The Value of the Atrial Electrokymogram in the Diagnosis of Mitral Regurgitation

Observations on Patients with Rheumatic Mitral Stenosis before and after Mitral Valvuloplasty

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The difficulty of correct clinical assessment of the functional state of the diseased mitral valve has prompted this re-evaluation of the atrial electrokymogram in 15 patients with rheumatic mitral disease. By means of a technic stressing careful placing of the pick-up device and recording from multiple locations along the left atrial border, a pattern characteristic of mitral regurgitation could be demonstrated. In general, the electrokymographic predictions correlated well with the operative findings.

The diagnosis of mitral insufficiency, correct as to presence and degree, has gained greater significance since the advent of the surgical treatment of mitral stenosis. A slight or moderate degree of insufficiency not infrequently accompanies mitral stenosis and does not prevent the improvement resulting from valvuloplasty. However, a number of instances have been reported where the operation was undertaken on the assumption that mitral stenosis was present either as the sole or the dominant lesion, but where a high degree of insufficiency was found.

The present communication attempts to evaluate the reliability of electrokymograms in the diagnosis of mitral insufficiency by correlation with the findings at subsequent valvuloplasty. The difficulties and limitations of the clinical diagnosis of mitral regurgitation, which have been discussed at length in a previous communication, justify this.

Atrial dilatation under normal and pathologic conditions results in outward movement of the atrial wall. Fredzell and co-workers in their studies on filling and emptying of the left atrium by rapid serial roentgenography during angiography, emphasize that the left atrium is similar to a sphere. Therefore contraction and dilatation occur in a rather concentric fashion, and there is little chance for paradoxical movement of parts of the wall such as may occur in more irregularly shaped chambers. The normal atrial movements have been observed by fluoroscopy, by classic roentgenkymography and more recently by electrokymography.

The normal electrokymographic tracings of the left atrium, as described by Luisada, Fleischer and Rappaport and confirmed by various authors, consist of a slow rise of the curve during ventricular systole, preceded by a sharp negative wave in presystole (inward motion caused by atrial contraction) and interrupted by a more rounded negative wave in early systole (inward motion caused by lowering of the A-V septum, only partly compensated by venous inflow into the atrium). According to general convention, the polarity of the recording apparatus is arranged in such a way that an outward movement of the border of the cardiac silhouette registers as upward deflection of the curve.
Mitral insufficiency produces regurgitation of blood during systole, resulting in a sudden distention of the left atrium. This systolic distention, if marked, can be recognized by fluoroscopy.5, 14-16 This abnormal distention was first identified graphically by means of roentgenkymography by Heim de Balzac and Pannier,17 and has been analyzed electrokymographically by Luisada and Fleischner18 and many others.10, 12, 13, 19-22 The typical pattern of mitral insufficiency consists of a rapid rise during isometric contraction and in early systole, followed by a horizontal line which may be straight, notched, or convex, and lasts throughout systole. Opening of the mitral valve is followed by a rapid fall of the tracing. This is the pattern which we18 have called the "positive systolic plateau." It should be emphasized, however, that the rapid early systolic rise of the tracing is the essential characteristic of the regurgitation pattern as discussed in more detail in a later paragraph.

The systolic positive plateau of the electrokymographic tracing is quite similar to Wiggers' left atrial volume curve in experimental mitral regurgitation in the animal,23 and resembles closely the left atrial pressure curves obtained in patients with mitral regurgitation by Munnell and Lam4 and by Wynn and co-workers.24 Most of the quoted authors emphasize the specificity of the "positive systolic plateau" of the atrial border tracing and have not found this sign in individuals with normal hearts. There are a few discordant opinions, however. Dussaillant and collaborators25 reported patterns of systolic expansion in occasional atrial border electrokymograms of normal subjects.* Similarly, Soloff, Zatuchni and Stauffer26 found a positive systolic plateau in 10 out of 15 healthy subjects. One of the present authors (W. H. A.)5 reported less specificity of the positive plateau in a previous study, performed, however, with less satisfactory technic.

