Intracardiac Phonocardiogram in Thirty Cases of Atrial Septal Defect

By George A. Feruglio, M.D., and Akkaya Sreenivasan, M.D.

Thirty cases of atrial septal defect proved by cardiac catheterization, surgery, or post-mortem examination have been investigated with the technic of intracardiac phonocardiography, which provided precise localization of the source of heart sounds and murmurs. The site and mechanism of origin of the many auscultatory signs in uncomplicated atrial septal defect and in cases of Lutembacher's syndrome, tricuspid atresia, and persistent atrioventricular canal were elucidated by direct intracardiac sound recordings and simultaneous external chest phonocardiograms.

There have been many recent reports of the auscultatory features of atrial septal defect and these have been reviewed both clinically and with the aid of chest phonocardiography.1-7

The commonest auscultatory findings in uncomplicated atrial septal defect are a basal systolic ejection murmur, usually soft, and a wide, fixed splitting of the second sound over the pulmonary area. Less frequently an early blowing diastolic murmur is heard at the base and along the left sternal border in the second and third left intercostal spaces. At the apex, or medial to it, systolic and diastolic murmurs may occasionally be present, together with an accentuated first sound. The systolic apical murmur is usually of regurgitant type (pansystolic); the diastolic apical murmur occurs in mid-diastole or in presystole.

There appears to be no general agreement about the site and mechanism of production of these signs. The relative importance of various factors such as the flow across the atrial septal defect, the increased flow through the tricuspid and pulmonary valves, and the anatomic changes in the mitral and tricuspid valves, has not been established with certainty.

The purpose of this study was to contribute to a better understanding of the site and mechanism of production of the altered heart sounds and murmurs in atrial septal defect with the help of intracardiac sound recording.

The technic originally described by Lewis et al.8 for intracardiac phonocardiography has been used. Precise localization of the sources of sounds and murmurs is possible with the aid of a barium titanate microphone incorporated in the leading tip of a specially designed catheter. Some intracardiac phonocardiograms by this and other technics in cases of atrial septal defect have been reported.9-12

Material and Methods

Thirty cases of proved atrial septal defect are included in this study: 18 were male and 12 female, and they ranged in age from 3 to 54 years, the majority being in the second and third decade of life. The diagnosis of atrial septal defect was made on clinical, radiologic, and electrocardiographic grounds and was proved by right heart catheterization, during which the defect was crossed in 28 of the 30 cases. Further confirmation was obtained in patients who underwent surgical repair (22 patients, including the 2 in whom the septal defect was not crossed by the catheter) or who succumbed (2 patients) and were examined post mortem (table 1).

To confirm clinical auscultation, a routine chest phonocardiogram was recorded with the aid of a 2-channel photographic apparatus (Twin-Beam,
TABLE 1.—Diagnosis in Thirty Cases of Atrial Septal Defect

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Proved by catheter</th>
<th>Confirmed by surgery</th>
<th>Post mortem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ostium secundum defect</td>
<td>20</td>
<td>16†</td>
<td>—</td>
</tr>
<tr>
<td>Ostium primum defect</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Lutembacher's syndrome</td>
<td>2</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>Persistent atrioventricular canal</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tricuspid atresia</td>
<td>2*</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Confirmed by angiocardiography.
†In 4 cases fibrous strands were found across the defect.

Sanborn). The findings, excluding the 2 cases of tricuspid atresia, are summarized in table 2.

In both cases of tricuspid atresia (ages 3 and 6 years), a loud apical first sound and a mid-diastolic murmur with presystolic accentuation were recorded. In addition, in 1 case a harsh pansystolic murmur was recorded in the third and fourth left intercostal space. The second sound at the base was rather loud and single in both cases, and was preceded by a soft ejection systolic murmur.

