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Frequency Content of Heart Sounds and Systolic Murmurs in Patients with Porcine Bioprosthetic Valves: Diagnostic Value for the Early Detection of Valvular Degeneration

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The frequency content of heart sounds and murmurs in patients with implanted bioprosthetic valves may reveal evidence of degenerative changes before such changes are clinically apparent. An increased dominant frequency of the heart sound caused by a bioprosthetic valve in either the aortic or mitral positions suggests

stiffening of the leaflets. While a musical systolic murmur of a bioprosthetic valve in the mitral position suggests flutter from a torn, insufficient leaflet, limited observations of musical systolic murmurs in the aortic position do not seem to indicate a degenerated valve.

The frequency content of heart sounds and systolic murmurs in patients with porcine bioprosthetic valves may reveal characteristics of valvular degeneration before any other clinical manifestations become apparent. Explanation for this fact derives from the mechanism of heart sounds and musical murmurs. The frequency of the first and second heart sounds in patients with mitral or aortic bioprosthetic valves is determined by the frequency of vibration of the closed semilunar valve cusps (1). This vibration frequency depends on the stiffness of the leaflets, as a higher frequency sound results from stiffer leaflets (2,3). Hemodynamic factors do not affect the frequency of vibration (3,4). The usual pathologic change in a degenerated valve is thickening, stiffening, and calcification or tearing of the leaflets. Consequently, as stiffening occurs, the frequency of sounds produced by the bioprosthetic valve should increase.

Musical systolic murmurs of bioprosthetic valves in the mitral position are known to derive from the flutter of a torn, insufficient leaflet (5). Accordingly, a musical systolic murmur detected in a patient with a bioprosthetic valve in the mitral position is likely to indicate a significant pathological process. However, systolic musical murmurs produced by bioprosthetic valves in the aortic position do not seem to have pathological significance.

The present report reviews our experience in analyzing the frequency content of heart sounds and systolic

murmurs for the purpose of early detection of bioprosthetic valve degeneration.

Methods

We analyzed phonocardiograms from 258 patients with porcine bioprosthetic valves. In 95 patients, the valves were in the aortic position, and in 163 patients they were in the mitral position. Sequential studies were performed on 93 patients. Thirty-nine patients with valves in the aortic position were studied 47 ± 5 months (mean \pm standard error of the mean) after insertion and again 75 ± 5 months after insertion. During this interval, four valves degenerated. Fifty-four patients with valves in the mitral position were studied 59 ± 5 months after insertion and again 84 ± 4 months after insertion. During this interval, nine valves degenerated.

We recorded heart sounds and murmurs during quiet respiration with the patient supine, using a heart sound microphone (Irex Medical Systems, model 120-131). Analyses of the first heart sound (S1) were obtained with the microphone placed at the site of the maximum pal-

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pable cardiac impulse. Murmurs caused by mitral and aortic bioprosthetic valves were analyzed at the sites of the respective heart sounds. In some instances, however, musical systolic murmurs produced by a mitral bioprosthetic valve were recorded best at the base of the heart or along the left sternal border. Frequency analyses of musical murmurs, therefore, were made at the site at which the murmur was best recorded.

Analyses of the second heart sound were obtained from recordings with the microphone placed at the second left intercostal space. The microphone was held in position by a suction cup, so that it could be applied uniformly and consistently. In each patient, we recorded the phonocardiogram, carotid pulse tracing, lead II of the electrocardiogram, and respirations on a photographic recorder (Electronics for Medicine VR-6). Phases of respiration were measured with a nostril thermistor

and were also recorded simultaneously on an eight-track magnetic tape recorder (Hewlett-Packard, model 8868A). The sound signal was filtered below 50 Hz and above 500 Hz. The frequency response of the sound amplifier and microphone combination was flat (within 1 db) between 80 and 300 Hz.

