Classification of the radiological morphology of the mitral valve

*Differentiation between true and pseudoprolapse**

HUGO SPINDOLA-FRANCO,† LARS BJORK, DOUGLASS F ADAMS, HERBERT L ABRAMS

From the Department of Radiology, Harvard Medical School, and Peter Bent Brigham Hospital, Boston, Massachusetts, USA

SUMMARY The morphology of the mitral valve apparatus was assessed on 100 normal left ventriculograms. Four distinct types of mitral valve were identified according to the position of the mitral fulcrum (the point of attachment of the leaflets to the annulus) and the configuration of the adjacent left ventricular wall (left ventricular fornix) during diastole. Types I and II closely simulated prolapse of the mitral valve (pseudoprolapse) in the right anterior oblique projection during the ejection period. Measurements showed that contraction of the ventricle failed to reduce the diameter of the mitral valve annulus in 26 per cent of normal left ventricles.

The normal and pathological anatomy of the human mitral valve has been studied extensively, particularly at necropsy, but the normal dynamic anatomy remains elusive. A thorough knowledge of the changes occurring in the normal mitral valve apparatus during both diastole and systole is essential particularly for making the correct angiocardigraphic diagnosis of mitral valve prolapse. In this report we describe the appearances of normal mitral valves during ventriculography and establish criteria for the identification of the normal mitral valve.

Subjects and methods

The biplane left ventriculograms of 100 patients with chest pain were analysed to determine the dynamic anatomy of the mitral valve. None of the patients had clinical or radiological evidence of mitral valve disease or papillary muscle dysfunction. The left ventricle was catheterised by the percutaneous transfemoral technique¹⁻³ with a polyurethane pigtail catheter, and 10 to 16 ml/s 76 per cent sodium-methylglucamine diatrizoate (Renografin 76) was injected in three seconds using a Viamonte/

Hobbs automatic injector. The 6-inch modes of biplane 10 6-inch caesium-iodide Siemens high resolution image intensifiers (4.5 line pairs/mm resolution) were used with high definition photography of the output phosphor. The electrocardiogram and pressure pulses were simultaneously recorded on paper and on the cine film. Echocardiograms and phonocardiograms were obtained in all patients using a Hoffrel Ultrasonoscope (Model 101), with either a 2.25 MHz transducer focused at 7.5 cm or an unfocused 2.9 MHz transducer, and a piezoelectric crystal microphone (type 53161, Kent Cambridge, Ossining, NY), displayed on the oscilloscope of a Cambridge multi-channel recorder, and permanently recorded on photographic paper. Prolapse of the mitral valve, mid-systolic clicks, and late systolic murmurs were specifically sought. Echocardiograms, phonocardiograms, and cine left ventriculograms were interpreted independently, and the results then pooled.

The configuration of the normal mitral valve and its dynamic changes were examined by tracing the image directly from projections of 16 mm cine film. Actual heart size was determined by the 1 cm grid technique (North American Medical Instrument Corp, Hudson Falls, NY). The outline of the left ventricle was traced at end-diastole and end-systole during the beat with optimal ventriculographic opacification. Premature ventricular contractions and post-extrasystolic contractions were excluded.

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† Present address: Department of Radiology, Albert Einstein College of Medicine of Yeshiva University at Montefiore Hospital and Medical Center, Bronx, New York 10467, USA.

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Observations were made on: (1) changes in mitral valve diameter; (2) position of the point of attachment of the posterior leaflet of the mitral valve to the mitral ring in diastole and systole; (3) delineation of the papillary muscles and chordae tendineae; (4) mitral leaflets and their scallops; and (5) posteromedial and anterolateral commissures. The percentage shortening of the mitral valve ring diameter between diastole and systole was calculated in all cases. The depth of bulging of the mitral valve leaflets into the left atrium was measured in all patients.

