Sound Spectrographic Diagnosis of Aortic Ball Variance

By John C. Hylén, M.D., Frank E. Kloster, M.D., Rodney H. Herr, M.D., Albert Starr, M.D., and Herbert E. Griswold, M.D.

SUMMARY
Abnormalities in the silastic poppets of cardiac valve prostheses have been detected with increasing frequency. Ball variance can cause serious mechanical dysfunction of the prosthesis and can result in sudden death. Contour sound spectrograms were recorded on 12 patients with ball variance confirmed by operation and 25 controls. In ball variance the frequency of the aortic opening sound at the second right intercostal space was decreased, with the peak frequency recorded being below 1,300 cycles/sec in 11 of the 12 patients. The peak frequency was greater than 1,300 cycles/sec in 24 of the 25 control patients. The remaining patient had peak frequencies in both the normal and abnormal range. The diagnosis of aortic ball variance in patients with triple valve replacement remains difficult because of the nearly synchronous tricuspid closing and aortic opening sounds. The sound spectrographic findings have been the most reliable objective evidence of ball variance in patients with Starr-Edwards aortic prostheses of the Model 1000 series.

Additional Indexing Words:
Silastic poppet Aortic opening sound Contour sound spectrogram
Starr-Edwards aortic prosthesis Aortic valvular dysfunction Heart sounds
Silicone rubber Triple valve replacement

Ball Variance has been defined\(^1\)\(^-\)\(^2\) as valvular dysfunction resulting from physical and chemical alterations in the silastic poppets in cardiac valve prostheses. These alterations include increased diameter of the ball with impingement (sticking) on the cage struts, grooving, cracking, decreased diameter, fragmentation of the poppet, or changes in the poppet core with formation of fluid lakes. Discoloration due to lipid infiltration, swelling of the poppet without impingement on the cage, and decreased elasticity of the silastic poppet are not included as ball variance because, while they may represent early stages of poppet transformation, they have not been found to cause mechanical dysfunction of the valve. This clinical definition is different from others\(^3\)\(^-\)\(^8\) which include any measurable change in weight, size, or lipid infiltration as being ball variance.

Abnormalities in the silastic poppets of cardiac valve prostheses have been detected in Starr-Edwards aortic\(^1\)\(^-\)\(^9\) and mitral,\(^4\)\(^,\)\(^6\) Magovern aortic,\(^30\)\(^-\)\(^32\) Harken aortic,\(^34\) Hufnagel disc aortic and mitral,\(^8\)\(^,\)\(^55\) Kay-Shiley disc mitral,\(^36\) Kay-Suzuki disc mitral,\(^37\) and the SCDR Cutter mitral valves.\(^38\)\(^-\)\(^40\) These abnormalities can cause serious mechanical dysfunction of the prosthesis and can result in sudden death.
From March 1962 to January 1965, the aortic valve was replaced with the Model 1000 series of the Starr-Edwards aortic prosthesis at the University of Oregon Medical School in 128 patients who lived longer than 12 months after insertion of the prosthesis. One hundred and five of these 128 patients have been available for follow-up examination. Ball variance has been documented in 49 patients, or 47% of those available for follow-up. It has been verified in 32 patients at reoperation and was discovered at autopsy in 17, in nine of whom it was considered the cause of death. Patients unavailable for follow-up live in other states or countries or died without autopsy being performed. Of 77 patients with the Model 1000 series valve who were operated upon less than 4 years ago, only two have had documented ball variance. The Model 1200 Starr-Edwards aortic valve has been in use over 3 years. One case of ball variance occurring 19 months after implantation of a Model 1200 valve has been reported.\(^1\)

Detecting changes in the siltastic poppet of the Model 1000 series Starr-Edwards aortic prosthesis is an increasingly frequent diagnostic problem. Phonocardiography has been a useful tool in evaluating ball variance by demonstrating a decrease in the intensity of the aortic opening sound,\(^1\) but it yields false positive and negative results.\(^1,2\) Sound spectrography was undertaken in an attempt to improve the accuracy of diagnosis of ball variance by detecting frequency changes in the aortic opening sound (AO). The problems in using sound spectrography as a diagnostic tool in patients with triple valve replacement are examined.