Physiologic studies (right heart catheterization, dye-dilution studies, oximetry during exercise) showed that all 24 patients with uncomplicated atrial septal defect had a predominantly left-to-right shunt. Blood flow measurements obtained by the Fick principle showed that while the systemic flow was within the normal range in all these cases, the pulmonary flow was 2 to 3 times the systemic flow in 8 instances, and over 3 times the systemic flow in the remaining 16. In the 4 cases of Lutembacher's syndrome and persistent atrioventricular canal, the systemic flow was normal, while the pulmonary flow was over 3 times the systemic flow. In the 2 cases of atrial septal defect with associated tricuspid atresia, there was increased flow across the mitral valve.

The intraaerdiac phonocardiograms were recorded with the aid of a specially designed phonocatheter, a preamplifier, and a phonocardiograph. The phonocatheter consisted of a sound transducer (a hollow cylinder of activated barium titanate, 1.5 mm. in diameter and 15 mm. long), soldered to a coaxial cable. The catheter had a plastic coating, which prevented direct contact of the transducer with the blood and inner walls of the heart and vessels (a possible source of artifact), and allowed chemical sterilization of the apparatus. The frequency response of the sound transducer ranged from 5 to 10,000 c.p.s. The preamplifier, to which the acoustical signals of the catheter were fed, provided linear amplification for the same frequencies. Tracings were recorded with the aid of a photographic 2-channel and a photographic 3-channel phonocardiograph used for routine clinical phonocardiography.

The sound catheter, which was clearly seen on fluoroscopy because of its metallic components, was introduced into the cavities of the heart and pulmonary artery by the technic of venous catheterization. Reference marks were placed on the screen during routine catheterization, to locate the pulmonary, tricuspid, and mitral orifices. Intraaerdiac phonocardiograms were recorded in the right, left, and main pulmonary arteries; in 3 different positions in the right ventricle and right atrium; and in the left atrium and left ventricle in the 24 cases in which the septal defect was crossed by the "sound" catheter. Continuous recordings were also made during the withdrawal of the catheter across the pulmonary, tricuspid, and mitral valves and across the atrial septal defect. In addition to intraaerdiac sounds, simultaneous external chest phonocardiograms were recorded for comparison.

**RESULTS**

In the analysis of the intraaerdiac phonocardiograms obtained in the cases of uncomplicated atrial septal defect, the following features were encountered.

Within the pulmonary artery were recorded an ejection type of murmur of varying intensity and a loud pulmonary closure occurring 0.04 to 0.06 second after the aortic closure (fig. 1). During inspiration both the murmur and the sound increased in intensity in 15 cases and remained unchanged in 9.

<table>
<thead>
<tr>
<th>Auscultatory signs</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loud first sound</td>
<td>22</td>
</tr>
<tr>
<td>Split second sound: not fixed</td>
<td>5</td>
</tr>
<tr>
<td>fixed</td>
<td>23</td>
</tr>
<tr>
<td>Basal systolic murmur</td>
<td>28</td>
</tr>
<tr>
<td>Basal early diastolic murmur</td>
<td>4</td>
</tr>
<tr>
<td>Apical systolic murmur</td>
<td>4</td>
</tr>
<tr>
<td>Apical diastolic murmur: nil</td>
<td>5</td>
</tr>
<tr>
<td>late</td>
<td>3</td>
</tr>
</tbody>
</table>

*Phonocatheters and preamplifiers were built and made available to the authors by the U.S. Naval Air Development Center of Johnsville, Pa.
A further delay in the pulmonary closure during inspiration was observed in 2 cases.

Within the right ventricle in all cases was recorded a loud tricuspid closure occurring 0.06 to 0.08 second after the onset of the QRS complex. Simultaneous intracardiac and external recordings from the apical region (fig. 2) showed that the maximal vibrations of the first sound on the chest phonocardiogram occurred at the time of the loud tricuspid closure. In addition to a loud first sound, in the inflow tract of the right ventricle a diastolic murmur was recorded in 9 cases. This murmur was mid-diastolic in 5 instances (fig. 3), presystolic in 4 (fig. 4), and increased slightly in intensity during inspiration. Only in 6 cases similar mid-diastolic or presystolic murmurs were observed in simultaneous external phonocardiograms from the second and third intercostal spaces (fig. 5) in all 4 instances. No murmurs were recorded in the right ventricle (fig. 1) in 11 cases.