The mitral fulcrum was defined as the point of attachment of the mitral leaflets to the annulus fibrosus. For the purposes of clarity the word "fulcrum" as used in this paper refers to the most inferior portion of the fulcrum as seen in the right anterior oblique projection (Fig. 1). The fornix of the left ventricle is defined as that part of the left ventricle between insertion of the mitral leaflets

Fig. 1 Early diastolic frame of a 16 mm cine left ventriculogram from a patient without heart disease. The fulcrum (short wide white arrow) or point of attachment of the mitral leaflets to the mitral annulus is clearly seen. The fornix (white bracket) is the left ventricular wall between the fulcrum and papillary muscles (pm). The papillary muscles are better seen on a systolic frame. Because of the high lying fulcrum and absence of notching of the fornix, this mitral valve has the type III configuration. The line of attachment of the posterior mitral leaflet (black arrow-heads) sharply outlines the width of the mitral valve. The membranous septum (atrioventricular portion) (long thin white arrows) can be seen in the subaortic region as a smooth straight or minimally curved line beneath the non-coronary leaflet. Unopacified left atrial blood entering into the left ventricle can be seen as the broad band of lucency encompassing the entire width of the ventricle and immediately in front of the attachment of the posterior mitral leaflet.

Fig. 2 Diagrams of diastolic frames of left ventriculograms demonstrating the four mitral valve configurations. The arrows identify the mitral valve fulcra. Types I and II have low fulcra, but II has a notched fornix. Types III and IV both have high fulcra, and the fornix is also notched in type IV. Types I and IV are more common than types II and III.

into the annulus fibrosus and the base of the papillary muscles. Ventriculography clearly delineates the fulcrum during the rapid filling phase of the cardiac cycle. The mitral fulcrum is seen at the interface formed by the unopacified blood rushing into the left ventricle and by the contrast trapped in the recess between the mitral leaflets and the adjacent ventricular endocardium (Fig. 1). The intimate relation of the most inferior portion of the mitral fulcrum to the posteromedial scallop of the posterior leaflet makes this portion of the fulcrum the best landmark for judging prolapse of the posteromedial scallop of the posterior leaflet. The posteromedial scallop is that most frequently involved in mitral valve prolapse.^{4,5} The ability to visualise the mitral fulcrum during cineangiography is the crux of this study and removes the subjective character of identification of mitral prolapse. The mitral fulcrum must be visualised in order to assess mitral valve prolapse objectively.

Results

Four distinct types of mitral valve were identified in the right anterior oblique projection, depending on the position of the mitral fulcrum in proto-diastole and the diastolic configuration of the fornix of the left ventricle (Fig. 2). Type I was characterised by a low-lying mitral fulcrum without notching of the ventricular fornix. Type II had a low-lying mitral fulcrum and a semilunar notch in the left ventricular fornix. In type III there was a high

Fig. 3 Components of the mitral valve apparatus (right anterior oblique projection). (a) The low lying fulcrum (arrow) and absence of notching of the left ventricular fornix (white bracket) in this diastolic frame make the mitral valve configuration type I. The upper margin of the fornix can be identified by the beak sign (arrows). pm, posterior papillary muscle. (b) During systole the posteromedial scallop (long white arrows) of the posterior mitral leaflet and posteromedial commissure (most superior linear lucency) are shown. The right margin of the outflow tract of the left ventricle formed by the atrioventricular septum is well delineated (white arrow-heads). Both papillary muscles are apparent (pm).

mitral fulcrum with no notching of the fornix. In type IV there was a high mitral fulcrum and a notched left ventricular fornix. Types I and IV were seen in 39 and 38 cases, respectively; types II and III were seen in nine and 14 cases, respectively. The papillary muscles were seen in all patients in the right anterior oblique projection during systole and in the left anterior oblique projection during both systole and diastole. Chordae tendineae were clearly visible in the right anterior oblique projection in five cases during systole. The posteromedial commissure was seen in 50 cases. The posteromedial scallop was by far the most commonly identified component (32 cases) of the posterior mitral leaflet (Fig. 3). The middle and anterolateral scallops were seen in six cases. All three scallops of the posterior leaflet of the mitral valve were identified in four instances.

The mitral fulcrum was always identified in the right anterior oblique projection by contrast trapped in the recess between the leaflet and the adjacent endocardium (Fig. 1 and 3a). The line of attachment of the posterior mitral leaflet sharply outlined

the width of the mitral valve ring in diastole (Fig. 1); the upper margin of the left ventricular fornix was distinctly seen and identified in systole and diastole as a dense beak (Fig. 1 and 3a). In 74 ventriculograms the diameter of the mitral ring on the right anterior oblique projection decreased by 2 to 23 per cent in systole; in 26 patients the diameter did not change. We were able to measure the diameter of the mitral valve ring in the left anterior oblique projection in six of the 26 patients who showed no change in the right anterior oblique projection: in two of them the diameter was unchanged, but in the other four it was less 5 to 14 per cent. In an additional 33 ventriculograms the diameter of the mitral ring could also be measured in the left anterior oblique projection; there was a reduction in diameter in systole up to 37 per cent, though there was no change in seven cases. The percentage change in mitral ring diameter from diastole to systole showed no correlation with the patient's age.