**Methods**

**Study Population**

All patients studied had undergone aortic valve replacement by the staff of the University of Oregon Medical School. Preoperative contour sound spectrograms (SSG) were recorded on 12 patients in whom ball variance of the Model 1000 series Starr-Edwards aortic prosthesis was documented at reoperation. The average time from aortic valve replacement to sound spectrographic diagnosis of ball variance was 52 months with a range of 33 to 67 months.

Three groups served as controls. Eleven patients were studied less than 15 months after aortic valve replacement with the Model 1200 series Starr-Edwards aortic prostheses. Eleven patients with the Model 1000 series aortic valve were studied less than 15 months after the siltastic poppet was replaced for ball variance. Preoperative records of three patients with Model 1000 series valve who did not have ball variance at reoperation were also controls.

Seventeen additional patients with prosthetic aortic, mitral, and tricuspid valves (triple valve replacement) had phonocardiograms (PCG) by methods previously described.\(^1\) Six patients with tricuspid replacement without aortic valve replacement also had PCGs and SSGs.

**Sound Spectrograms**

Tape recordings were made of the heart sounds in a soundproof room (Industrial Acoustic) with a 4-cm diaphragm microphone (Sanborn, Model 62-1500-C10) connected directly to the microphone input of a tape deck (Ampex 602-2). Recordings were obtained with the patients in the supine position and with the breath held in full expiration. The microphone was placed over the second right intercostal space (2RICS) at the sternal edge and at the cardiac apex. To avoid transducer differences the same microphone was used in each position. Sound spectrograms were obtained from the tape recording with a sound spectrograph (Kay\(^*\) 7029A).

Changes in the equipment such as different microphones, tape recorder, or sound spectrograph resulted in different frequency responses in recording SSGs on the same patient. Variations in the position of the microphone on the chest wall or of pressure over the microphone also critically changed the frequency response. Therefore, standardization of recording technics and all equipment with control patients was required.

**Peak Frequency of Aortic Opening Sound**

Contour sound spectrograms (SSG) are recorded with frequency on the vertical axis and time on the horizontal axis. Intensity of sound is displayed by contour lines in steps of 6 decibels. Figure 1 is a normal SSG of a Starr-Edwards aortic prosthesis showing two cardiac cycles as recorded from the 2RICS. The aortic opening sound has a peak frequency of 1,900 cycles/sec, shown by the upper arrow. Note that the loudest sound is demonstrated by the dark shading and occurs in the 200 to 400 cycles/sec range. The average of the peak frequency of the aortic

\(^*\)Kay Electric Co., Maple Avenue, Pine Brook, New Jersey 07058.

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opening sound (fig. 1, upper arrow) was determined from four or more cardiac cycles in patients with ball variance and in the controls. The average peak frequency of aortic opening sound was determined at the 2RICS and at the apex. Heart beats with an R-R interval of less than 0.5 sec (rate greater than 120/min) were excluded from the study.

**Results**

**Peak Frequency of the Aortic Opening Sound**

The most frequent finding in ball variance is a loss of the high frequency components of the aortic opening sound (AO). The SSG at 2RICS of a typical patient with ball variance is shown in figure 2 with the peak frequency of AO depressed to 700 cycles/sec. The peak frequency of AO at the 2RICS was less than 1,300 cycles/sec in 11 of the 12 patients with documented ball variance (table 1). The peak frequency at the same intercostal space was greater than 1,300 cycles/sec in 24 of the 25 cases without ball variance (table 2). Figure 3 shows the distribution of the peak frequency of AO at the 2RICS in patients with ball variance and the control groups. The value for F resulting from an analysis of variance for the control groups with the group with aortic prostheses of Model 1000 and 1200 series was not significant (F = 1.12; df = 1.20). A test over group mean differences (Newman-Keuls procedure) indicated a significant difference (P < 0.005) between the patients with ball variance and the control groups. There was no significant difference between the control groups.

