Dystrophic Degeneration of Papillary Muscle and Ventricular Myocardium

A Basis for Mitral Valve Prolapse in Duchenne's Muscular Dystrophy

SHYAMAL K. SANYAL, M.B.B.S., WARREN W. JOHNSON, M.D., M. R. DISCHE, M.D., PH.D., SAMUEL E. PITNER, M.D., AND CAROLYN BEARD, H.T.

SUMMARY The hearts of three children who died with Duchenne's progressive muscular dystrophy and features of mitral valve prolapse syndrome were examined to find if the valve disorder arose from cardiomyopathy due to the primary disease or from dystrophic changes in the mitral valve itself. Gross, histologic and ultrastructural features of mitral valve annulus, anterior and posterior leaflets, chordae tendineae, right and left ventricles, and anterior and posterior papillary muscles were compared with those of similar tissues from normal children of matched age and sex. Fibrosis and myofibrillar lysis — most extensive in posterior papillary muscle and in the posterobasal segment of the left ventricle — were the main histopathologic findings. Myofibrillar lysis was characterized by a total loss of actin and myosin myofilaments. By contrast, the mitral valve annulus, its leaflets and the origin, distribution pattern, length and thickness of chordae tendineae were entirely normal. These observations establish that mitral valve prolapse syndrome in Duchenne's dystrophy is an expression of cardiomyopathy involving papillary muscle and ventricular myocardium rather than a result of dystrophic changes in the mitral valve leaflets, annulus or chordae tendineae.

MITRAL VALVE PROLAPSE (MVP) syndrome, first described by Reid1 and Barlow et al.5 nearly 2 decades ago, has emerged as one of the most common cardiac disorders, especially in adults.8 Efforts to clarify the obscure etiology of the MVP syndrome have resulted in numerous reports of its association with other diseases, such as coronary artery disease,4,5 rheumatic heart disease8 and systemic inherited connective tissue disorders.7-10 We recently documented a high prevalence of this syndrome among children with Duchenne's progressive muscular dystrophy.11 Of 20 patients studied prospectively, seven had combined auscultatory, phonocardiographic and echocardiographic evidence of the MVP syndrome; the diagnosis was made by echocardiography in four other patients.

Our earlier electron microscopic studies12 indicated that multifocal myofibrillar lysis, characterized by a loss of thick and thin myofilaments, is the ultrastructural hallmark of cardiomyopathy in patients with Duchenne's dystrophy. That such extensive dystrophic changes in papillary muscles, ventricular myocardium or the mitral valve could cause prolapse of the mitral leaflets seemed reasonable. However, comparative studies of the morphologic features of such structures in patients with Duchenne's dystrophy and the MVP syndrome were lacking. We therefore determined the gross, histologic and ultrastructural characteristics of mitral valve annulus, leaflets, chordae tendineae and ventricular myocardium, including anterior and posterior papillary muscles, from patients with Duchenne's dystrophy. Comparison of the findings with those for equivalent tissues from normal controls of matched age and sex indicated that degeneration of papillary muscle and ventricular myocardium, rather than mitral valve leaflets or chordae tendineae, was responsible for the valve disorder.

Materials and Methods

The hearts of three boys, ages 14, 15 and 17 years, who died with Duchenne's progressive muscular dystrophy were studied. In each patient, the diagnosis of Duchenne's dystrophy was made by the neurologist on the basis of characteristic clinical, biochemical, electromyographic and muscle biopsy findings. Auscultatory evidence of a nonejection systolic click substantiated by phonocardiography (table 1) indicated prolapse of the mitral valve. The diagnosis was confirmed by echocardiography according to criteria reported in an earlier publication.11

The hearts were obtained within 1-2 hours of death and perfused with 2.5% glutaraldehyde, 0.1 M sodium cacodylate, pH 7.2, at 4°C. Each heart was perfused continuously for 4 hours as described earlier.12

The hearts from three healthy children who died in accidents served as controls. These subjects were matched for age and sex and had no history of congenital or acquired heart diseases.