Thus the method of atrial electrokymography merits discussion in some detail.

* Recently, Dussaillant and associates reported that when several points of the left atrium of normal subjects are studied, a pattern suggesting systolic expansion is found only in an exceptional tracing.18
Fig. 1. Healthy male, age 26. (A) Left atrial border tracing, high, right anterior oblique. (B) Aortic Knob. (C) Left atrial border tracing, right anterior oblique, 2 cm below tracing A. Each strip shows phonocardiogram, electrocardiogram and electrocardiogram, in this order. In the slow speed tracing, top left, the curve simulates the "systolic plateau" of mitral regurgitation. The fast speed tracing, top right, however, reveals the similarity with the aortic tracing, bottom right. Tracing A thus is the summation effect of the weak atrial and the superimposed stronger descending aortic pulsation. The normal atrial pattern in tracing C demonstrates the value of tracings from multiple sites.

which represents the site of potential projection of a large left atrium, were chosen for recording. In this view, the standard tracings of the apex, pulmonary artery, aortic knob, and "right atrium low" were also taken. The left atrial border, furthermore, was recorded in the right anterior oblique position in three places, high, mid and low, and similarly in the left anterior oblique position, high, mid and low. Thus a minimum of six and a maximum of eight border tracings of the left atrium were obtained. The "third curve" was not obtainable in instances without sufficient bulge of the left atrial appendage or postoperatively, and "right atrium high" did not record the left atrium when this did not project on the right side. In order not to rely entirely upon border movement, we placed the slit of the pick-up device in such a way that we included this border eccentrically, having the greater portion of the slit over the body of the atrium, thus obtaining a fair amount of densography of the atrial body at the same time. All leads were recorded at both 25 mm. per second and 75 mm. per second paper speeds.

Case Material

In addition to numerous previous studies on normal subjects where only two or three tracings of the posterior wall of the left atrium were obtained, five healthy medical students served as controls for this extended schedule with three tracings of the posterior atrial wall in both right and left anterior oblique positions.

Fifteen patients with rheumatic mitral valvular disease were studied. All had an apical diastolic murmur characteristic of mitral stenosis. Of these, 11 showed no evidence of mitral regurgitation by history, physical examination, electrocardiogram, x-ray films and fluoroscopic examination of the heart.

Patient 8 showed a grade 2 apical systolic murmur, left axis deviation by electrocardiogram, right ventricular hypertrophy and marked left auricular enlargement with systolic expansion on fluoroscopy; these findings were interpreted as indicative of at least moderate regurgitation. Patients 11 and 12 were suspected of mild regurgitation on the basis of grade 2 apical systolic murmurs. Patient 14 was suspected of mild to moderate regurgitation on the basis of a grade 2 systolic murmur at the apex and an electrocardiogram showing left axis deviation.

All 15 patients subsequently underwent mitral valvuloplasty, and 10 were studied again post-operatively.

Interpretation of Electrocardiograms

A. Tracings in the presence of normal sinus rhythm. The presystolic downward deflection in the atrial kymogram in patients with mitral stenosis and normal sinus rhythm is frequently seen to be rather pronounced (fig. 2). This apparent change in the downward deflection of greater amplitude and duration than in normal tracings, as stressed by Anderson,5 is probably a consequence of the preceding delayed and abnormally slow fall of the curve during early diastole signaling impaired atrial emptying. Two factors may contribute to this delayed contraction of the left atrium, namely delayed evacuation of the atrium due to resistance of the narrow mitral ostium and accelerated refilling of the atrium from the reservoir of the engorged pulmonary veins. Increased pulmonary venous pressure may also be responsible for faster atrial filling after atrial contraction which is suggested by a rapid rise of the curve often seen immediately following the accentuated fall in presystole. This rise may coincide with the period of isometric contraction of the ventricle and may be misinterpreted as evidence of mitral regurgitation. The following upward surge in early systole, however, is less steep than that of mitral regurgitation.

