Geometry of Left Ventricular Contraction in the Systolic Click Syndrome

Characterization of a Segmental Myocardial Abnormality

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SUMMARY

Left ventricular (LV) shape change during systole was characterized in nine patients with typical clinical findings of the systolic click syndrome (SCS) by means of cineangiographic measurements of three segmental diameters of the LV cavity and of the mitral valve ring (MVR) and contrasted with findings in eight patients with normal LV function. In the latter group, shortening of the proximal, midventricular, and apical segment diameters was comparable, averaging 38.6, 40.3, and 46.8%, respectively; MVR shortening averaged 31.8%. The velocity of fiber shortening, estimated as mean circumferential fiber shortening rate (mean FSR), was also similar in the three segments (1.66, 1.64, and 2.09 circ/sec). In patients with SCS, the extent of shortening and mean FSR in the proximal ventricular segment were consistently reduced (average 22.2%, $P < 0.005$; and 0.96 circ/sec, $P < 0.025$ respectively), and the MVR exhibited either reduced extent of contraction (four patients) or was unchanged or increased in diameter during systole (five patients). However, shortening of the midventricular and apical segments was normal, averaging 37.5 and 40.5%, respectively, as was the mean FSR in these segments (averages 1.60 and 1.70 circ/sec).

These findings are consistent with a primary disorder of the myocardium in SCS localized to the inflow region of the left ventricle.

Additional Indexing Words: Billowing posterior mitral leaflet syndrome - Mitral regurgitation - Papillary muscle dysfunction - Regional shape changes - LV contractility - Ventricular asynergy

The apical mid- or late systolic click is now recognized in association with a variety of cardiac abnormalities which involve the mitral valve apparatus and which result in mitral regurgitation. The frequent occurrence of ECG abnormalities, postexercise ventricular arrhythmias, and sudden death in patients in whom only minimal valvular abnormality is present, and the observation that the auscultatory manifestations of this syndrome may appear following acute myocardial infarction, have suggested the likelihood of an underlying primary myocardial disorder in the systolic click syndrome. However, no quantitative analysis of left ventricular performance has been undertaken previously to identify or characterize myocardial dysfunction in this syndrome.

In the present study a consistent localized disorder of myocardial function was identified in nine patients with the systolic click syndrome by means of a segmental dimensional analysis of left ventricular contraction. In addition, a similar contraction abnormality was documented using this technique in three patients with coronary artery disease in whom atypical or late systolic mitral regurgitation developed following myocardial infarction.

Methods

Nine patients (eight female, one male) ranging in age from 27 to 59 years (average 40.7 years), in whom clinical findings were considered typical of the systolic click syndrome, were studied. In each instance the cardiac evaluation was prompted by disabling cardiorespiratory symptoms. All patients described protracted substernal pain usually occurring without relation to effort, although intensified by activity and excitement,
frequently lasting several hours. Other prominent symptoms included exertional dyspnea (six patients), episodic rapid heart action (five patients), easy fatigability (five patients), and syncope (two patients). The disability characteristically was more severe by history than could be documented by objective submaximal treadmill exercise testing. None had experienced frank congestive heart failure. In no patient did the history suggest previous acute rheumatic fever, significant chest trauma, or myocardial infarction. Two patients reported a family history of sudden death. The 7-year-old daughter of one patient exhibited a prominent apical midsystolic click; examination of family members of three other patients failed to reveal evidence of the systolic click syndrome.

On physical examination all patients were in normal sinus rhythm, with normal blood pressures. A mid- or late systolic click was documented in seven patients (fig. 1); in two of these patients the click was present intermittently. In one patient with a typical clinical history and ECG abnormality, no click was found. A late systolic murmur, delayed in onset and extending into the second heart sound, was recorded in all but one patient. Evidence of ventricular enlargement or atrial or ventricular gallop sounds were not found. Stigmata of Marfan’s syndrome and gonadal dysgenesis were not observed.

Chest roentgenograms demonstrated a normal cardiac size and contour in each instance. The ECG was abnormal in all patients, revealing T-wave inversion in leads II, III, and aVF, in four patients and in leads V₃-V₄, in one patient, while three patients had nonspecific S-T segment and T-wave changes. Significant Q waves in leads II, III, and aVF, with left-axis deviation, were found in one patient without previous history of myocardial infarction and with normal coronary arteriograms.

