Phonocardiography in Patent Ductus Arteriosus

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The study of 28 patients proved that patients with uncomplicated patent ductus arteriosus have a typical phonocardiographic picture. This consists of a single late systolic-early diastolic murmur which may be either continuous or noncontinuous. These patients also have no electrocardiographic evidence of right ventricular hypertrophy and no elevation of pulmonary arterial pressure. Atypical murmurs are found only when additional aortic or pulmonic lesions or severely elevated pulmonary pressure due to intrapulmonary vascular changes is present. The high percentage of atypical or complicated ducti in infancy explains why infants frequently have atypical murmurs. Phonocardiography increases the accuracy of diagnosis.

In many congenital heart diseases, diagnosis can be made without resorting to cardiac catheterization or angiocardiography. "The latter procedures are useful adjuncts but by themselves seldom give the correct answer. Furthermore, they are not innocuous procedures; therefore, they should not be used routinely, but only to obtain specific information on some particular point."

The diagnosis of uncomplicated patent ductus arteriosus can almost always be made by auscultation. However, the accuracy of auscultation is somewhat impaired by several limitations of the human ear and, moreover, cannot give information about low-pitched sounds, the exact timing of murmurs, and the configuration of the murmurs. Phonocardiography, on the other hand, especially if performed in close connection with and under the guidance of the stethoscopic examination, is able to supply all the above information and may be a useful tool for diagnosis.

We have tried to find out if any typical phonocardiographic pattern might be useful for diagnosis in congenital heart diseases, starting with patent ductus arteriosus. Therefore, a series of observations, based upon graphic studies of the heart sounds and murmurs was started. Correlation of these with all other clinical and laboratory data, and confirmation of diagnosis by thoracic exploration or autopsy, was a necessary complement of the study.

This paper presents the results of the study of 28 cases of patency of the ductus which were confirmed by surgery or autopsy, all other cases having been discarded.

HISTORY

Comprehensive and systematic studies of phonocardiography in congenital heart diseases are not available. More numerous are studies in cases with patency of the ductus. Their mention should be preceded by that of the auscultatory findings on account of the close connection between auscultation and phonocardiography.

Clinical diagnosis of patency of the ductus was first reported by Bernutz in 1847. Reliable clinical observations are rare in the following years so that only 20 cases were published until 1893. It is interesting, but not accidental, that the great majority of the cases reported up to that time had cardiac failure or pulmonary hypertension; this conclusion can be reached by reviewing the findings in the light of our present knowledge.

In 1849 Skoda described the typical murmur of patent ductus as "a continuous murmur with systolic reinforcement" best audible over the pulmonic area. In 1867 Gerhardt stated that, although the murmur may vary considerably in intensity, it usually has a systolic accentuation and continues into

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diastole. He also described a decrease of intensity of the murmur following sustained inspiration. On the other hand, several other investigators noted only a systolic murmur.\textsuperscript{1-6} More recent publications again mention the possibility that the murmur may be only systolic. Abbott\textsuperscript{10} stated that "... the presence of a patent ductus is not always marked by adventitious sounds; when murmur is present, it may be short and systolic in rhythm." Taussig\textsuperscript{11} mentions that, in infancy and early childhood, patency of the ductus usually causes only a systolic murmur.

When routine physical examination became more widespread, patency of the ductus was recognized as the second most frequent congenital abnormality. Occasional diagnostic errors were still demonstrated by autopsy.

Following successful ligation of the ductus by Gross,\textsuperscript{12} accurate diagnosis became even more imperative on account of the possible danger which may result to the patient by either an exploratory thoracotomy or undue delay of surgery.

Patency of the ductus with normal pulmonary pressure and patency of the ductus with elevated pulmonary pressure (so-called reversed shunt) have been established as two separate clinical syndromes, with the help of cardiac catheterization. The second group, however, includes only about 5 per cent of the cases.