We consider a left atrial tracing indicative of
Fig. 2. Case 2. C. T. Pure mitral stenosis. Normal sinus rhythm. Three tracings of the posterior wall of the left atrium in right anterior oblique position, high, middle, and low, each with phonocardiogram, (top), electrokymogram, (middle), and electrocardiogram (bottom). The strips showing records with slow (25 mm./second) on the left and fast (75 mm./second) motion on the right are arranged below each other in such a way that the QRS complexes of the first cycle in fast recording are aligned in a vertical line. Line interval equals 0.04 second. The top and middle tracings show a deep presystolic wave: forceful atrial contraction. All three tracings show the normal slow expansion of the atrium during systole.

Mitral regurgitation when a rapid rise occurs during the period of isometric ventricular contraction or early during the period of rapid ventricular ejection reaching a peak early during systole. This is followed by a horizontal line which may be straight, slightly sloping upward or downward, or convex. The early systolic negative wave caused by the ventricular pull is often completely effaced or noticeable as a small notch (fig. 3A). In rare instances a rapid early systolic rise may be followed by a slower fall during late systole. We consider this tracing as of doubtful evidence of mitral regurgitation (fig. 3B). Whenever the upward movement reaches its peak after the first third of systole, the tracing is not considered to indicate mitral regurgitation (fig. 3C).

B. Tracings in the presence of atrial fibrillation. Mitral stenosis produces no characteristic signs in the absence of atrial contraction, while the signs of mitral regurgitation are the same as with normal sinus rhythm (fig. 4).

Interpretation of Operative Findings

The electrokymographic findings were compared to the anatomic diagnosis made by the surgeon at the time of cardiotomy. The surgeon's diagnosis is based upon the size of the mitral valve area during systole and diastole and takes into consideration the absence or presence and degree of a regurgitant jet, as felt by the finger inserted into the left auricle. While the surgeon's diagnosis has great advantages over a diagnosis based on clinical data or on autopsy findings, especially with regard to the degree of functional closure or competence of the valve during systole, it also has definite limitations which have been discussed previously. While the area of the mitral valve may be estimated in this manner with a high degree of accuracy, the detection of a regurgitant jet is a function of its size, form and direction as well as of the sensory threshold of the finger, which is raised by the glove. Furthermore, during cardiotomy the blood pressure usually is lower than normal and may be very low, in which case regurgitation may be minimal even with a structurally
incompetent mitral valve. Not enough emphasis has been placed upon the fact that opening of the chest disturbs the normal physiologic conditions in several respects. The flopping pulsation of the heart in the presence of pneumothorax or pneumopericardium has been observed roentgenologically long ago. If the lung with its damping effect is replaced by free air, the ventricle swings with bigger amplitude. The same must occur when the chest is opened. It is not as yet evident which additional role is played by the changed position of the diaphragm, the opening of the pericardium and the exposure of the veins and atria to atmospheric pressure instead of the changing lower pressures within the closed chest.

Furthermore, arrhythmia favors the occurrence of mitral regurgitation. In runs of bigeminy one may observe mitral regurgitation during the second beat of the couple, not discernible at normal sinus rhythm. According to Wiggers, the fraction of the tidal volume that flows back into the left atrium is larger when the myocardium is depressed. These and possibly other factors make it plausible that observations of the function of the mitral valve at the time of operation may differ from those made with the chest closed and the patient under more normal conditions. Notoriously, in contradistinction to mitral stenosis, mitral insufficiency is greatly dependent upon the functional condition of the heart and the circulatory dynamics, and thus the amount of regurgitation is subject to momentary fluctuations.

**Results**

*Normal Subjects*

Auricular electrokymograms taken in five normal subjects showed consistently normal patterns. In no instance was the picture suggestive of mitral regurgitation.