All patients underwent diagnostic right and left heart catheterization and selective left ventricular (LV) cineangiography; in seven patients, selective coronary arteriography was also performed, demonstrating normal coronary arteries in each instance. The method of study was as follows: biplane LV cineangiograms were exposed in the frontal and lateral projections at 100 frames/sec during intraventricular injection of 75% sodium diatrizoate (Hypaque), 1 ml/kg, over a period of 2 sec. The moment of each radiographic exposure was recorded by means of an oscillographic recorder, together with the arterial pressure pulse and ECG to permit precise correlation of angiographic data and electrical and pressure events.

LV cavity silhouettes were then drawn in both frontal and lateral projections at end-diastole, determined using the time interval between the inscription of the Q wave in the ECG and the insura of the LV pressure pulse recorded immediately prior to the cineangiogram, and at end-systole. Silhouette area and dimensions were corrected for X-ray magnification and spherical distortion. LV end-diastolic volume, stroke volume, and ejection fraction were calculated using the area-length method for biplane films. Mitral regurgitant volume was determined by subtracting effective LV stroke volume, derived from an indicator dilution measurement of cardiac output immediately prior to the cineangiogram, from the total stroke volume as estimated from the angiogram.

A segmental analysis of LV geometry during systole was carried out by measurement of dimensions in the lateral projection at 10-msec intervals throughout contraction, in a manner described in a previous communication. In brief, a long axis of the left ventricle was drawn from the midpoint of the mitral valve plane to the ventricular apex; three diameters, or chords, were then constructed perpendicular to and quadrisecting the long axis. These chords were designated as proximal (LV inflow), midventricular (minor equatorial), and apical (distal) segment diameters (fig. 2). The mitral valve ring was readily

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**Figure 1**

The phonocardiogram recorded from the cardiac apex at high frequency in a patient with the systolic click syndrome is shown in the lower tracing demonstrating the typical midsystolic click (SC). The reference ECG (lead II) is recorded in the upper tracing.

**Figure 2**

The left ventricular cavity silhouette at end-diastole is illustrated in a cineangiographic frame exposed in the lateral projection (left), and its schematic representation (right), to demonstrate the ventricular long axis (L), segmental diameters, and mitral valve ring (MVR) employed in the quantitative analysis of ventricular geometry.
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identified in the lateral projection (fig. 2), and its diameter was also measured frame-by-frame throughout systole. The lateral projection was chosen for measurement of segmental and mitral valve ring diameters, since in this view the LV cavity is projected very nearly in profile. In the frontal view, the long axis of the left ventricle is foreshortened, making measurement of segments comparable to those in the lateral view virtually impossible. In addition, it was observed that the mitral valve ring was obscured, particularly inferiorly, in the frontal projection by the superimposed LV cavity, so that accurate measurement of its diameter could not be obtained in this projection.

Mean fiber shortening rate was calculated for each segment by dividing the extent of shortening of its circumference in centimeters, by the ejection time, measured as the time interval between end-diastolic and end-systolic cine frames, subtracting 50 msec for the isovolumic phase of contraction.12 Fiber shortening rates were normalized by dividing by the end-diastolic circumference, and expressed in terms of circumferences/second (or cm/sec/cm). All beats analyzed represented ventricular contractions originating from normal electrical depolarizations.

In addition, the head of the inferior LV papillary muscle (IPM) was identified angiographically at end-diastole and end-systole and its orientation within the LV cavity was determined by measurement of the ratio of the distances between the papillary muscle and mitral valve ring, and LV apex and mitral valve ring: (IPM – MVR)/(apex – MVR).

Similar measurements were made in a group of eight patients evaluated because of angina pectoris without previous myocardial infarction in whom normal LV function was documented by standard hemodynamic indices and ventricular volume characteristics. Measurements were also made in three patients with coronary artery disease in whom late systolic or atypical mitral regurgitation developed following myocardial infarction.

Statistical analysis of comparative data was made by means of the two-tailed Student t test.

Results

Hemodynamic Findings and Left Ventricular Volume Measurements

Normal sinus rhythm and normal systemic arterial pressures were present in each patient with the systolic click syndrome (SCS). The left ventricular end-diastolic (LVED) pressure was normal (< 12 mm Hg) in six patients and slightly elevated in three.14–17 The cardiac index was normal (> 2.5 liters/min/m²) in all but two patients in whom it was slightly reduced. LVED volume was normal in seven patients, ranging from 68.9 to 95.7 ml/m² (average 80.9 ml/m²) and slightly elevated (100.7 and 132.7 ml/m²) in two patients. The ejection fraction was normal in eight patients, ranging from 0.56 to 0.75 (average 0.64), and mildly reduced (0.43) in one patient in whom the LVED volume was significantly increased.