Examination of the Heart

After the hearts had been weighed and their gross external morphology noted, the pulmonary veins were opened and the incision was extended to include the
atrial wall, giving a left atrial view of the mitral valve. An incision was then made from the ascending aorta to the left ventricular apex, parallel to the interventricular septum, to permit a left ventricular view of the intact mitral valve apparatus. The gross characteristics of the anterior and posterior leaflets, their points of coaptation, origin and insertion, and the distribution pattern of chordae tendineae were recorded using the classification of Ranganathan et al. A second incision was then made through the midportion of the anterior leaflet of the mitral valve. Care was taken not to cut any chordae tendineae or the anterior or posterior papillary muscles. The circumference of the valve ring was noted. The features of the chordae tendineae were determined according to the classification of Lam et al. Special attention was directed to the number of chordae as counted at their site of origin, the distribution and arrangement of chordae and the gross morphology of chordae at their sites of insertion. The length of each chorda was measured from the site of origin at a papillary muscle to the site of insertion into the valve leaflets, by using a caliper and metric rule graduated to 1 mm. Thickness was measured at the midpoint by the method of Lam et al.

For histologic studies, multiple sections were taken from the proximal, middle and distal portions of each leaflet; the sections were made at right angles to the free edge of leaflet and included the annulus and a small area of the left atrial myocardium. Multiple longitudinal sections of each type of chorda tendinea attached to anterior and posterior leaflets were made. Similar sections, some with attached chordae, as well as multiple cross-sections, were taken from the anterior and posterior papillary muscles. Multiple sections were also taken from different regions of the four chambers of the heart, including the left ventricular posterobasal segment, the left ventricular free wall, the interventricular septum, the free wall of the right ventricle, and the left and right atrial walls.

For light microscopy, tissues were fixed in 10% formalin and processed by standard methods. In addition to hematoxylin and eosin, the following special stains were used to study mitral valve leaflets: Weigert-van Gieson for atrialis (elastic tissue); PAS-H for spongiosa (mucoid tissue) and Masson's trichrome for fibrosa (collagen).

For electron microscopy, multiple sections were obtained from the free margin, middle and proximal portions of anterior and posterior mitral valve leaflets, annulus, chordae tendineae (rough zone chordae, basal chordae, cleft chordae, strut chordae, anterolateral and posteromedial commissural chordae), anterior and posterior papillary muscles, left ventricular posterobasal segment, interventricular septum, left and right ventricular free walls and left and right atrial walls. Sections of perfused-fixed tissues less than 1-mm thick were postfixed in OsO₄ in Millonig's phosphate buffer, dehydrated in ethanol and propylene oxide and embedded in plastic embedding media ("Spur"). From each region mentioned above, at least five sections of tissue were made at a thickness of 0.5-1 μ and stained with toluidine blue. Ultrathin sections (about 9 nm each) were stained with uranyl acetate and lead citrate and examined with a Siemens's Elmskop I electron microscope.

The hearts from normal controls were obtained within 3 hours of death, and, in each instance, the mitral valve apparatus, including the annulus, valve leaflets and chordae tendineae, was examined systematically. Tissues were obtained from the mitral valve apparatus and four chambers of the heart, as described above, and prepared for light microscopic and ultrastructural studies in the same manner as for hearts from patients with Duchenne's dystrophy.

**Results**

None of the patients had clinical evidence of congestive heart failure or cardiomegaly before death. However, the hearts from all three patients were enlarged at autopsy. Patchy white areas were seen over the epicardial surface of the ventricular free walls and, on cut sections, over the myocardial surfaces of the left and right ventricles (left ventricular myocardium mainly) and the midportion of the interventricular septum. The endocardium appeared normal.