The murmur of patent ductus is its most distinctive feature and a reliable diagnosis can be made if this is present, even in the absence of any other symptoms or signs. Routier\textsuperscript{13} in France was the first investigator to record this murmur graphically, demonstrating the murmur in 14 patients between the ages of 4 and 47. In 1943 Hubbard\textsuperscript{14} published another phonocardiographic study of patent ductus. Without mentioning the number or ages of his patients, he stated that "the records are so distinctive as to permit diagnosis from examination of the tracing alone." Routier, as well as Hubbard, found both systolic and diastolic vibrations. Hubbard observed a late systolic, while Routier mentioned an early diastolic accentuation of the vibrations. In several textbooks and studies\textsuperscript{2, 3, 15-20} phonocardiograms with a continuous murmur which has either a late systolic or an early diastolic accentuation and which "rides over the second sound" are reproduced.

Hultgren and coworkers\textsuperscript{21} presented eight cases of patent ductus with pulmonary hypertension. The phonocardiograms of six cases were supposed to reveal only a systolic murmur. However, diastolic vibrations can be seen in three patients, even though atypical.

Reinhold and Nadas\textsuperscript{22} found a crescendo late systolic murmur in all typical cases with patent ductus and in five of seven atypical cases.

\section*{Material and Method}

The present study deals with a group of 28 patients in whom the clinical diagnosis of patent ductus was confirmed by surgery in 25, by autopsy in two, and both by surgery and autopsy, in one. Twenty-four were studied at Cook County Children's Hospital,\textsuperscript{*} and three at Mount Sinai Hospital of Chicago, while one is a case who died at Beth Israel Hospital, Boston.

Before undergoing surgery,\textsuperscript{†} all patients were studied by means of x-ray, fluoroscopy, electrocardiography, and phonocardiography; 13 were also studied by cardiac catheterization and most of them, by angiography. Most phonocardiographic tracings were taken with a Sunborn Twinbeam Cardilette, the others with the Sanborn Stethocardiette. Recordings were made over the usual auscultatory areas (apex, midp ruecordium, pulmonic, aortic, tricuspid areas) with the stethoscope and logarithmic devices. Regional low-frequency tracings with the linear microphone were also taken.

\textit{Age and Sex.} One patient was 5 months old, another, 12 months old and still another, 14 months old. Altogether, 11 cases were 5 years of age or younger. Eight cases were between 5 and 10; four were between 10 and 20; two between 20 and 30; and 3 between 30 and 40 years of age. There were 24 females and 4 males.

\textit{Diagnosis.} The diagnosis of patent ductus was made in every case prior to surgery. Three patients also had coarctation of the aorta, three had a small ventricular septal defect, and one had a slight pulmonic stenosis.

\textsuperscript{*} Catheterization studies were done by Drs. D. Fischer or R. Dillon.

\textsuperscript{†} All surgical cases were operated on by Dr. E. F. Fell of the Cook County Hospital except two cases which were operated on by Dr. S. Mackler of Mount Sinai Hospital.
Typical continuous murmur (Case 7). The phonocardiogram taken at the pulmonic area shows a continuous murmur throughout systole and diastole: it has a systolic accentuation and overrides the second sound. (A) Stethoscopic tracing and electrocardiogram in lead II. (B) Logarithmic tracing and jugular tracing.

RESULTS

A summary of the data of 28 patients between the ages of 5 months and 38 years is given in table 1.*

Phonocardiograms

The findings in tracings recorded at the pulmonic area, apex, and aortic area, are separately analyzed.

(A) Pulmonic Area. A typical murmur was present in 24 of the 28 patients. In 13 patients there was a continuous murmur throughout systole and diastole while in the other 11, either the systolic or the diastolic component (more frequently the latter) was shorter. A late-systolic crescendo plus early-diastolic decrescendo murmur was considered typical of patent ductus, as described in previous graphic studies. In 13 patients, the murmur started right after the first sound and terminated only before the following first sound; in 11 patients, there was a pause before and after the first sound. Therefore, a distinction was made between the “typical, continuous” (fig. 1) and the “typical, noncontinuous” murmur (fig. 2). One patient who presented a typical, continuous murmur was 5 years old; one with occasionally continuous murmur was 4½ years old, while the other 11 were above 5 years. Eight patients with typical, noncontinuous murmur were under 5 years of age: the youngest was 5 months old, one was 1 year old, another 14 months old, and two were 2 years old. An atypical murmur was found in only 4 out of 28 patients (table 1, cases 11, 12, 15 and 24* and fig. 3).

