A Phonocardiographic Study of Patients with Total Prosthetic Mitral Valve Replacement*

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DURING THE PAST YEAR, AN INCREASING number of patients have had total replacement of their mitral valves with ball-cage or Starr-Edwards' valves. Since the acoustic phenomena associated with the closing and opening of these valves are so distinctive, these patients afford an unusual opportunity to document the temporal relationships of the opening and closing of the ball valves to other acoustic and hemodynamic events.

This report deals with a phonocardiographic study of six patients whose mitral valves were replaced with Starr-Edwards ball-cage valves. The operations had been carried out by either Dr. John Kirklin or Dr. Dwight McGoon, to whom the authors are indebted for advice and for the opportunity to study the patients.

METHODS

Phonocardiographic tracings were recorded by means of a direct writing instrument (an Elema Cardirex 42A Mingograf) at paper speeds of 100 mm. per second. The positions of the microphone on the chest and the filter frequencies were varied, as noted in each figure. In some instances, a second-sound recording amplifier (the Elema 42B) was used to record simultaneously from a second area on the chest, an arrangement utilized by Kjellberg and co-workers.† Respirations were recorded by means of a thermocouple appropriately connected to one of the galvanometer systems. Apical and external carotid pulsations were recorded by means of the Infratont†† direct pulse pickup.

RESULTS

Thoracic roentgenograms of a patient with a ball-cage valve in place (Fig. 1)

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Starr-Edwards valve No. 3 has a diameter of 1.12 inches at the base and 0.700 inch at the hydraulic opening. In terms of function, the valve area (approximately 2.8 sq. cm.) may be regarded as slightly stenotic.

In the two cases illustrated in Fig. 2, Q-1 intervals (intervals between Q waves of QRS of ECG and the first sounds) were normal. The first sound was characterized by a high frequency component of large amplitude, caused by the impact of the ball at closure of the prosthetic valve; this was the "closing valve sound" (CVS). Second sounds were unremarkable, despite the presence of aortic prostheses in each patient. Following the second sound (S₂) by a considerable interval, there was another high frequency, high amplitude vibration related to the opening of the ball valve, the "opening valve sound" (OVS).

The relationship of the Q-CVS and S₂-OVS intervals to the apex cardiogram (apical pulse record) in three patients with Starr-Edwards valves is illustrated in Fig 3. The Q-CVS interval is within the normal range in all three cases, and the OVS occurs at the nadir of the apex cardiogram in a similar position to that characteristically occupied by an opening snap in mitral stenosis.

The interpretation of the relationship of the aortic S₂-OVS interval to respiration might be erroneous if the chest areas from which recordings were made were not

![Figure 2: Records of two patients after surgical replacement of mitral and aortic valves. (Mitral valves replaced in both patients with Starr-Edwards prostheses; aortic valve prostheses differed—upper panel represents patient with Bahnson leaflet, and lower panel patient with McGoon prosthesis.) Upper panel includes phonocardiograms from two areas, while lower panel includes phonocardiograms from only one area. CVS = closing valve sound, and OVS = opening valve sound of mitral prosthesis. S₂ = second sound. Carotid = carotid pulse. Systolic murmur recorded in mid precordial area in both instances is believed related to ventricular outflow and not to any mitral incompetence.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21389/)
identified. An apparent increase in the S2-OVS interval with expiration (Fig. 4) was clarified when recordings were taken in the aortic area or measurements were made of the relationship of S2 to the carotid pulse. In this example, the changing interval was due to movement of the pulmonary component (PS2); the AS2-OVS interval remained constant.

It has been shown in patients with mitral stenosis and atrial fibrillation that there is a relationship between the preceding electrocardiographic R-R interval and both the Q-l interval and AS2-OS interval (interval between the aortic second sound and the opening snap). With increments of R-R interval, there is a longer diastolic period, thus allowing greater atrial decompression. The left atrial to left ventricular pressure gradient is thus reduced; and, hence, at the onset of the next cycle, the opening snap occurs farther from the S2 and the Q wave occurs closer to the first sound.

The S2-OVS and Q-CVS intervals in patients with prosthetic mitral valves also varied with the preceding R-R interval and in the same direction as in mitral stenosis (Fig. 5). After a short R-R interval, the Q-CVS interval was longer and the S2-OVS interval shorter than after a longer R-R interval. Simultaneously, the systolic

Figure 3: Phonocardiograms with simultaneous electrocardiograms and apex cardiograms (apex pulsations, presumably mainly of left ventricular origin) illustrate relationship of OVS to apical events. Records in lower panel obtained from same patient as records in lower panel of Fig. 2.
time, as measured in the carotid pulse, increases after a longer R-R interval.

This relationship of varying R-R intervals on the S$_2$-OVS interval is readily demonstrated (Fig. 6); that is, a long preceding R-R interval is followed by an increase in the S$_2$-OVS interval. An inverse relationship between the Q-CVS interval and the previous R-R interval occurred in the same patient (Fig. 7).

**Comment**

Results of this study are consistent with the existence of a small pressure gradient across these ball-cage valves. In fact, the relationship of AS$_2$-OVS intervals to the heart rate would be evidence *per se* of mild stenosis. The comparison with mitral stenosis and the opening snap is apt and the time relationships have similarities; for, as indicated earlier the area of the valve orifice of the prosthesis is approximately...
2.5 sq. cm., or physiologically a very mild mitral stenosis.