We analyzed the frequency content of the entire first heart sound. The aortic component of the second heart sound (A2) was identified as the first major component of the second sound. Analyses were performed only in

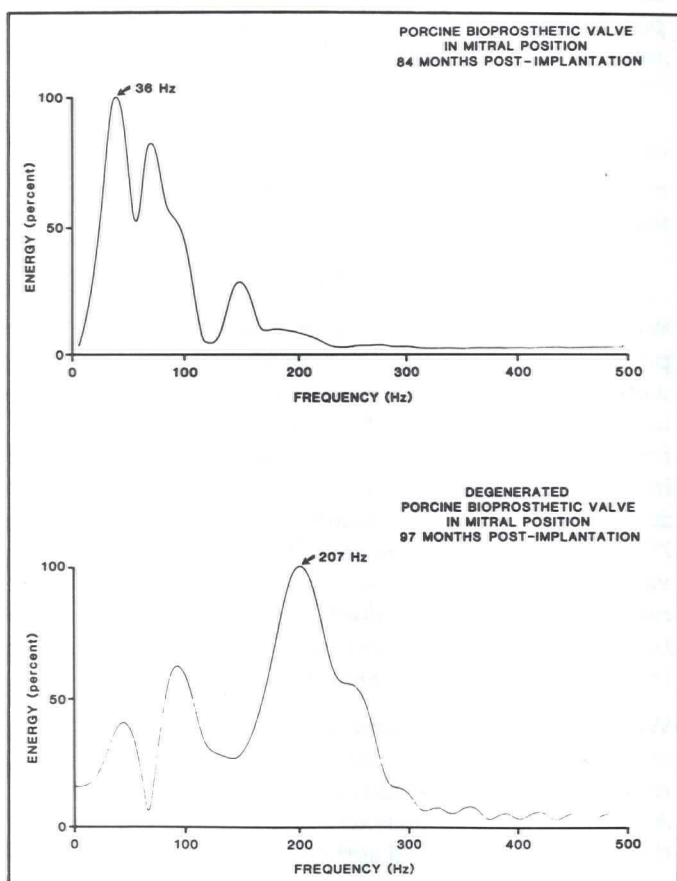


Fig. 1

Frequency spectra of the first heart sound in a patient with a porcine bioprosthetic valve in the mitral position. In the top graph, sound was recorded 84 months after valve insertion. Dominant frequency was 36 Hz. In the bottom graph, the sound was recorded 97 months after insertion. At this time the valve had degenerated. Dominant frequency of the first heart sound increased to 207 Hz.

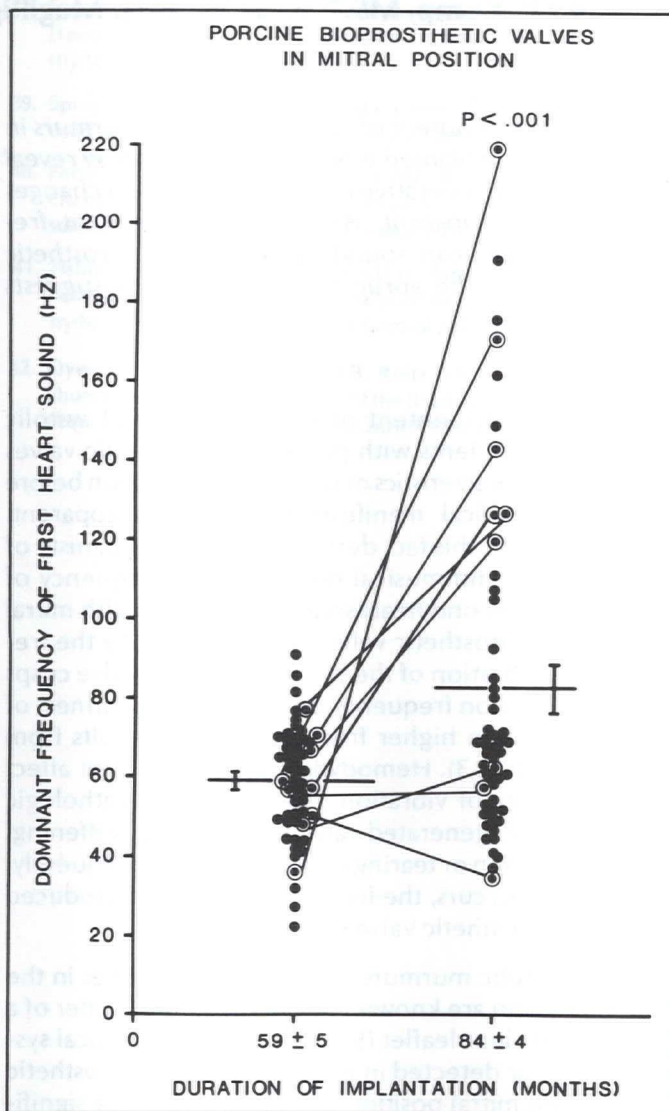


Fig. 2

Dominant frequency of S1 in 54 patients with porcine bioprosthetic valves in the mitral position. Sounds were recorded 59 ± 5 months and again 84 ± 4 months after insertion. Dominant frequency of S1 increased from 59 ± 2 Hz to 83 ± 6 Hz ($P < .001$). Circles indicate frequency of valves that degenerated and were removed shortly after second phonocardiogram was recorded.