Only one patient (J.B., fig. 3; table 2) with peak frequencies of AO below 1,300 cycles/sec did not have ball variance at reoperation. However, he did have three records in the normal range and one SSG with a peak frequency of AO of 2,100 cycles/sec. The one patient given a false negative diagnosis (F.C. fig. 3; table 1) had a barium impregnated poppet and the diagnosis was made from radiographic findings.2

A different sound spectrographic pattern was seen in one individual in whom the peak frequency of both the aortic opening and closing sounds were depressed (fig. 4). Similar findings on PCG have been previously described1 and have been noted in three cases.

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*Figure 1*

Normal contour sound spectrogram of Starr-Edwards aortic prosthesis. The peak frequency of the aortic opening sound is 1,900 cycles/sec. Abbreviations: AO = aortic opening sound; EM = systolic ejection murmur; AC = aortic closing sound; PC = pulmonic closing sound; db = decibels.

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Abnormal contour sound spectrogram. The peak frequency of AO is 700 cycles/sec. Abbreviations are the same as figure 1.

Double Valve Replacement
Figure 6 shows a normal SSG of a patient with mitral and aortic valve replacement. The peak frequency of the AO is 1,800 cycles/sec (arrow). Figure 7 shows the loss of the high frequency components of the aortic opening sound in a patient with double valve replacement. The peak frequency of the AO is 600 cycles/sec. Ball variance was documented at reoperation (Z.G., table 1).

Triple Valve Replacement
Figure 8A shows the PCG of a patient with triple valve replacement who has simultaneous tricuspid closing (TC) and aortic opening (AO) sounds. Figure 8B shows the separations of TC and AO during inspiration. Figure 8C shows an increase in the intensity of the mitral closing and tricuspid closing sounds following an atrial paced premature beat. The aortic closing sound is decreased in intensity during this beat.

Of the 17 patients with triple-valve replacement who had PCG, seven (41%) had simultaneous occurrence of the TC and AO. Four patients had this as a consistent finding.
Table 1
Sound Spectrographic Analysis of Patients with Ball Variance

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age (yr)</th>
<th>Postop (mo)</th>
<th>2RICS</th>
<th>Apex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z.G.</td>
<td>F</td>
<td>39</td>
<td>33</td>
<td>925</td>
<td>625</td>
</tr>
<tr>
<td>S.B.</td>
<td>F</td>
<td>44</td>
<td>42</td>
<td>850</td>
<td>725</td>
</tr>
<tr>
<td>G.M.</td>
<td>M</td>
<td>54</td>
<td>46</td>
<td>1250</td>
<td>925</td>
</tr>
<tr>
<td>G.O.</td>
<td>M</td>
<td>59</td>
<td>48</td>
<td>525</td>
<td>825</td>
</tr>
<tr>
<td>E.W.</td>
<td>M</td>
<td>49</td>
<td>49</td>
<td>400</td>
<td>450</td>
</tr>
<tr>
<td>J.D.</td>
<td>F</td>
<td>48</td>
<td>53</td>
<td>500</td>
<td>550</td>
</tr>
<tr>
<td>H.B.</td>
<td>M</td>
<td>59</td>
<td>52</td>
<td>900</td>
<td>400</td>
</tr>
<tr>
<td>B.L.</td>
<td>F</td>
<td>58</td>
<td>51</td>
<td>700</td>
<td>875</td>
</tr>
<tr>
<td>S.L.</td>
<td>M</td>
<td>40</td>
<td>60</td>
<td>800</td>
<td>675</td>
</tr>
<tr>
<td>F.C.</td>
<td>M</td>
<td>43</td>
<td>60</td>
<td>1825</td>
<td>1125</td>
</tr>
<tr>
<td>C.S.</td>
<td>M</td>
<td>55</td>
<td>60</td>
<td>475</td>
<td>650</td>
</tr>
<tr>
<td>F.V.</td>
<td>M</td>
<td>62</td>
<td>61</td>
<td>825</td>
<td>775</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>51</td>
<td>56</td>
<td>883</td>
<td>717</td>
</tr>
</tbody>
</table>