*Patients with Mitral Valvular Disease*

1. **The Preoperative Examination.** In the presence of normal sinus rhythm, the electrokymographic diagnosis was arrived at in the following manner: If the pattern of mitral regurgitation (any of tracings A), was present in one or two tracings, mild mitral regurgitation was assumed, designated mr in the tables. If three to five of the tracings showed this pattern, a moderate degree of mitral regurgitation was diagnosed, mR. More than five positive tracings were considered to signalize marked mitral regurgitation, MR. This admittedly is an arbitrary and incomplete classification kept so strict for the purpose of objective evaluation of the method. In clinical practice we relate these findings to the size of the left atrium. A certain volume of regurgitating blood may produce an outward movement of the atrial wall of considerable amplitude when the atrium is small. The same amount of blood flowing back into a grossly dilated atrium may cause a small or even subliminal outward movement.

The analysis of the electrokymographic tracings is presented in table 1. Table 2 shows
the correlation of the electrokymographic diagnosis with the clinical and operative findings. From this listing, it will be seen that the agreement of the electrokymographic and surgical diagnosis was satisfactory in the seven patients with normal sinus rhythm. In the only case where there was disagreement (case 1) the electrokymogram suggested mitral stenosis with some regurgitation, but no regurgitant jet was felt at cardiotomy. However, the mitral valve area was slightly larger than usual in tight mitral stenosis, and the systolic blood pressure was only moderately decreased.

Table 1.—Analysis of the Border Electrokymogram of the Left Atrium

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age and Sex</th>
<th>Rhythm</th>
<th>Status</th>
<th>Individual Electrokymographic Leads</th>
<th>Electrokymographic Diagnosis of Regurgitation</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Left Atrium</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right Atrium High</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>2</td>
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<tr>
<td>1. C. S.</td>
<td>38F</td>
<td>NSR</td>
<td>Preop.</td>
<td>1S</td>
<td>1</td>
</tr>
<tr>
<td>2. C. T.</td>
<td>28F</td>
<td>NSR</td>
<td>Preop.</td>
<td>S</td>
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</tr>
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<td>3. B. L.</td>
<td>19F</td>
<td>NSR</td>
<td>Preop.</td>
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<tr>
<td>4. A. H.</td>
<td>43F</td>
<td>NSR</td>
<td>Preop.</td>
<td>S</td>
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</tr>
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<td>NSR</td>
<td>Preop.</td>
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</tr>
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<td>6. M. L.</td>
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<td>NSR</td>
<td>Preop.</td>
<td>S</td>
<td>0</td>
</tr>
<tr>
<td>7. G. D.</td>
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<td>1</td>
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<td>14. G. M.</td>
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注：S” stands for deep presystolic negative wave, indicative of mitral stenosis. “1” stands for positive systolic plateau typical of mitral regurgitation; “2” for early systolic expansion; “3” for insignificant late systolic plateau, as explained in figure 3; “0” for normal tracings or insignificant changes.

RAO = Right Anterior Oblique. LAO = Left Anterior Oblique.
pressure was only 60 at the time of intracardiac palpation. Moreover, at the time of operation and before the heart was opened, the left atrium exhibited visible systolic expansion.

In the presence of atrial fibrillation, tracings permit no comment as to the presence of mitral stenosis. The electrokymographic diagnoses of mitral regurgitation, when compared with the operative findings, were satisfactory in four of the eight patients with atrial fibrillation. In the remaining three, (cases 10, 11, and 13) the degree of mitral regurgitation was probably overestimated (table 1).

The only patient who on preoperative evaluation showed a pattern of mitral regurgitation in all leads (case 8) was found to have marked mitral regurgitation as predicted from the electrokymogram.