patients who manifested a distinct splitting of the second sound during inspiration. The frequency content of systolic murmurs was analyzed over the entire duration of the murmur. A musical murmur was defined as a murmur with most of its energy localized to a narrow band of frequency. Utilizing the data recorded on the magnetic tape recorder, we analyzed the frequency content of sounds and murmurs with a digital signal processor (Spectral Dynamics SD360, San Diego, CA). After capture of the portion of the cardiac cycle to be analyzed (i.e., the first or second heart sound, or a systolic murmur), remaining sounds were deleted. A fast Fourier transform was performed on the signal and displayed on linear

coordinates over a frequency of 0 to 500 Hz. The dominant frequency of the sound was defined as the frequency with the highest magnitude shown in the frequency spectrum.

Results

Heart sounds

We determined the frequency content of normally functioning valves by analyzing the heart sounds of patients whose valves were less than 1.5 years old and presumably had not undergone degenerative changes. The dominant frequency of S1 among 31 such patients with valves in the mitral position was 52 ± 3 Hz. In 25 patients

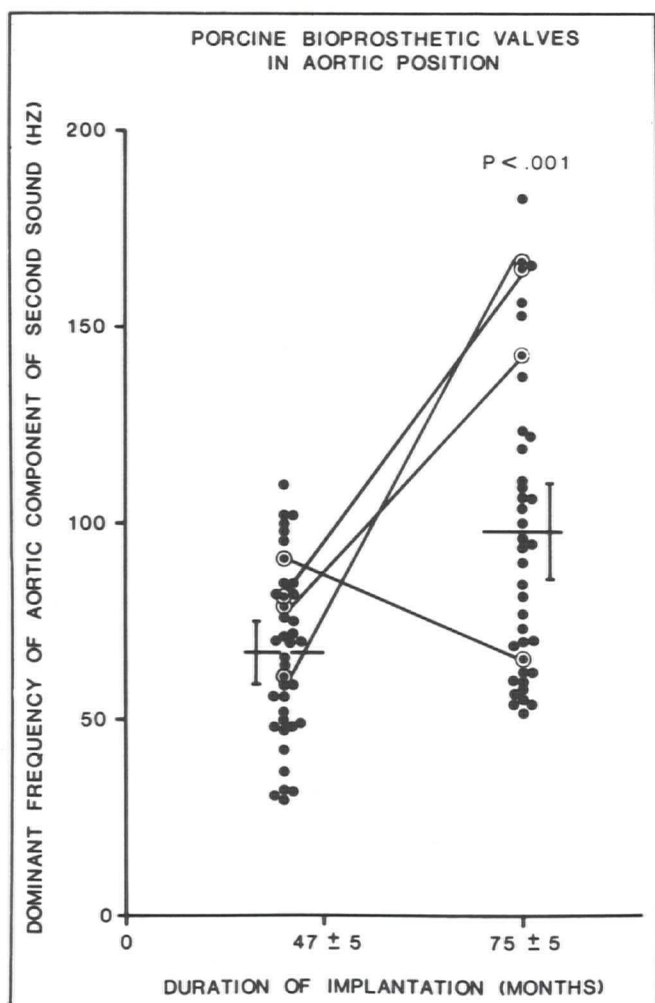


Fig 3

Dominant frequency of A2 in 39 patients with porcine bioprosthetic valves in the aortic position. Sounds were recorded 47 ± 5 months and again 75 ± 5 months after insertion. Dominant frequency of A2 increased from 67 ± 8 Hz to 98 ± 12 Hz ($P < .001$). Circles indicate frequency of valves that degenerated and were removed shortly after second phonocardiogram was recorded.

