophylactic reasons; they have been followed as long as 12 years, and none has yet developed endarteritis.

SUMMARY

A patent ductus may exist through a long life with few if any symptoms, provided the leak is a small one. Commonly, patients develop cardiac fatigue in adult life, even though they might have been symptom-free in childhood and adolescence. Cardiac strain may be severe enough to lead to failure in adult life. If patients are followed for sufficiently long periods of time, superimposed infections will be found in about one-fourth of them. Patients with a ductus who reach maturity have a life expectancy which is only about half of that of the population as a whole.

Patent ductuses can be recognized with a high degree of accuracy by simple office examinations which are available to any physician. Fluoroscopic and electrocardiographic studies are helpful in the study of any patient with a cardiovascular anomaly, but a diagnosis of a patent ductus should rarely be made from these two tests if the patient does not have a typical continuous murmur in the pulmonary area. Angiocardiographic and catheterization studies are helpful in study of occasional patients, but they are not necessary for the recognition of average ductus cases.

Surgical treatment for the patent ductus arteriosus has now been carried out by many surgeons and clinics. The operation has been placed on a sound basis with over-all excellent results and with exceedingly low mortality rates.

It is clear that surgical closure of a ductus should be performed for those children with physical retardation in growth, for all who have any evidence of cardiac fatigue, embarrassment or failure, and for those who have bloodstream infection, even though the latter has been cured by chemotherapeutic means. Some clinicians prefer to defer operation for children and adolescent individuals who are symptom-free. It is our firm conviction, based on low surgical fatality rates, that it is advisable to operate upon all children and young adults who have an open ductus, believing that this prophylactic procedure is of considerable value in warding off cardiovascular complications in later years.

An open ductus can be closed by some form of ligation, by the improved suture-ligation technic of Blalock, or by complete division. We believe that the latter is the ideal measure and that it can be carried out satisfactorily as a routine procedure without undue risk, provided the operator is willing to study and develop the technic and has a reasonable familiarity with vascular problems. In a series of 412 ductus patients treated by operation the last 369 have had complete division of the ductus, without fatality from hemorrhage at the time of operation or subsequent thereto. In this division group there have been 8 deaths from various causes, giving an over-all mortality rate of 2.1 per cent. For patients who had no complications prior to surgery, the mortality rate was under 0.5 per cent.

Studies on patients who have been operated upon leave no doubt about the benefits of closure of a shunt of this type. Experience from many sources clearly indicates the effectiveness of surgical treatment when various complications have already developed. Follow-ups, some as long as 12 years, also give ample backing to the use of the operation as a prophylactic measure for patients who have not previously had cardiovascular symptoms.

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ROBERT E. GROSS and LUTHER A. LONGINO

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