(B) Apex. A systolic murmur of irregular configuration, made of both low and high-pitched vibrations, was recorded in every

* At the request of the Editor, table 1 is being omitted. This table will be furnished on request.
case. An early diastolic murmur, with "decrescendo" character and consisting mostly of high-pitched vibrations, was registered in seven patients (cases 1, 2, 5, 14, 16, 17 and 22); a loud, irregular, presystolic murmur was recorded in four patients (cases 9, 3, 14 and 15). Two patients (cases 21 and 19) had a loud third sound. It should be noted that both had a rapid heart rate when studied.

(C) Aortic Area. A systolic murmur was registered over this area. This was similar in character to that registered at the apex but was of longer duration, lasting in the majority of cases through the entire systole. In 18 of the 28 patients, a diastolic murmur was also present; it started immediately after the second sound; it was of a somewhat irregular character, and consisted mostly of high-pitched vibrations. One patient had a loud fourth (atrial) sound (case 24). The second sound was split in eight patients (cases 1, 2, 4, 17, 18, 19, 22 and 23) and was markedly decreased in one (case 12).

Description of Findings in the Atypical Cases

Case 11. N. G., a 9 year old female, had a clinical diagnosis of patent ductus with pulmonary hypertension (Table 1*). The phonocardiogram showed a short, early systolic, and an early diastolic decrescendo murmur at the pulmonic area, both consisting of high-pitched vibrations. At the aortic area, there was an all-systolic murmur with irregular vibrations, and, at the apex, a short systolic murmur, similar in character to that recorded at the aortic area. The electrocardiogram showed both right and left ventricular hypertrophy. Autopsy

* See footnote page 503.
showed a short ductus, a severely enlarged pulmonary artery and hypertrophy and dilatation of both ventricles.

Case 12. H. F., a 9 year old male, had a clinical diagnosis of patent ductus plus coarctation of the aorta (table 1*). The phonocardiogram showed an all-systolic murmur and an early diastolic decrescendo murmur at the pulmonic area (fig. 3). There was an all-systolic murmur with irregular vibrations at the aorta and at the apex; also, a weak second aortic sound. The electrocardiogram suggested both right and left ventricular hypertrophy. Surgery revealed the existence of the clinically diagnosed lesions. The patient was successfully operated on.

Case 15. B. D. was a 38 year old male. The clinical diagnosis was patent ductus plus coarctation of the aorta (table 1*). The phonocardiogram at the pulmonic area showed irregular, late-systolic and early-diastolic vibrations. There also was an atrial type of triple rhythm. The tracing made at the aortic area showed an all-systolic plus an early-diastolic murmur, similar in character to that recorded at the pulmonic area. At the apex, there was an all-systolic and a presystolic murmur. The electrocardiogram revealed both right and left ventricular hypertrophy. Autopsy revealed the coarctation and the ductus and bilateral ventricular hypertrophy.

Case 24. S. D. was a 3 year old female. The clinical diagnosis was patent ductus. The phonocardiogram at the pulmonic area showed a diamond-shaped, systolic murmur and a high-pitched, early diastolic murmur; the second pulmonic sound was split. The same murmurs were recorded at the aortic area, while the apex showed only the diamond shaped, systolic murmur. The electrocardiogram suggested right ventricular hypertrophy. Following surgery, catheterization was performed because of the persistence of a systolic murmur. Slight pulmonic stenosis was recognized.

In all cases where a typical murmur was recorded at the pulmonic area, the second sound appeared distinctly within the vibrations of the murmur.
Electrocardiogram

Analysis of the tracings of the 28 patients showed that they belonged to one of the following three electrocardiographic groups: (1) normal tracing; (2) left ventricular hypertrophy; (3) left and right ventricular hypertrophy.