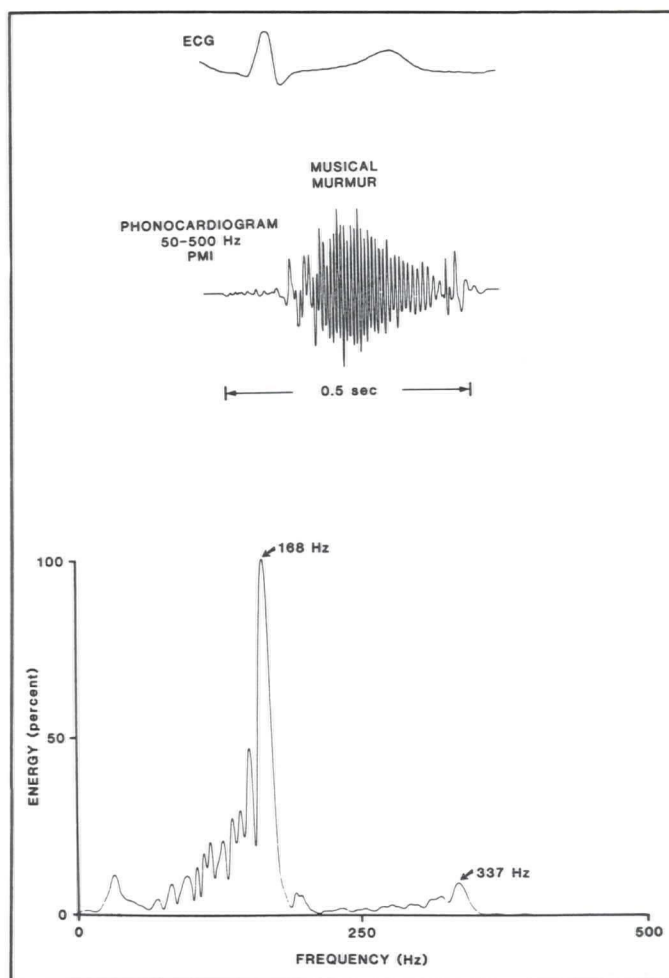


Fig. 4

Top: Musical systolic murmur recorded at the site of the palpable maximum cardiac impulse (PMI) in a patient with a degenerated mitral bioprosthetic valve. Bottom: Frequency spectrum of the musical murmur. Sound energy at various frequencies is shown as a percent of the sound energy of the fundamental frequency (168 Hz).

with valves inserted in the aortic position, the dominant frequency of A2 was 55 ± 4 Hz.

Sequential analyses of the heart sounds were performed on 54 patients with bioprosthetic valves in the mitral position 59 ± 5 months and again 84 ± 4 months after insertion (Figs. 1,2). The dominant frequency of S1 increased from 59 ± 2 Hz to 83 ± 6 Hz ($P < .001$, paired t-test). Nine of these valves degenerated during this interval. In seven of nine, the frequency of S1 increased, and in six the frequency of S1 exceeded 120 Hz.

Thirty-nine patients with bioprosthetic valves in the aortic position had sequential studies 47 ± 5 months and again 75 ± 5 months after insertion (Fig. 3). The dominant frequency of A2 increased from 67 ± 8 Hz to 98 ± 12 Hz ($P < .001$). Four valves degenerated during this interval; in three, frequency of the aortic component of the second sound increased to over 140 Hz.

Of 258 patients in whom frequency analyses of the heart sounds were made, 26 had degenerated bioprosthetic valves. In these patients, heart sounds were recorded shortly before the valves were replaced. Of these degenerated valves, 19 were in the mitral position and had an S1 dominant frequency of 98 ± 12 Hz. In eight of the 19, the dominant frequency of S1 exceeded 100 Hz. Six excised valves had heavy deposits of calcium on at least two cusps. Among 11 patients with a dominant frequency of S1 below 100 Hz, nine valves had torn leaflets only, or grossly visible calcification was limited to one leaflet only.

In seven of the 26 patients with degenerated valves, the valves were in the aortic position. In these seven, the frequency of A2 was 118 ± 15 , and in three of seven, it exceeded 120 Hz. In each, severe thickening or grossly visible calcification was evident on at least two leaflets. Among the four patients with degenerated valves in the aortic position whose A2 was less than 100 Hz, two showed only tears with no visible calcification.

Musical systolic murmurs

Musical systolic murmurs were recorded in six patients with bioprosthetic valves in the mitral position (Fig. 4). In three, the valves had degenerated and were replaced. In three others, musical systolic murmurs were recorded, but there was no other evidence of valvular degeneration. In two of the latter three, the frequency of the first sound exceeded 100 Hz.

Musical systolic murmurs were recorded in four patients whose bioprosthetic valves were in the aortic position. None revealed clinical evidence of degeneration, and

none had an early diastolic murmur. Three had a normal frequency of A2.