Table 2
Sound Spectrographic Analysis of Patients Without Ball Variance

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age (yr)</th>
<th>Postop (mo)</th>
<th>2RICS</th>
<th>Apex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A: Determined at reoperation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R.O.</td>
<td>F</td>
<td>63</td>
<td>43</td>
<td>2050</td>
<td>1400</td>
</tr>
<tr>
<td>J.B.</td>
<td>M</td>
<td>70</td>
<td>51</td>
<td>1400</td>
<td>975</td>
</tr>
<tr>
<td>V.W.</td>
<td>M</td>
<td>37</td>
<td>66</td>
<td>1700</td>
<td>1200</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>57</td>
<td>58</td>
<td>1583</td>
<td>1117</td>
</tr>
</tbody>
</table>

Group B: 15 months or less following silastic poppet replacement into a Model 1000 series valve |

| Group C: 15 months or less following replacement with Model 1200 series valve |
| R.M.    | M   | 15       | 3           | 2050   | 1425 |
| W.K.    | F   | 50       | 6           | 1175   | 1500 |
| S.H.    | M   | 53       | 9           | 2625   | 1100 |
| L.P.    | M   | 60       | 9           | 2025   | 1150 |
| M.R.    | M   | 59       | 10          | 1925   | 2275 |
| R.A.    | M   | 53       | 10          | 1675   | 2025 |
| L.L.    | F   | 49       | 11          | 1625   | 1025 |
| G.R.    | F   | 56       | 11          | 1925   | 2700 |
| K.T.    | M   | 44       | 14          | 1450   | 1325 |
| C.S.    | M   | 55       | 15          | 1775   | 1425 |
| L.B.    | M   | 51       | 15          | 1650   | 875  |
| Mean    |     | 50       | 10          | 1993   | 1640 |

on two or more PCCs. SSGs on patients with tricuspid valve prostheses but without aortic valve prostheses showed that the peak frequency of the TC was more than 1,300 cycles/sec in three of six patients.

Discussion

Although approximately half (47%) of the patients have developed ball variance 4 years after replacement with the Model 1000 Starr-Edwards aortic valve, the postoperative interval has not been a good index for evaluating the presence of ball variance. One patient developed ball variance 3½ months after operation, while two others developed it within 11 months. One patient, 65 months after operation, and another (V.W., table 2), 71 months after operation, had no evidence of ball variance at reoperation. Therefore, criteria other than length of time since operation have been developed to diagnose this problem.

Circulation, Volume XXXIX, June 1969
Sound spectrogram with depressed AO and AC.

Figure 5

Circles indicate the average peak frequency of AO from one sound spectrogram recorded at the cardiac apex. Connected circles represent the results of more than one sound spectrogram on the same patient.

Aortic Valve Replacement

Clinical auscultation is most useful in detecting changes in the opening sound due to ball variance in patients with an aortic prostheses only. Absence of the aortic opening sound by auscultation has been associated with ball variance and marked changes in the PCG and SSG. Ball variance can be suspected by auscultation in most cases. Changes in intensity and frequencies of the aortic opening sound (AO), however, can best be assessed by PCG and SSG. The PCG shows a decrease in the intensity of AO as compared to AC. The AO is usually less than half the intensity of AC (AO/AC ratio less than 0.5) in patients with variant poppets.

Patients with ball variance have been noted to have an AO of lower frequency (thud rather than click) than is usually found with the Starr-Edwards aortic prosthesis. Changes in the frequencies of AO have been noted by auscultation and in the PCG but cannot be quantitated by these technics. The loss of the high frequency components of the aortic opening sound is a characteristic finding of ball variance by sound spectrography (fig. 2).