Group 1.—Normal tracings were present in eight patients, seven of whom had patency of the ductus as the sole congenital anomaly, while one (case 19) also had a small ventricular septal defect. Catheterization data, available in two of these patients, revealed normal or borderline right ventricular pressures.

Group 2.—Pattern of left ventricular hypertrophy was found in 15 patients, two of whom also had a ventricular septal defect (cases 3 and 7). Cardiac catheterization, done in nine of these cases, revealed slightly elevated right ventricular pressures in four (cases 1, 3, 7 and 9).

Group 3.—Pattern of right and left ventricular hypertrophy was found in five patients (cases 11, 12, 14, 15 and 24). In three of them, autopsy confirmed the type of hypertrophy indicated by the electrocardiograms (cases 14, 15 and 11) while catheterization revealed markedly elevated right ventricular pressures in the other two (cases 12 and 24).*

Discussion

The graphic characteristics of the murmur caused by patency of the ductus, as described by Routier and confirmed by others, set this murmur apart from those caused by valvular lesions. It is seldom appreciated that all murmurs due to valvular lesions are strictly limited by the phases of valvular action; they are either systolic or diastolic. Even when a complex valvular lesion causes a double murmur, the following characteristics can usually be recognized (fig. 4):

(a) Mitral murmurs. The systolic murmur is poorly transmitted to the pulmonic area; in general, it has low vibrations in late systole before the second sound. If there is a mid-diastolic murmur, this is clearly separated from the second sound. Therefore, the second pulmonic sound, which is usually loud, is clearly separated from both the systolic and the diastolic vibrations.

(b) Pulmonic murmurs. If there is pulmonic stenosis, the systolic murmur may last throughout systole and reach the second sound; this, being weak, may not be visible. However, there usually is no diastolic murmur and the vibrations terminate coincident with the end of the T wave. If there is pulmonic insufficiency, the diastolic murmur starts after the second sound; the latter, however, is separated from systolic vibrations.

(c) Aortic murmurs transmitted to the pulmonic area. In general, the systolic murmur is diamond shaped and decreases before the second sound. This is loud because it is a second pulmonic sound. The early-diastolic, aortic murmur starts soon after the second sound or sometimes later. The second sound

* In the last case, catheterization was performed only after surgery; therefore, the findings are not reported in the table.
is usually separated from the systolic murmur, or from the diastolic, or from both.

Therefore, the only cases where no sharp limitation can be found are those with multiple murmurs (mitral, aortic, pulmonic) and a faint second sound. These cases, which are rather unusual, have clinical pictures which are quite different from those of patent ductus.

(d) Both atrial and ventricular septal defects are accompanied by a murmur which is of lesser intensity at the end of systole and is sharply terminated by a loud second sound. The rare cases where a septal defect has an associated pulmonic or aortic insufficiency have two murmurs, one systolic and the other early-diastolic, with a loud second sound dividing the two and preceded by a pause or a zone of low vibrations.*

Therefore, most valvular lesions and the septal defects have murmurs with different characteristics from those found in another group of cardiovascular conditions: (a) patent ductus arteriosus; (b) aortic septal defect; (c) coarctation of the aorta; (d) arteriovenous fistula of the lung; (e) arteriovenous fistula of other vessels.

The murmur of the arteriovenous fistula, including those of the lungs, is observed in various areas of the chest, neck, or limbs, but not over the pulmonic area.† The murmur of coarctation of the aorta is frankly systolic over the pulmonic area and the back upon auscultation, even though diastolic vibrations may be found in phonocardiograms recorded over the back.²³

The venous hum has the following characteristics: (a) it is soft and high-pitched; (b) it usually has the maximum intensity over the right supraclavicular space; (c) if recorded over the precordium, it is louder at the right than at the left of the sternum; and (d) it is highly modified by changes in position of the patient or of the patient’s head.