**Mitral Valve Leaflets**

In each patient, the mitral valve consisted of two leaflets — a large, semicircular, anterior leaflet and a posterior leaflet. Neither was redundant or voluminous (figs. 1A and B) and neither had thickened

---

**Table 1. Pertinent Physical, Phonocardiographic and Echocardiographic Findings in Patients with Duchenne's Dystrophy and Mitral Valve Prolapse Syndrome**

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Nonejection systolic click</th>
<th>Phonocardiographic features</th>
<th>Systolic murmur</th>
<th>Thoracic deformity</th>
<th>Echocardiographic features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17</td>
<td>+</td>
<td>(Early systolic)</td>
<td>+ (Midsystolic)</td>
<td>+</td>
<td>Midystolic</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>+</td>
<td>(Midsystolic)</td>
<td>+ (Midsystolic)</td>
<td>+</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>+</td>
<td>(Midsystolic)</td>
<td>None</td>
<td>None</td>
<td>Multiple</td>
</tr>
</tbody>
</table>

*Posterior motion of the mitral valve leaflet that was > 4 mm from the CD line.11
Abbreviations: PCML = posterior coaptation of mitral leaflet; + = present.
free margins. The atrial surface of the anterior leaflet, similar to that of normal controls, had a ridge about 1 cm from the free margin. The area distal to the ridge — the rough zone — was opaque to transillumination, whereas the area between the rough zone and the annulus of the mitral valve was membranous and clear to transillumination. The ratio of rough zone to clear zone in the anterior leaflet varied from 0.5–0.6, similar to control values. The posterior leaflet in each dystrophic heart and in normal controls was triscalloped (fig. 1B); a large scallop occupied the middle portion and two smaller scallops were near the commissural areas. The smaller scallops, anterolateral and posteromedial, were separated from the middle scallop by insertion of cleft chordae (fig. 1B, box). Each posterior leaflet presented three zones: a rough zone extending from the free margin to the line of closure of the leaflet, a narrow clear zone extending to within 2–3 mm of the valve annulus and a basal zone lying between the clear zone the annulus. The heights and widths of the anterior and posterior leaflets in patients with Duchenne’s dystrophy were similar to those of normal controls (table 2). In patients as well as in normal controls, the two leaflet...
### Table 2. Height and Width of Anterior and Posterior Leaflets of the Mitral Valve in Patients with Duchenne’s Dystrophy vs Normal Control Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Duchenne’s dystrophy</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior leaflet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>2–3</td>
<td>1.9–3</td>
</tr>
<tr>
<td>Width</td>
<td>2.6–4.6</td>
<td>2.6–4.8</td>
</tr>
<tr>
<td>Posterior leaflet (MS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>0.9–1.8</td>
<td>1–1.7</td>
</tr>
<tr>
<td>Width</td>
<td>1.2–3.6</td>
<td>1.1–3.7</td>
</tr>
<tr>
<td>Posterior leaflet (ALCS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>0.8–1.8</td>
<td>0.7–1.9</td>
</tr>
<tr>
<td>Width</td>
<td>1.1–3.2</td>
<td>0.9–3.4</td>
</tr>
<tr>
<td>Posterior leaflet (PMCS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>0.6–1.8</td>
<td>0.7–1.7</td>
</tr>
<tr>
<td>Width</td>
<td>1–3</td>
<td>0.9–3.1</td>
</tr>
</tbody>
</table>

Values are given as the range (cm).

Abbreviations: MS = middle scallop; ALCS = anterolateral commissural scallop; PMCS = posteromedial commissural scallop.

areas were separated by anterolateral and posteromedial commissural areas characterized by insertion of anterolateral and posteromedial commissural chordae (fig. 1B, circle). The heights and widths of the commissural areas in patients were similar to those of normal controls.

Histologic examination of the leaflets from patients with Duchenne’s dystrophy disclosed two major components — fibrosa and spongiosa — and a thin layer of atrialis (fig. 2A). The fibrosa consisted of dense collagen and was continuous with the fibrous tissue of the annulus at the level of posterior leaflet and with aortic mitral intervalvular fibrosa at the level of anterior leaflet. Spongiosa consisted of myxomatous tissue that was PAS-positive. The mitral valve leaflets in patients with Duchenne’s dystrophy were similar to those in normal controls (fig. 2B), and showed no evidence of excessive proliferation of spongiosa or disruption of the fibrous layers. A few parallel elastic fibers, best demonstrated by Weigert-van Gieson stain, were present in atrialis.