Only one of the 12 patients with ball variance (F.C., fig. 3) had a normal SSG. Another patient (J.B., fig. 3) had records in both the normal and abnormal range and did not have ball variance at reoperation. However, sound spectrography is more specific in the diagnosis of aortic ball variance compared to phonocardiography, which had four false negative and three false positive
SOUND SPECTROGRAPHIC DIAGNOSIS

Figure 6
Normal sound spectrogram of patient with mitral and aortic valve replacement. Abbreviations: MC = mitral closing sound; AO = aortic opening sound; EM = systolic ejection murmur; AC = aortic closing sound; PC = pulmonic closing sound; MO = mitral opening sound.

Figure 7
Sound spectrogram of patient with mitral and aortic valve replacement. The peak frequency of AO is 600 cycles/sec. Abbreviations are the same as figure 6.

results in the 12 cases. The low specificity of our phonocardiograph was partially due to its low frequency response (100 to 290 cycles/sec).

Bircks and Loogen33 have described a decrease in the intensity of AO and in the high frequencies of AO by PCG in a patient with ball variance of a Magovern sutureless aortic valve. These findings suggest that similar criteria for the diagnosis of ball variance can be established with aortic valves other than the Starr-Edwards prosthesis. The accuracy of diagnosis of aortic ball variance by screening patients with phonocardiography and sound spectrography who have other aortic valves awaits documentation.

Circulation, Volume XXXIX, June 1969
Multiple Valve Replacement

Analysis of the prosthetic sounds is particularly valuable in patients with double valve replacement because of the difficulty in clinical assessment of the closely related mitral closing and aortic opening sounds. In three patients, with double valve replacement, a large depression in intensity and of the high frequencies of AO were missed by auscultation.

The late onset of right ventricular contraction with tricuspid valve replacement and the simultaneous occurrence of the tricuspid closing sound (TC) and aortic opening sound (AO) have previously been reported. This makes the diagnosis of aortic ball variance in patients with triple valve replacement extremely difficult. Even when the TC and AO are separate enough to be identified on PCG, the time response of the contour sound spectrograph is too slow to give an accurate analysis of AO. Therefore, no screening test for aortic ball variance is now available in patients with triple valve replacement whose poppets are not barium impregnated. Depression of the TC may be obtained with right heart catheterization by catheter passage through the valve. However, this is not practical at 6-month intervals as a screening procedure. The importance of this problem is emphasized by cases of sudden death reported by Cohen and associates of six patients (100%) and by Roberts and Morrow of eight out of 11 patients (73%) with aortic ball variance documented at autopsy. Therefore, further attempts to obtain a reliable screening procedure for patients with triple valve replacement should be sought.

Sound Analysis

While a loss of the high frequency components of AO has been documented, technics for recording sound are difficult to standardize. Differences observed in the frequencies of the normal and abnormal range may be anticipated in other laboratories even if similar equipment is used. Therefore, control patients should be used to standardize sound spectrographic equipment.

In patients who have absence of the aortic opening sound by auscultation, the peak frequency of the aortic opening sound is usually depressed to the same frequency as the systolic ejection murmur (fig. 2). Patients who have similar frequency components of the AO and the ejection murmur may be useful in the standardization of equipment, since this finding has been noted only in patients with ball variance.

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SOUND SPECTROGRAPHIC DIAGNOSIS

Tape recordings of prosthetic valve sounds can be mailed to several centers for analysis by SSG. * Presently, patients with aortic valves with silicone rubber poppets are re-examined at 6-month intervals. Careful auscultation is performed with particular attention to the quality of AO and a PCG is recorded. 1 Those developing dizzy spells, syncopal episodes, fatigue, angina, palpitations, signs of embolic phenomena, congestive heart failure, hemolytic anemia, jaundice, late onset of aortic regurgitation, or abnormal or borderline PCG findings are studied by SSG.

Patients with a peak frequency of the aortic opening sound consistently less than 1,300 cycles/sec on two or more occasions are given a diagnosis of ball variance by sound spectrographic criteria. To date, all patients reoperated on this basis have had aortic ball variance.

References


*Voiceprint Lab., P. O. Box 835, Somerville, N. J. 08876; Signatection Inc., 225 Crescent St., Waltham, Mass. 02154.

Circulation, Volume XXXIX, June 1969


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