The murmurs of both patent ductus and the aortic septal defect have a common mechanism: they are caused by a shunt connecting two arterial vessels. The blood may pass through the shunt during the entire cycle and the only reason for an acceleration of flow and an intensification of the murmur is a greater gradient of pressure between the two vessels. In aortic septal defect, the coincidence of the two pressure pulses with the cardiac cycle is greater on account of the proximity to the ventricles; therefore, the highest flow takes place at the peak of the aortic pulse which is usually at the middle or in the second half of systole and the murmur may be louder over the third intercostal space.²⁵ ²⁶

A special case should be made for the distal aortopulmonary fistula. This actually represents an extremely short ductus. The gradient of pressure between aorta and pulmonary artery is the same as in the case of a ductus but the shortness of the channel may somewhat change the type of murmur. Moreover, pulmonic insufficiency may also be present on account of the severity of the shunt and of pulmonic hypertension.²²

In patent ductus, the following factors play a role:

(a) The peak of the aortic pulse occurs later on account of the transmission time between left ventricle and the end of the aortic arch: this peak is very near the second sound.
(b) The time necessary for the blood to pass through the ductus causes a further additional delay, so that the maximal flow is likely to occur at the time of the second sound.
(c) The extremely low level (5 to 10 mm. Hg) of pulmonic diastolic pressure in comparison with the aortic diastolic pressure creates a suction which prolongs the flow through the ductus, a fact which is particularly apparent during inspiration, as observed by François-Frank.

Therefore, the murmur of patent ductus, is loudest in the first and second intercostal spaces (that of aortic septal defect is loudest in the third space), and typically “rides over” the second sound. Thus, it is incorrect to

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* Such a murmur was present in a case presented by Morgan and Burchell²⁴ where other clinical data simulated patency of the ductus.
† An exception is represented by arteriovenous fistula of the coronary vessels which presents a continuous murmur over the precordial area.²⁹ ⁴⁰ This lesion, however, is extremely rare and is accompanied by typical changes of the electrocardiogram.
describe such murmur as systolic and diastolic, as is usually done: it is either a continuous or a late systolic—early diastolic murmur and it has either a late-systolic or an early-diastolic accentuation.

It should be noted that infants or young children with a ductus may have a purely systolic murmur, not because of their age but because of unusual conditions of pressure. It is logical to expect that a high pulmonic diastolic pressure will change the characteristics of the murmur by decreasing the gradient between aortic and pulmonic pressure, especially during diastole. This possibility was demonstrated by some of the cases of Hultgren. It should be noted that, among our cases, older children and adults had a typical, continuous murmur, while infants and young children had a typical, noncontinuous murmur. This interruption of the murmur may contribute to the auscultatory impression of only a systolic murmur. Moreover, the second sound, being within the murmur, may not be accurately heard, and the murmur may seem only systolic. Aortic pressure is lower in infants; this causes a less important gradient between aorta and pulmonary artery and may explain the intermittent flow (late systolic—early diastolic). Whenever the ductus is complicated by valvular, aortic, or pulmonary lesions, the gradient of pressure between aorta and pulmonary artery may vary; there may be equalization of pressure or even reversal of flow. Moreover, heart failure may decrease the gradient of pressure.\textsuperscript{27, 33} It is natural then to expect completely atypical murmurs.\textsuperscript{27, 33, 34} These complex or atypical cases are chiefly encountered among infants on account of their higher mortality and have contributed to the clinical impression of a high percentage of atypical murmurs in infants. Adults with secondary pulmonary complications may also experience such an increase of pulmonic pressure.

**Correlation among the Murmurs at the Pulmonic Area, Electrocardiographic Pattern and Intracardiac Pressures**

A very definite correlation was found between the type of murmur found at the pulmonic area, the electrocardiographic pattern, and the intracardiac pressures in each case.