Electron microscopic examination of the proximal portion of the leaflets from patients disclosed dense, regular collagen fibers with regular periodicity and alignment and normal nuclei. The sections from the middle portion of the leaflets showed a spectrum of changes that ranged from marked hypocellularity with few mononuclear cells containing round or slightly elongated nuclei and scant cytoplasm within a loose matrix (fig. 3) to areas that had features resembling those of the proximal portion. The distal portion of the leaflets resembled the hypocellular portion of the middle portion of the leaflets. Granular cells or abnormal collagen fibrils within cells were not seen.

**Figure 2.** (A) Histologic features of posterior leaflet of mitral valve in Duchenne’s muscular dystrophy: fibrosa (F), spongiosa (S) and atrialis (A). Normal control tissue (B) has identical appearance. Note the absence of proliferation of spongiosa and interruption of fibrosa (hematoxylin and eosin, magnification × 85).
An average of 25 chordae tendineae were inserted into the mitral valve leaflets. The types of chordae tendineae (figs. 1B (circle and box), IC, ID and 4), their mode of insertion and lengths are given in table 3. Comparison of the findings with those for age-matched normal controls did not disclose any appreciable differences.

Histologically, the chordae tendineae appeared as dense uniform collagen fibers aligned parallel to their long axis of chordae. No evidence of mucinous degeneration was found. Electron microscopic examination disclosed the presence of collagen fibrils (fig. 5) having a consistent periodicity of 64 nm, which was similar to the control value. There was no evidence of degeneration.

**Annulus**

This structure consisted of dense collagen fibers with a few fibroblast nuclei. At the subcellular level, the alignment of collagen fibrils was less regular than in chordae tendineae. There was no evidence of degenerative changes.

**Papillary Muscles and Ventricular Myocardium**

The spectra of histologic changes found in papillary muscles and ventricular myocardium were similar in all three patients and consisted of multifocal areas of degenerative changes of varying severity and stages. A few areas, not related to blood vessels, showed early degenerative changes, chiefly loss of cytoplasmic and nuclear details (figs. 6A and B). Areas showing advanced stages of degeneration characterized by a loss of myofibrils, variation in size and shape of myofibers, fibrosis and islands of fatty tissue were more common (fig. 6C). Inflammatory cells were not seen.

Electron microscopic examination of myofibrils disclosed marked morphologic variation from one area of the myofiber to another. All myofibrils from a particular cell generally showed the same degree of alterations, ranging from small, localized osmiophilic areas to complete loss of striation and dissolution of myofilaments. Myofibrillar lysis was characterized by...
TABLE 3. Comparison of Type, Number and Length of Chordae Tendineae in Patients with Duchenne’s Dystrophy vs Normal Control Subjects

<table>
<thead>
<tr>
<th>Type of chordae</th>
<th>Number of chordae</th>
<th>Length of chordae (cm, mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duchenne’s dystrophy</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Anterior leaflet</td>
<td></td>
</tr>
<tr>
<td>Rough-zone chordae</td>
<td>5–8</td>
<td>6–9</td>
</tr>
<tr>
<td></td>
<td>1.68 ± 0.35</td>
<td>1.67 ± 0.33</td>
</tr>
<tr>
<td>Strut chordae</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1.75 ± 0.43</td>
<td>1.74 ± 0.41</td>
</tr>
<tr>
<td></td>
<td>Posterior leaflet</td>
<td></td>
</tr>
<tr>
<td>Rough-zone chordae</td>
<td>10–14</td>
<td>9–15</td>
</tr>
<tr>
<td></td>
<td>1.38 ± 0.13</td>
<td>1.37 ± 0.11</td>
</tr>
<tr>
<td>Basal chordae</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.85 ± 0.24</td>
<td>0.83 ± 0.26</td>
</tr>
<tr>
<td>Cleft chordae</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1.28 ± 0.28</td>
<td>1.29 ± 0.27</td>
</tr>
<tr>
<td></td>
<td>Commissural area</td>
<td></td>
</tr>
<tr>
<td>Anterolateral chordae</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.1 ± 0.27</td>
<td>1.2 ± 0.25</td>
</tr>
<tr>
<td>Posteromedial chordae</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.2 ± 0.50</td>
<td>1.15 ± 0.41</td>
</tr>
</tbody>
</table>

a loss of actin and myosin filaments. In severely affected areas, there was a total loss of myofilaments, lending a “moth-eaten” appearance to the myofiber (fig. 7). Z-bands showed striking alterations that consisted of widening, clumping and even splitting of the bands. The transverse tubules, by contrast, were well preserved, even in areas with extensive myofibrillar lysis (fig. 7).