The 2 patients with Lutembacher’s syndrome, who underwent surgical repair of the septal defect and the mitral stenosis, had the intracardiac phonocardiographic features of uncomplicated atrial septal defect in the right side of the heart. In only one of these could the sound catheter be advanced through the septal defect into the left side of the heart. In this case, in which atrial fibrillation was present, a mid-diastolic murmur (fig. 6) was recorded in the inflow tract of the left ventricle and no murmurs were recorded in the left atrium. In spite of the mitral stenosis a significant pressure gradient across the mitral valve was not demonstrated. The systemic blood flow in this case was at the lower limits of normal.

In the 2 cases of tricuspid atresia, the sound catheter as well as the ordinary cathe-
Postoperative Studies. Twelve patients were reinvestigated 4 to 10 weeks postoperatively; no evidence of shunt was found by oximeter after exercise or dye-dilution studies and there was no pressure gradient across the pulmonary valve. The intracardiac phonocardiogram showed changes. Within the pulmonary artery the systolic murmur decreased considerably in intensity. The second sound also decreased in intensity but there were no significant changes in the delay of the pulmonary valve closure. Within the right ventricle the mid-diastolic and presystolic murmurs disappeared with no exception. In 2 cases, an early diastolic murmur was still present in the outflow tract of the right ventricle.

Discussion

It is generally accepted that the commonest auscultatory finding in atrial septal defect is a basal systolic murmur.\(^1\)\(^-\)\(^6\) This murmur was thought to be due to flow across the defect\(^\text{13}\) or dilatation of the pulmonary artery\(^\text{14}\) or to the increased flow through the pulmonary valves.\(^5\)\(^-\)\(^6\) The last hypothesis was strengthened by the observations of Soulié et al.,\(^\text{10}\) Feruglio and Dalla Volta,\(^\text{15}\) and Luisada and Testelli,\(^\text{11}\) who recorded a systolic murmur within the pulmonary artery in cases of uncomplicated atrial septal defect by means of different intracardiac phonocardiographic technics.

A systolic murmur, localized within the pulmonary artery, was also the most common and striking intracardiac phonocardiographic abnormality observed in the present series. This was the only murmur recorded in 15 of the 24 cases of uncomplicated atrial septal defect. In simultaneous recordings from within the pulmonary artery and externally from the second and third left intercostal spaces, this murmur appeared with the same characteristics of frequency, shape, and duration (fig. 9). The absence of any other systolic murmur in the 4 cavities of the heart and the close similarity between intracardiac and external recordings confirm the idea that the basal systolic murmur

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**Fig. 2** Top. Simultaneous recordings from within the right ventricle by the phonocatheter and externally from the apical region in a normal subject A, and in a patient with uncomplicated atrial septal defect B.

**Fig. 3** Middle. Intracardiac phonocardiogram in a case of uncomplicated atrial septal defect. A, systolic ejection murmur within the pulmonary artery; B, no murmurs within the right atrium; C, loud tricuspid closure and a mid- and late diastolic murmur within the inflow tract of the right ventricle.

**Fig. 4** Bottom. Uncomplicated atrial septal defect with, A, no murmur within the right atrium, B, a loud tricuspid closure and a presystolic murmur within the inflow tract of the right ventricle.
in uncomplicated atrial septal defect is produced in the pulmonary artery.