Discussion

Before analyzing the frequency of heart sounds in patients with bioprosthetic valves, we evaluated the frequency of A2 in patients with calcific aortic stenosis to determine if stiffened aortic valves produce higher frequencies of A2 (6). The A2 frequencies were higher in these patients than in subjects with normal valves (6). The dominant frequency in normal subjects was 53 ± 3 Hz, while in patients with calcific aortic stenosis it was 87 ± 5 Hz ($P < .001$). Frequency analysis of A2 obviously is not essential to the diagnosis of clinically apparent calcific aortic stenosis. However, the fact that the A2 frequency is higher in patients with this disorder suggests that analysis of that sound may be useful in identifying patients with less advanced stiffening of the valve, like that which occurs in the early stages of valvular degeneration.

Previously, we evaluated the frequency of A2 in 49 patients who had porcine bioprosthetic valves in the aortic position to determine if higher frequencies develop over time (6). The duration of valve insertion ranged from a few days to 7.5 years. In patients who had the aortic bioprosthetic valve for 18 months or less, the dominant frequency of A2 was 48 ± 5 Hz, which was approximately the same as in patients with normal natural aortic valves. In patients in whom the valve had been inserted for five to 7.5 years, the dominant frequency of A2 was higher, 81 ± 4 Hz ($P < .001$). The dominant frequency recorded in patients with valves inserted five years or longer was within the frequency range observed in patients with calcific aortic stenosis. The increased dominant frequency observed with an increased duration of implantation suggests that the leaflets gradually stiffened, although stiffening was not clinically apparent.

We have also compared the frequency content of the first heart sound between normal subjects and patients with porcine bioprosthetic valves inserted in the mitral position (7). If the S1 of patients with bioprosthetic valves in the mitral position is attributed to vibration of the closed semilunar cusps, those factors that affect the frequency of vibration of the aortic valve are assumed also to affect the frequency of vibration of a semilunar valve in the mitral position. The frequency of S1 in patients whose valves had been inserted in the mitral position for five years or longer was significantly higher than that of patients whose valves had been inserted for 18 months or less (7): 43 ± 3 Hz for the former, 67 ± 2 Hz for the latter ($P < .001$). It is likely that subclinical degenerative

changes characterized by stiffening had affected valves that were inserted longer.

The present study extends these observations with additional information which suggests that an analysis of heart sound frequencies assists in the early detection of bioprosthetic valve degeneration. We found that: 1) Individual patients developed higher frequency sounds the longer the valves remained implanted. 2) As the bioprosthetic valve degenerated, the observed frequency often was higher than that of a normal valve. 3) In degenerated valves that produced higher frequency heart sounds, grossly visible calcification was usually present in two or more leaflets. Conversely, in degenerated valves that produced normal frequency heart sounds, grossly visible calcification was limited to one leaflet or was not present.

The frequency characteristics of systolic murmurs, particularly in patients with bioprosthetic valves in the mitral position, also may give a clue to degeneration. A systolic murmur was recorded at the apex in approximately 80% of the patients with bioprosthetic valves in the mitral position even without other signs or symptoms of valvular degeneration. To evaluate the significance of systolic murmurs produced by these valves, we analyzed the frequency of the murmurs. We searched particularly for murmurs having a single frequency suggestive of a musical characteristic. Based upon flow studies performed with a degenerated bioprosthetic valve

in a pulse duplicator system, we anticipated that a musical systolic murmur produced by a bioprosthetic valve in the mitral position would indicate a torn cusp. We had studied a porcine bioprosthetic valve which, before its removal from the mitral position because of degeneration, had caused a grade VI cooing pansystolic murmur. We reproduced this murmur in an in vitro test system and demonstrated that flutter of a torn leaflet was the mechanism that caused the murmur (5). Motion pictures of the valve in the cardiac simulator indicated that the leaflet fluttered at a rate similar to the frequency of the murmur (5,8).

We have now seen six patients with musical systolic murmurs produced by porcine bioprosthetic valves in the mitral position. Three had proven degeneration which required replacement of the valves. Three had a pansystolic musical murmur without other clinical evidence of degeneration. These three patients will be examined regularly for the possible development of clinically significant mitral regurgitation. These observations suggest that a musical systolic murmur of a bioprosthetic valve in the mitral position may indicate flutter of a torn leaflet. By contrast, musical systolic murmurs of bioprosthetic valves in the aortic position do not necessarily indicate a pathological process. Only one of nine patients in whom we have observed such musical systolic murmurs had evidence of aortic valvular degeneration.

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