11. The Postoperative Atrial Electrokymogram. In 10 patients, electrokymographic examinations were repeated one to two months after mitral valvuloplasty. The atrial electrokymogram became normal in five cases (cases 1, 2, 5, 11, 13), four of which had shown regurgitation preoperatively. The tracings remained unchanged in four cases (cases 3, 9, 10, 12), and suggested mitral regurgitation induced by the operation in one case (case 4, fig. 5).

One may raise the question whether the postoperative electrokymographic changes are any measure of the success of the operation in terms of correction or mitral stenosis and/or production of mitral regurgitation. On the basis of the present material, this question cannot be answered.

**COMMENTS**

The problem of assessing the degree of mitral regurgitation present in a patient with mitral valve disease may be viewed from two perspectives. The experimental physiologist may express the volume of regurgitated blood either absolutely per beat or minute, or relatively as a percentage of the total forward flow through the mitral valve. No method is known today to fulfill these demands in man under normal

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### Table 2. —Electrokymographic Diagnoses and Findings at Cardiotomy

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age and Sex</th>
<th>Rhythm</th>
<th>Electrokymographic Diagnosis</th>
<th>Findings At Cardiotomy</th>
<th>Blood Pressure Preop.</th>
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<td>Postop.</td>
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<td>MS</td>
<td>N</td>
<td>IIA</td>
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<td>MR</td>
<td>IA</td>
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<td>mR</td>
<td>IA</td>
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* MS = mitral stenosis; mR = mild mitral regurgitation; mR = moderate mitral regurgitation; MR = marked mitral regurgitation.

† Type I: rigid valve with marginal leaflet fusion and, usually, calcification. Type II: flexible funnel fusion of leaflets. Group A: mitral orifice pointing toward ventricular wall. Group B: mitral orifice pointing into outflow tract. (Harken and colleagues.)*

†† Postmortem; operative death.

§ The electrokymographic diagnosis was unknown to the surgeon.
conditions. Hence, the accuracy of the electrokymographic findings cannot be absolutely validated. The problems facing the clinician, fortunately, do not require as rigorous an exactitude. The particular questions in evaluating a patient with mitral valve disease are: (1) Is there mitral insufficiency (alone or in addition to known mitral stenosis)? (2) If so, is it "significant," that is, regurgitation of a degree which would contraindicate operative treatment of stenosis, or affect adversely the postoperative prognosis?

It seems that the presence of mitral regurgitation can be established with a fair degree of accuracy by electrokymography. The theoretic-physiologic rationale and the practical experience of many authors support the value of this method. Very isolated observations in the literature of a "false positive" tracing may be due to individual circumstances of technic or clinical condition. We are not aware, however, that mitral regurgitation if present did not manifest itself in the electrokymogram (no "false negatives").

As to the second question, further long range follow-up observations on patients who have undergone valvuloplasty are required before one can determine how much regurgitation is "significant." On the other hand, methods are desirable to assess the degree of regurgitation before operation in order to make such followup studies meaningful. For the present, then, we have classified the findings as signaling mild, moderate, or marked regurgitation. It appears reasonable to accept the operative findings of a regurgitant jet as evidence of regurgitation. If a jet is strong, it may be safe to conclude that regurgitation must be at least moderate during normal life. If the jet is weak, the level of the systolic blood pressure and the area and type of the mitral valve as palpated may give clues as to the probable severity of regurgitation during normal life. The tendency, however, is likely to be toward underestimation rather than overestimation of regurgitation by the palpatory method.

On the other hand, the operative findings being regarded as yardstick, overdiagnosis by electrokymography is to be expected, especially in cases where no jet is felt by the surgeon and the electrokymographic diagnosis of mild regurgitation is based on some definite abnormal tracings among others that are normal. In no instance of the present series was mitral regurgitation encountered at operation without having been predicted from the electrokymogram, nor was regurgitation ever of higher degree than predicted. Thus, while electrokymography may prevent the unexpected encounter with high grade mitral insufficiency, the validation of electrokymography in respect to the positive diagnosis of mild degrees of regurgitation will have to await comparison.
with a method of physiologic quantitation of regurgitation which is not subject to the limitations of the observations at cardiotomy.