(A) **Typical murmurs.** Twenty-three patients (out of 24 with typical murmurs) had either a normal electrocardiogram, with or without left axis shift, or showed evidence of left ventricular hypertrophy. Only one case had a right focal block besides the electrocardiographic signs of left ventricular hypertrophy (case 14). The patient died of cardiac failure; autopsy revealed minimal coarctation of the aorta and hypertrophy of both ventricles. In the 11 cases where cardiac catheterization was performed, the right ventricular systolic pressures were found normal in six patients and slightly elevated in five patients.

(B) **Atypical murmurs.** The four patients with atypical murmurs showed marked right and left ventricular hypertrophy in their electrocardiograms (cases 11, 12, 15 and 24). Cardiac catheterization performed before surgery showed moderately elevated pulmonary pressures in one patient (case 12) and markedly elevated pressures in the other (case 11). Case 24 was not catheterized before surgery, when only a patent ductus was diagnosed, but after ligation it appeared necessary to do catheterization because of a persisting systolic murmur at the pulmonic area. Elevated pressure was found in the right ventricle and the diagnosis of pulmonary stenosis was made. Case 15 was not operated on. At autopsy, coarctation of the aorta, a wide, short, and calcified ductus, and hypertrophy of both ventricles was found.

**Correlation between the Murmurs at the Pulmonic Area and the Cardiovascular Lesions**

Out of 24 patients with typical murmurs, only four had lesions in addition to patency of the ductus (three had a small interventricular septal defect and one had coarctation of the aorta).

Out of four patients with atypical murmurs, two had an additional coarctation of the aorta, one had pulmonary stenosis, and one had pulmonary hypertension due to vascular changes and marked hypertrophy of both ventricles.

Therefore, a close relationship among
cardiac dynamics, murmurs, electrocardiogram, and intracardiac pressures was found. This confirms previous observations of Cabrera and coworkers,\textsuperscript{24} Edwards and his colleagues,\textsuperscript{25} and several other investigators.\textsuperscript{26-31}

Uncomplicated patent ductus always has a typical murmur, no electrocardiographic evidence of right ventricular hypertrophy, and no important elevation of pressure in the pulmonary artery. Atypical murmur always means atypical ductus, having either additional cardiovascular lesions or severely elevated pulmonary pressure due to intrapulmonary vascular changes.

Conclusion

The phonocardiogram of uncomplicated patent ductus arteriosus shows a typical configuration of the murmur. This has no resemblance to that caused by valvular lesions or septal defects and is not limited by the valvular events of the heart. It is a single murmur which has either a late-systolic or an early-diastolic accentuation, and which frequently continues throughout the entire cardiac cycle. The graphic configuration of this murmur has diagnostic significance and is typical at any age. An atypical murmur is encountered if there is severe pulmonary hypertension or complicating lesions modifying the gradient of pressure or causing additional murmurs.

Infants present the highest percentage of atypical murmurs, not because of their age but because of the higher relative frequency of complex lesions and atypical ducti.

Summary

1. The phonocardiograms of 28 patients with patent ductus arteriosus were studied. They were correlated with the electrocardiograms, catheterization data, and surgical or autopsy data.

2. The typical murmur is a late systolic-early diastolic murmur. It may be either continuous or noncontinuous. Infants and young children have a noncontinuous but still typical murmur unless there are complicating lesions of the heart, vessels, or lungs.

3. The conditions causing this type of murmur and the factors of possible modification, are analyzed.

Sumario Español

1. Los fonocardiogramas de 28 pacientes con conducto arterioso patente fueron estudiados. Fueron correlacionados con los electrocardiogramas, datos de cateterismo y datos de autopsia o quirúrgicos.

2. El soplo típico es tardo en sistole y temprano en diastole. Puede ser continuo o no continuo. Infantes y niños jóvenes tienen un soplo no continuo pero no obstante es un soplo típico a menos que no existan otras complicaciones cardíacas o de los grandes vasos y pulmones.

3. Las condiciones que causan este tipo de soplo y los factores de posible modificación, son analizados.

References

5. Quoted by Hochhaus.\textsuperscript{4}
7. Smith: Quoted by Gerhardt\textsuperscript{4}.
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