On the intrapulmonary phonocardiogram, as in the external phonocardiogram, this murmur had the features of a flow murmur. It was high pitched, had a midsystolic accentuation, and ended before the pulmonary closure. Its intensity had good correlation with the estimated pulmonary blood flow and decreased considerably after surgical correction of the defect. The predominant factor in the mechanism of production of the basal systolic murmur in atrial septal defect therefore seems to be increased blood flow through the pulmonary valve.

In the 4 cases in which an early basal diastolic murmur was present on external recordings a similar murmur was recorded in the intracardiac phonocardiogram from the upper outflow tract of the right ventricle, suggesting pulmonary insufficiency as the mechanism of production of this murmur. This substantiates the hypothesis of Barber et al.\textsuperscript{1} and Leatham and Gray.\textsuperscript{5}

There is great diversity of opinion regarding the source and mechanism of the apical mid-diastolic and the presystolic murmurs in atrial septal defect. The possibilities suggested are an associated mitral stenosis,\textsuperscript{16-18} flow across the septal defect,\textsuperscript{1, 19, 20} and increased flow through the tricuspid valve.\textsuperscript{5, 21} In this series diastolic apical murmurs were recorded on routine chest phonocardiograms in 10 cases, which included 2 cases of associated mitral stenosis and 2 cases of tricuspid atresia.

The intracardiac phonocardiogram was most helpful in localizing the source and mechanism of production of these apical diastolic murmurs. In the uncomplicated atrial septal defect presystolic and mid-diastolic murmurs were localized to the inflow tract of the right ventricle. This confirms the view that the murmurs originate at the tricuspid valve. Subsequent to the surgical correction of the defect, these murmurs disappeared in the intracardiac phonocardiogram, strongly suggesting that their mechanism of produc-

![Fig. 5 Top. Simultaneous recordings from within the outflow tract of the right ventricle (by the phonetheter) and externally from the second left intercostal space in a case of uncomplicated atrial septal defect.](http://circ.ahajournals.org/)

![Fig. 6 Middle. Intracardiac phonocardiogram in a man aged 57 with Lutembacher’s syndrome (proved by surgery) and atrial fibrillation. A, a mid-diastolic murmur is recorded in the inflow tract of the left ventricle, and also B, in the inflow tract of the right ventricle.](http://circ.ahajournals.org/)

![Fig. 7 Bottom. Intracardiac phonocardiogram in a boy aged 6 with tricuspid atresia. A mid-diastolic murmur with presystolic accentuation is recorded in the inflow tract of the left ventricle, due to increased flow across the mitral valve.](http://circ.ahajournals.org/)
Fig. 8 Top. High and low frequency \( (h.f., l.f.) \) intracardiac phonocardiogram in a 5-year-old boy with persistent atrioventricular canal. \( A \), a loud pansystolic murmur in the outflow tract of the right ventricle; \( B \), a regurgitant systolic murmur in the right atrium.

Fig. 9 Bottom. Simultaneous recordings in a case of uncomplicated atrial septal defect from within the pulmonary artery (by phonocatheter) and externally from the second left interspace, showing a close similarity in the systolic murmur recorded from both sites.

demonstrable across the mitral valve. This intracardiac phonocardiographic finding alone led to the diagnosis of associated mitral stenosis, which was confirmed later at surgery. It is of interest that in this case a mid-diastolic murmur was present in the inflow tract of the right ventricle as well, probably due to increased flow across the tricuspid valve. It was not possible to differentiate this murmur on the chest phonocardiogram from the similar diastolic murmur recorded in the inflow tract of the left ventricle.

The intracardiac phonocardiographic features in persistent atrioventricular canal were a loud pansystolic murmur within the outflow tract of the right ventricle and a systolic regurgitant murmur in the atrial chambers in the proximity of the atrioventricular valves. Flow due to an interventricular shunt is responsible for the former pansystolic murmur and the incompetence of the atrioventricular valves is responsible for the latter regurgitant murmur. In no instance, other than in these 2 cases of persistent atrioventricular canal, were murmurs recorded within the right or left atrium or during pullback of the sound catheter across the atrial septal defect, including the 4 cases in which, at surgery, strands across the defects were found. This observation probably means that the flow across the defect in either direction is silent. The intracardiac phonocardiographic observations of Soulé et al.\(^{10}\) and our previous experience\(^{15}\) agree with this conclusion.