FIGURE 6. Histologic features of posterior papillary muscle in Duchenne’s dystrophy. (A) Early dystrophic changes in some areas (Hematoxylin and eosin, magnification × 106). (B) As evident at higher magnification (× 300) of the area indicated in panel A, the changes consist of loss of cytoplasmic details ranging from reduction in cross striation to granular appearance to total loss of myofibers, and an increase in the number of sarcolemmal nuclei. (C) Advanced dystrophic changes characterized by myofibers of varying size and shape, reduction in number of myofibers, and replacement of myofibers by dense fibrous tissue (hematoxylin and eosin, magnification × 105).
Mitochondria were increased in number; some showed minimal swelling, partial loss of cristae and, occasionally, electron-dense particles. The sarcoplasmic reticulum was usually dilated, with striking ectasia of the cisternae in some instances. Sarcolemmal changes were rare. The structure of nuclei, even in the dystrophic areas, was normal. Clumping of chromatin of intracellular filaments was not seen. The nucleus and the cytoplasm were free of virus-like particles. Other cytoplasmic structures, such as glycogen granules, lipid droplets or lipochrome pigments, were absent.

These degenerative changes, both histologic and ultrastructural, were most extensive in the posterior papillary muscle and the posterobasal segment of the left ventricle and less extensive in left ventricular free wall, interventricular septum, right ventricle and anterior papillary muscles. The atrial musculature showed only minimal changes.

**Discussion**

The pathogenesis of MVP syndrome is controversial. To account for reports of varied clinical and pathologic findings, some investigators have distinguished two forms of this disorder, based mainly on the presence or absence of a leaflet-chordal abnormality. Myxomatous transformation of the mitral valve leaflets due to proliferation of spongiosa with or without an increase in length of chordae tendineae in excess of left ventricular dimensions is thought to be the pathologic hallmark of the primary (or idiopathic) variety of MVP syndrome. By contrast, the secondary form of the disorder, according to Jeresaty, is associated with other diseases and is essentially an angiographic finding without auscultatory evidence of a nonejection systolic click or echocardiographic evidence of a prolapsed leaflet. Our clinical findings do not support such a strict distinction between a primary and secondary form of this valve disorder and indicate that auscultatory evidence of nonejection click does not constitute proof of idiopathic MVP syndrome, just as the mere presence of angiographic evidence of prolapse does not imply that there is only a leaflet chordal abnormality with a myxomatous valve.

Each patient with Duchenne's dystrophy and MVP syndrome in our study presented with an audible nonejection systolic click that was substantiated by phonocardiography (table 1). Echocardiographic findings were similar to those reported for the primary form of MVP syndrome and confirmed the diagnosis. Gross, histologic and ultrastructural studies of mitral valve leaflets, annulus and chordae tendineae failed to disclose any morphologic abnormalities. By contrast, papillary muscles and ventricular myocardium in all patients showed alterations that were quite distinct from the features of normal controls. These morphologic alterations extended from early changes in one area of a myofiber (fig. 6A) to severe changes in another, characterized at the cellular level by extensive fibrosis (fig. 6B) and subcellularly by a total loss of thick and thin myofilaments, lending a "moth-eaten" appearance to the myofiber (fig. 7). The dystrophic changes were most extensive in the posterior papillary muscle and the posterobasal segment of the left ventricle.

The vital role of papillary muscles in maintaining the functional integrity of the mitral valve apparatus is well recognized. At the beginning of ventricular systole, the papillary muscles contract so that apposed areas of mitral valve leaflet become tightly sealed. Late during the ejection phase of the ventricular systole, as the left ventricular cavity dimension decreases, synergistic contraction of the papillary muscles again ensures that chordae tendineae are pulled taut. It seems reasonable that in patients with Duchenne's muscular dystrophy, degeneration of the posterior papillary muscles and, to a lesser degree, of anterior papillary muscle would severely limit the ability of the muscles to contract or to sustain contraction synergistically during ventricular systole, thus compromising the tautness of chordae tendineae. This
in turn could cause eversion of the mitral leaflet into the left atrium.