In 80 patients no bulging of mitral leaflets into the left atrium could be detected. In the remaining 20 patients (Fig. 4) the normal mitral valve pro-

Fig. 4 Pseudoprolapse of the mitral valve. (a) Right anterior oblique projection. Early diastolic frame from left ventriculogram. The fulcrum is low lying (arrow) and the fornix is notched (square bracket) making this a type II mitral valve. (b) During systole there is normal bulging of the mitral leaflets (long arrows), but no posterior and inferior displacement beyond the fulcrum (short wide arrow), thus identifying this as a pseudoprolapse. An echocardiogram showed a normal mitral valve. Phonocardiography showed no mid-systolic click or late systolic murmur. It is essential to identify the fulcrum as a point of reference before making the diagnosis of prolapse of the mitral valve. (c) Left anterior oblique projection. No prolapse of the mitral valve is seen. (d) Panels A and B represent diastolic and systolic frames shown in Fig. 4a and b. The arrow indicates the fulcrum. The dotted line depicts the usual configuration of the mitral valve in systole. However, in some normal patients (20%) the mitral leaflet may bulge

(a)

(b)

(c)

(d)

in systole without posterior and inferior displacement beyond the fulcrum. In this patient (panel B) only leaflet bulging was noted. If prolapse had been present, the silhouette depicted in panel C would have been recorded. In this sketch mitral leaflet bulges inferiorly and posteriorly to the fulcrum. The diagnosis of mitral valve prolapse depends on identification of the fulcrum on technically excellent angiocardigrams.

truded from 3.5 to 6.5 mm (mean $\pm$ SEM 4.95 ± 0.2 mm) into the left atrium during systole. In no case was there any posterior and inferior para-annular displacement of the mitral valve leaflet beyond the level of the mitral valve fulcrum. No wall motion abnormalities were detected in any of these patients.^{4,6} Echocardiograms and phonocardiograms showed no evidence of prolapse of the mitral valve and mid-systolic click or late systolic murmur. In these patients, failure to recognise the mitral fulcrum could have led to the incorrect diagnosis of prolapse of the mitral valve.

Discussion

Although there have been numerous clinical,⁷⁻¹² echocardiographic,¹³⁻¹⁸ and angiocardio-graphic^{4,5,10,12,15-22} studies of the mitral valve, mitral valve prolapse is still erroneously diagnosed from ventriculograms or echocardiograms or both. Such errors are the result particularly of an incomplete knowledge of the normal angiocardio-graphic morphology of the mitral valve. Ranganathan *et al.*⁵ have stated that normal mitral valve leaflets may assume a convex configuration during systole, but that a distinct bulge into the left atrium is not apparent. However, this distinction is vague, and faulty assessment of the degree of convexity or bulging may have caused the angiocardiographer to overdiagnose mitral prolapse and greatly exaggerate its incidence in patients undergoing cardiac

catheterisation.²³⁻²⁵ Measurements on the patients reviewed here indicate that 20 per cent of normal people have mitral leaflets which bulge into the atrium during systole by less than 6.5 mm from the plane of the mitral valve. In none of these normal cases was there posterior and inferior displacement of the mitral valve leaflet beyond the level of the mitral valve fulcrum. The reports by Smith *et al.*,²³ Raizada *et al.*,²⁴ and Ruwitch *et al.*²⁵ document the frequent observation of end-systolic bulging of the mitral leaflets. It is not surprising that some degree of systolic mitral leaflet bulging might occur since the cross-sectional area of the leaflet is one-and-a-half times or twice as big as that of the mitral orifice.²⁶ The normal bulging of the mitral leaflets into the left atrium has been shown previously by the Luciani test²⁷ in normal hearts at necropsy soon after death. Chauveau²⁸ called this phenomenon "dome multiconcave" and described it as resembling wind filling out a sail. Chiechi *et al.*²⁹ recorded the observation of billowing of normal mitral valve leaflets towards the left atrium at the time of operation on the heart. We have termed this phenomenon pseudoprolapse of the mitral valve (Fig. 4). In our patients pseudoprolapse occurred most often in type I and II mitral valves. An illustration of true prolapse of the mitral valve proved at operation is included for comparison (Fig. 5). True prolapse of the mitral valve is characterised by posterior and inferior displacement of the mitral valve leaflet beyond the