Luisada and Testelli\(^{11}\) and Liu and Jacino\(^{12}\) recorded systolic and diastolic murmurs within the right atrium in cases of uncomplicated atrial septal defect. It was not possible to confirm these findings nor the other findings of Liu and Jacino\(^{12}\) of duplication of the first sound within the pulmonary artery, fourth sound or presystolic murmurs within the pulmonary artery, and diastolic murmurs within the pulmonary artery. These authors used an entirely different technique for intracardiac phonocardiography\(^{22}\) which consisted of using a glucose solution within a regular catheter as the carrier of sounds to a pressure transducer situated outside the body.

In many reports on intracardiac phonocardiography in atrial septal defect\(^{10-12,15}\) accentuation of the first heart sound is not mentioned although this is considered a common feature on auscultation.\(^{5,23}\) The accentuation of the first heart sound on chest phonocardiography is due mainly to an increased intensity of the second main group of vibrations of the first heart sound.\(^{5,23}\) Simultaneous intracardiac and external phonocardiograms show that this loud first heart sound corresponds to the closure of the tricuspid valve.

**Summary**

Thirty cases of atrial septal defect (20 of ostium secundum type, 4 of ostium primum type, 2 of Lutembacher's syndrome, 2 of persistent atrioventricular canal, and 2 of tricuspid atresia) were studied by means of an intracardiac microphone of activated barium titanate incorporated in the tip of a specially designed catheter.

In uncomplicated cases of atrial septal defect, the intracardiac phonocardiogram
demonstrated that both systolic and early diastolic murmurs heard at the base arose in the pulmonary artery, increased flow across the tricuspid valve was responsible for apical mid-diastolic and presystolic murmurs and the loud first sound was of tricuspid origin. No murmurs could be attributed to flow across the septal defect in either direction.

Among the cases of complicated atrial septal defect, the intracardiac phonocardiogram was of diagnostic help in cases of persistent atrioventricular canal by showing a pansystolic murmur in the outflow tract of the right ventricle, which suggested the presence of shunt at that level, and by showing a regurgitant murmur in the atrial chambers, which indicated incompetence of the atrioventricular valves. It was of diagnostic value in a case of Lutembacher’s syndrome with atrial fibrillation, by revealing a mid-diastolic murmur within the inflow tract of the left ventricle in the absence of a pressure gradient across the mitral valve.

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SUMMARIO IN INTERLINGUA

Trenta casos de defecto atrio-septal—20 de ostio secunde, 4 de ostio primo, 2 de syndrome de Lutembacher, 2 de persistente canal atrioventricular, 2 de atresia tricuspidic—esseva studiate per medio de un microfono intracardiac in le forma de un specialmente construite catheter con un puncta in que activate titanato de barium eseva incorporate.

In noncomplicate casos de defecto atrio-septal, le phonocardiogramma intracardiac demonstrava que le murmures tanto systolic como etiam eodiasticque es esaudibile al base habeva lor origine in le arteria pulmo-

REFERENCES

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The subject of the encouragement, or, as it is sometimes called, the endowment of research, has of late years greatly exercised the minds of men in England. Many seem to think that this question is mainly one of money; that you can go into the market and buy research, and that supply will follow demand, as in the ordinary course of commerce. This view does not commend itself to my mind. My own conviction is admirably summed up in the passage of your president's address, "that the best investigators are usually those who have also the responsibilities of instruction, gaining thus the incitements of colleagues, the encouragement of pupils, and the observation of the public."—THOMAS H. HUXLEY. American Addresses with a Lecture on the Study of Biology. London, MacMillan and Co., 1877, p. 120.
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