Segmental Analysis of Left Ventricular Contraction

Left ventricular dimensions and segmental fiber shortening characteristics in all patients are shown in table 1.

Patients with Normal Left Ventricular Function

The extent of shortening of the diameters of all segments was comparable in patients with normal LV function, averaging 38.6, 40.3, and 46.8% in the proximal, midventricular, and apical segments, respectively (fig. 3). Mean circumferential fiber shortening rates (FSR) were also similar in the three ventricular segments. The extent of shortening of the mitral valve ring (MVR) was somewhat less than the other segments, averaging 31.8% (fig. 4).

Figure 3

The extent of systolic shortening of the proximal, midventricular, and apical segmental left ventricular diameters, expressed as percent of end-diastolic diameter, is shown on the vertical axis in (left) patients with normal left ventricular function (closed circles), and (right) those with the systolic click syndrome (SCS, open circles).
Table 1
Left Ventricular Dimensions and Segmental Fiber Shortening Characteristics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control (N=8)</th>
<th>Systolic click syndrome (N=9)</th>
<th>Patients</th>
<th>Previous diaphragmatic MI (N=3)</th>
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<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
<td>Range</td>
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<tr>
<td>Dimensions:</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mitral valve ring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED (cm)</td>
<td>4.4</td>
<td>3.7-6.0</td>
<td>4.9</td>
<td>3.3-5.5</td>
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<td>Δ (cm)</td>
<td>-1.4</td>
<td>(-0.8-(-1.9)</td>
<td>0.1</td>
<td>(-0.5(+1.1)</td>
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<tr>
<td>Δ (%)</td>
<td>-3.8</td>
<td>(-19.7-(-42.9)</td>
<td>2.5</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED (cm)</td>
<td>5.7</td>
<td>3.9-7.7</td>
<td>5.4</td>
<td>3.9-6.5</td>
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<tr>
<td>Δ (cm)</td>
<td>-2.2</td>
<td>(-2.0-(-2.8)</td>
<td>-1.2</td>
<td>(-0.5-(-1.9)</td>
</tr>
<tr>
<td>Δ (%)</td>
<td>-38.6</td>
<td>(-30.3-(-47.9)</td>
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<td>ED (cm)</td>
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<td>4.3-7.8</td>
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<tr>
<td>Δ (%)</td>
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<td>(-24.4-(-45.1)</td>
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<td>4.0-5.8</td>
<td>4.2</td>
<td>3.3-6.2</td>
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<tr>
<td>Δ (cm)</td>
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<td>(-1.6-(-2.8)</td>
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<td>(-1.2-(-3.1)</td>
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<tr>
<td>Δ (%)</td>
<td>-46.8</td>
<td>(-33.4-(-56.0)</td>
<td>-40.5</td>
<td>(-31.9-(-50.0)</td>
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<td>Mean fiber shortening rate:</td>
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<tr>
<td>Proximal (cm/sec)</td>
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<td>(circ/sec)</td>
<td>1.66</td>
<td>1.09-2.81</td>
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<td>(cm/sec)</td>
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<td>(circ/sec)</td>
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<td>Apical (cm/sec)</td>
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<tr>
<td>(circ/sec)</td>
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<td>1.10-3.15</td>
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<td>1.28-2.31</td>
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<td>Δ IMP - MVR</td>
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<td>(-0.05-(-0.05)</td>
<td>0.10</td>
<td>0.03-0.24</td>
</tr>
</tbody>
</table>

Abbreviations: MI = myocardial infarction; Δ = change in dimension from end-diastole to end-systole; IMP = inferior LV papillary muscle; Apex = apex of left ventricle.
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The change in mitral valve ring diameter (MVR) from end-diastole to end-systole, expressed as percent of end-diastolic diameter, is shown on the vertical axis in patients with normal left ventricular function (closed circles) and those with the systolic click syndrome (open circles). The dashed horizontal line indicates no change in MVR diameter, while values above the line indicate decrease and those below, an increase in this diameter.