Fig. 5 True prolapse of the mitral valve. (a) The high mitral fulcrum (arrow) and absence of notching of the fornx in this diastolic frame make the mitral valve configuration type III. (b) During systole there is posterior and inferior displacement of the mitral valve tissue beyond the fulcrum (arrow) resulting in true prolapse (p) of the mitral valve. Very mild mitral regurgitation is shown. LA, left atrium. (c) A systolic frame in the left anterior oblique projection clearly shows para-annular displacement of the posterior leaflet of the mitral valve characteristic of true prolapse of the mitral valve (arrows). Simultaneous echocardiogram and phonocardiogram showed mitral valve prolapse and a mid-systolic click.

level of the mitral valve fulcrum in the right anterior oblique projection. Systolic leaflet bulging is not sufficient to make the correct diagnosis of prolapsing mitral valve. Because of the low fulcrum in types I and II, the erroneous diagnosis of mitral prolapse is most likely to be made in these groups. Since the frequency of type I and II mitral valves is 39 and 9 per cent, respectively, the potential for the misdiagnosis of mitral valve prolapse is present in nearly 50 per cent of normal angiocardigrams. The recent work of Cohen *et al.*³⁰ using these criteria showed their accuracy in diagnosing mitral valve prolapse, with elimination of false positives.

Redundancy of the leaflets and/or elongation of the chordae tendineae, usually secondary to mucoid degeneration³¹ (blue valve syndrome),³² alters the line of coaptation of the mitral leaflets and produces prolapse of the mitral valve. During closure of the normal mitral valve, there is initially apposition of the edges of the leaflets with subsequent contact of their atrial surfaces. Progressive contraction of the myocardial fibres and increased intraventricular pressure cause traction on the chordae tendineae, further surface contact, and bulging of the cusps into the left atrium. The ratio of valvar tissue surface area to mitral orifice area required to produce closure is nearly two to one.²⁶⁻²⁹ On transillumination the anterior and posterior mitral leaflets have three zones: basal, membranous (clear), and rough. The rough zone of the anterior and posterior leaflets forms the coaptation surface area, which is distinctly delineated by a ridge on the atrial aspect of the mitral leaflets. This ridge marks the line of leaflet closure and according to Ranganathan *et al.*³³ is 0.8 to 1.0 cm from the free margins of the leaflets. If the line of coaptation is disturbed but there is still partial contact of the coaptation leaflet surfaces, mitral prolapse is produced with no mitral regurgitation. If there is loss of coaptation, however, mitral regurgitation will ensue. The degree of mitral regurgitation will depend on the extent of mitral prolapse. Any degree of mitral prolapse with or without mitral regurgitation can be detected on angiocardiology as long as the fulcrum and the type of mitral valve are identified in early diastole in the right anterior oblique projection.

With the advent of caesium iodide intensifiers and their increasing use in angiocardiology, it is important to recognise the normal anatomy of the mitral valve in the right anterior oblique projection if errors in diagnosis are to be avoided. This is particularly true of the posterior leaflet of the mitral valve, which is in most cases a tri-scalloped structure.²⁹⁻³³ The posteromedial commissure and posteromedial scallop are by far the most commonly

identified components of the mitral valve during ventriculography. It is important to differentiate these normal scallops from the cleft anterior mitral leaflet found in endocardial cushion defects.

In 26 per cent of patients with normal mitral valves and ventricles without annular calcification, contraction of the ventricle failed to reduce the diameter of the mitral valve annulus in the right anterior oblique projection. This observation indicates that the sphincter-like action of the annulus³⁴ plays only a secondary role in the mechanism of mitral valve closure. Our studies did not support See³⁵ and Harken *et al.*³⁶ who contend that the anterior leaflet of the mitral valve acts like a curtain extending across the mitral orifice (which remains entirely hidden) and that the posterolateral wall moves in and buttresses the posterior leaflet. No correlation could be identified between the degree of mitral annular shortening and age of the patient.

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Requests for reprints to Dr Hugo Spindola-Franco, Department of Radiology, Montefiore Hospital and Medical Center, 111 East 210th Street, Bronx, New York 10467, USA.