We wish to emphasize that the duration of AS2-OVS intervals in patients with prosthetic mitral valves exceeds that of the characteristic AS2-OS of mitral stenosis and that the former involves velocity of a ball while the latter involves a reversal of curvature of the anterior leaflet. The ball travel in the Starr-Edwards valve can be considered to be akin to travel of the midportion of the anterior leaflet in mitral stenosis.

It is interesting to conjecture that the sounds produced by movement of the ball may be analogous to those caused by another mass normally foreign to the heart, a left atrial myxoma. In both situations, movements of a mass give rise to a distinct sound occurring in early diastole when the left atrial-left ventricular pressure gradient and the velocity of blood can exert their maximum effects.

A normal Q-CVS interval and long S2-OVS intervals indicate that the pressure gradient across the valve is small. After insertion of prosthetic valves, left atrial pressures frequently have returned to normal. The relationship of the AS2-OVS and the R-R intervals does not appear to be a simple linear function, for only at slower heart rates did the interval increase (Fig. 6). At any particular heart rate there was considerable variation in the interval.

Since, in many patients in whom this type of operation was carried out, the left ventricular end-diastolic pressures were elevated, any increase in left atrial-left ventricular pressure gradient might reflect a decrease in left ventricular end-diastolic pressure. In this situation, lengthening of the Q-CVS interval and shortening of the S2-OVS interval with no change in the preceding R-R interval should suggest improvement in cardiac status rather than be interpreted as an unfavorable sign as in

![Effect of previous R-R interval on AS2-OVS in patient with ball cage mitral valve (breath held)](image)

**Figure 6:** Relationship of AS2-OVS interval to preceding R-R interval in a patient with Starr-Edwards valve, atrial fibrillation, and good exercise tolerance. (One should recognize that a sequence of beats would have an effect on the atrial distention, not alone the single preceding beat.)
mitral stenosis. We have not studied patients a sufficient length of time postoperatively to determine if there is any long-term prognostic significance in these items.

**SUMMARY**

Phonocardiographic studies of six patients with Starr-Edwards ball-cage mitral valve prostheses revealed that the intervals between the Q wave and the closing valve sound (CVS) and between the aortic second sound (S₂) and the opening valve sound (OVS) vary with the preceding R-R interval. The aortic S₂-OVS interval was constant during respiration. Observed results are considered indicative of a small atrial-ventricular pressure gradient across the ball-cage valve. Increasing of the Q-CVS interval and decreasing of the aortic S₂-OVS interval without a change in the preceding R-R interval suggest improvement of the cardiac status.

**RESUMEN**

En estudios fonocardiográficos de seis enfermos con válvula protésica Starr-Edwards, de jaula con esfera, los intervalos entre la onda Q y el sonido de cierre de válvula (CVS) varía con el intervalo R-R que la precede. El intervalo aórtico S₂-CVS fue constante durante la respiración. Los resultados observados se consideran indicadores de un gradiente de presión pequeño atrio-ventricular a través de la válvula de esfera. Al aumentar el intervalo de Q-CVS y al decrecer el intervalo aórtico S₂-CVS sin cambio en el intervalo precedente R-R, esto sugiere mejoria de la condición cardiaca.

**RESUMÉ**

Des études phonocardiographiques de 6 malades ayant eu une prothèse valvulaire mitrale du type Starr-Edwards ont montré que les intervalles entre l'onde q et le bruit de fermeture de la valve (CVS), et entre le 2ème bruit aortique (S₂) et le bruit d'ouverture de la valve (OVS) varient avec l'intervalle R-R précédent. L'intervalle aortique S₂-OVS est resté constant durant la respiration. Les résultats observés semblent indiquer un léger gradient de pression atrio-ven-
TOTAL PROSTHETIC MITRAL VALVE REPLACEMENT 17


8 ZITNIK, R. AND BURCHELL, H. E.: Unpublished data.


PULMONARY EMBOLECTOMY IN ACUTE PULMONARY EMBOLISM

Renewed attention to embolectomy in acute pulmonary embolism was discussed by Dr. Karl Voeschschulte, Gelsen/Lahn, Germany. It was made clear that this cannot be a matter of sudden decision which depends upon the situation after the result of an intervention. The conditions for operation are described and a distinction drawn between acute and chronic pulmonary embolism. The surgical management of acute pulmonary embolism in 32 cases is considered in detail and the numerous advantages of the trans-ternal method are set forth. The method is very simple technically and allows ample vision and access. The risks are reduced and the problem of relapse embolism is no longer a threatening complication. The method has thus achieved remarkable success and may be of great value in the future.

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RESECTION OF SOLITARY PULMONARY METASTASES

The appearance of a solitary metastatic lesion in the lung months or years after removal of an extra-pulmonary primary growth is not uncommon, said Dr. Myer Glick, Sydney, Australia. An operation to remove such a lesion is a gamble as it can only be presumed that the lesion seen on x-ray examination is the only one present. Justification for considering removal can be presented on two accounts. First, if the opacity is a metastasis and is not treated, the outcome is fatal. Secondly, the opacity seen is an undiagnosed lesion and may be another primary or benign lesion amenable to complete and curative removal. The status of the site of the original primary lesion must be assessed before embarking on resection of presumed solitary metastases. Successful eradication of the primary can only be presumed in other than superficially placed lesions. Five personal cases were presented.

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