The fluoroscopic observation of the atrial outward movement was rather reliable when the left atrium projected considerably on the right side; in other instances, the agreement was only fair, with errors in either direction if we apply the electrokymographic findings as yardstick.

The clinician will now ask: What can the electrokymogram add to the conventional clinical preoperative evaluation? In the present group of patients, selected for mitral valvuloplasty, a fully adequate clinical diagnosis was possible in all but one patient. In this case (case 8) mitral regurgitation was considered moderate clinically, marked by electrokymography, and actually found predominant at postmortem examination. This was the only patient in this series who could not have been benefited by mitral valvuloplasty. Thus in the occasional patient with clinically unsuspected predominance of mitral regurgitation, the electrokymogram may give the warning signal.

SUMMARY AND Conclusions

Electrokymograms of the left atrium were taken in five normal subjects and in 15 patients with rheumatic mitral valvular disease, 10 of whom were re-examined after mitral valvuloplasty. The need for precise technic, accurate timing of the cardiac cycle, and multiple atrial tracings was emphasized.

Some abnormal atrial tracings were seen in all patients with rheumatic mitral disease, none in the healthy control subjects.

With the surgeon's observation of a regurgitant jet during cardiotomy accepted as a base for comparison, the electrokymographic diagnosis of absence, presence or degree of mitral regurgitation showed a fair consistency. This was almost complete in patients with normal sinus rhythm, while in those with atrial fibrillation the electrokymogram tended to slightly "overdiagnose" mitral regurgitation. In no instance, however, was mitral regurgitation found to be of higher degree at operation than had been predicted by electrokymography.

After mitral valvuloplasty, the atrial electrokymogram became normal in five patients, four of whom had shown electrokymographic evidence of regurgitation preoperatively. The tracings remained unchanged in four, and suggested mild mitral regurgitation in one.

It is concluded that with careful technic atrial electrokymography may be a valuable adjunct to the preoperative evaluation of the degree of mitral regurgitation in patients with rheumatic mitral disease.

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SUMARIO Español

Se obtuvieron electroquimogramas del atrio izquierdo en 5 sujetos normales y en 15 pacientes con enfermedad reumática de la válvula mitral, 10 de los cuales fueron reexaminados luego de valvuloplastía mitral. La necesidad de técnica precisa, determinación exacta del tiempo en el ciclo cardíaco y trazados atrales múltiples se enfatizan.

Algunos trazados atrales anormales se observaron en todos los pacientes con enfermedad reumática mitral, ninguno en los sujetos controles normales.

Con la observación del cirujano de un chorro regurgitante durante la cardiotomía aceptado como una base para la comparación, el diagnóstico electroquimográfico de ausencia, presencia o grado de regurgitación mostraron una consistencia favorable. Esto fue casi completo en los pacientes con ritmo sinusal, mientras en aquellos con fibrilación auricular el electroquimograma tendió ligeramente a "sobre diagnosticar" regurgitación mitral. En ningún caso, sin embargo, se encontró la regurgitación mitral ser de un grado mayor durante la operación que lo que predijo el electroquimograma.

Luego de la valvuloplastía mitral, el electro-
quimograma se tornó en normal en cinco pacientes, cuatro de los cuales habían mostrado evidencia electroquimográfica de regurgitación preoperatoriamente. Los trazados permanecieron sin cambiar en cuatro y sugirió regurgitación mitral ligera, en uno.

Se concluye que con una técnica cuidadosa la electroquimografía atrial puede ser un aditamento valioso para la evaluación preoperatoria del grado de regurgitación mitral en pacientes con enfermedad reumática mitral.

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FELIX G. FLEISCHNER, WALTER H. ABELMANN and ROBERT BUKA

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