Besides papillary muscles, the degenerative changes in Duchenne's dystrophy characteristically involve, with varying degrees of severity, the posterobasal segments and free wall of the left ventricle. Such involvement could cause an asymmetric, disordered pattern of left ventricular contraction and impairment of myocardial contractility, thus providing the myocardial basis for MVP syndrome in these patients, similar to the mechanism described by Mathey et al.²⁸ and others²⁹–³² for patients with systolic-click syndrome. Recent observations by Kovick et al.³³ that maximal endocardial velocity is sharply decreased in patients with Duchenne's dystrophy, and by Hemsyfield et al.³⁴ that such decreases are progressive with age, further support this contention.

Because cardiomyopathy in Duchenne's dystrophy is usually progressive, the degree of papillary muscle dysfunction and left ventricular hypokinesia are likely to increase as the disease progresses and may ultimately result in prolapso of the mitral valve and even clinical evidence of mitral regurgitation in some patients. This possibility is strengthened by necropsy findings of extensive fibrosis in the posterior papillary muscle of a patient with Duchenne's dystrophy who had mitral insufficiency for 4 years before developing intractable congestive heart failure.³⁵ Finally, ventricular dilatation associated with progressive cardiomyopathy in Duchenne's dystrophy may alter the spatial relationships between papillary muscles, chordae tendineae and the atrioventricular orifice,³⁶ with further loss of support to mitral valve leaflets.

Jeresaty³⁷ suggested that a high prevalence of MVP syndrome in the general population could result in coincidental associations of this valve disorder with other diseases, including Duchenne's dystrophy. In prospective screening for MVP syndrome in patients with Duchenne's dystrophy, we found echocardiographic evidence of prolapso in 11 of 20 subjects.¹¹ In another study, Reeves et al.³⁷ reported echocardiographic evidence of MVP syndrome in 25% of patients with Duchenne's muscular dystrophy who were evaluated for this complication. On the basis of these observations and the fact that progressive myopathy is an integral part of Duchenne's dystrophy and seems to be the basis of MVP syndrome, we contend that the association between the two disorders is causal rather than merely a chance association.

Observations from the present study confirm our earlier speculation¹¹ that MVP syndrome in Duchenne's dystrophy is an expression of underlying cardiomyopathy and not the result of isolated, dystrophic involvement of the mitral valve leaflets, annulus or chordae tendineae. Related factors, such as thoracic-skeletal deformities³⁸ and cardiomegaly resulting from progressive myopathy, may explain the wide clinical spectrum of MVP syndrome in these patients, extending from "silent" prolapso in some to an early-to-midsystolic nonejection systolic click in others.¹¹ Whether this syndrome also occurs in asymptomatic carriers of Duchenne's dystrophy, 25% of whom are known to have electrocardiographic abnormalities similar to those in symptomatic patients, is not well established³⁹ and warrants prospective evaluation.

Acknowledgment

The authors thank John Zacher and Jerry Luther for their assistance in photography and John Gilbert for his help in preparation of the manuscript.

References

18. Barlow JB, Pocock WA: Mitral valve prolapse, the specific bellowing mitral leaflet syndrome, or an insignificant nonejection systolic click. Am Heart J 97: 277, 1979
21. Ishner JH, Roberts WC: Morphologic observations on the mitral valve at necropsy in patients with systolic clicks with or without systolic murmurs and/or echocardiographic evidence of mitral valve prolapse (abstr) Am J Cardiol 43: 368, 1979


Dystrophic degeneration of papillary muscle and ventricular myocardium. A basis for mitral valve prolapse in Duchenne's muscular dystrophy.
S K Sanyal, W W Johnson, M R Dische, S E Pitner and C Beard

Circulation. 1980;62:430-438
doi: 10.1161/01.CIR.62.2.430

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1980 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/62/2/430

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/