Patients with the Systolic Click Syndrome (SCS)

End-diastolic LV dimensions in patients with the SCS were similar to those observed in patients with normal LV function (table 1). However, the extent of shortening of the proximal LV segment diameter was reduced in patients with SCS, averaging 1.2 cm (22.2%) as compared to 2.2 cm (38.6%) in patients with normal LV function ($P < 0.001$ and $P < 0.005$, respectively). In two patients in whom the systolic click was absent or only intermittently present, shortening of the proximal segment was at the lower limit of values observed in patients with normal LV function. Shortening of the midventricular and apical segments in patients with SCS averaged 2.1 cm (37.5%) and 1.7 cm (40.5%); these values were similar to those observed in the normal group (statistical difference ns) (fig. 3). A reduced extent of shortening of the midventricular segment was observed in one patient with SCS.

Mean FSR was reduced in the proximal segment in patients with SCS, averaging 0.96 circ/sec as compared to 1.66 circ/sec in patients with normal LV function ($P < 0.25$), while normal values for mean FSR were found in the midventricular and apical segments, also consistent with an abnormality of myocardial contraction localized to the inflow region of the left ventricle.

The systolic change in MVR diameter was consistently abnormal in patients with SCS; a reduced extent of shortening was observed in four patients, while in the remaining five patients the MVR was unchanged or increased in diameter during systole.

Figure 5 illustrates the time course of dimensional changes in the MVR and the three ventricular segment diameters in a typical patient with SCS (right) as compared to measurements obtained in a patient with normal LV function (left). As in this representative example, in five patients with SCS the MVR contracted during early and midsystole, then increased in diameter in the later phases of systole. In four patients, the MVR exhibited no contraction, expanding progressively during systole.

Patients with Previous Myocardial Infarction and Atypical Mitral Regurgitation

Three patients with proven occlusive major-vessel coronary artery disease and previous diaphragmatic myocardial infarction involving the inferior portion of the LV inflow tract exhibited an LV contraction abnormality similar to that observed in patients with SCS. In each patient, shortening of the MVR and proximal ventricular segment was reduced, averaging 8.8 and 13.6%, respectively. Shortening of the midventricular segment was also reduced in two of the three patients, averaging 23.0%, while shortening of the apical segment was normal. Mean FSR was also substantially reduced in the proximal ventricular segment in all three patients, while midventricular segment FSR was reduced in two
patients. Apical mean FSR was normal in all three patients.

Papillary Muscle and Mitral Valve Function

Mitral regurgitation confined to mid- and late systole was demonstrated angiographically in five patients with SCS, but was considered mild in all but one patient (regurgitant fraction 70%) in whom hemodynamic data were consistent with significant mitral incompetence. However, in only two patients was the posterior mitral leaflet seen to prolapse during systole.

The inferior papillary muscle (IPM) head was readily identified in the lateral projection of the cineangiogram at end-diastole and end-systole in six patients with the SCS and in five patients with normal LV function. In the latter group, the papillary muscle orientation within the cavity was altered only slightly during systole, the ratio of IPM−MVR and apex−MVR distances changing by an average of 0.02, from 0.41 to 0.43. In contrast, in patients with SCS, the (IMP − MVR)/(apex − MVR) decreased by an average of 0.10, from 0.42 to 0.32, indicating movement of the IPM away from the normal midventricular location and toward the MVR during systole, suggesting failure of contraction of the IMP in these patients.

In three patients with coronary artery disease and previous myocardial infarction, mid-to-late systolic mitral regurgitation resulted in an average regurgitant fraction of 12.5% (range 8.5–17%). The (IMP − MVR)/(apex−MVR) decreased abnormally from end-diastole to end-systole in two patients (0.36 to 0.26 and 0.40 to 0.32) and was unchanged in the third.

Discussion

While the apical mid- or late systolic click was recognized initially in association with fibromyxomatous degeneration of the mitral valve,1,2 it has become clear that it also occurs in a variety of cardiac lesions which share in common a presumptive abnormality of the mitral valve apparatus. These include rheumatic endocarditis, chest trauma, hypertrophic obstructive cardiomyopathy, congestive cardiomyopathy,3 various congenital abnormalities including the Marfan syndrome, gonadal dysgenesis, and secundum atrial septal defect,4 ischemic heart disease,6 and a familial variety chiefly affecting young girls and women.7,8,9 In many patients, the association of this unique auscultatory finding with clinical and angiographic evidence of mitral regurgitation has provided further evidence of mitral valve dysfunction. However, the late systolic timing of mitral incompetence is not readily accounted for by disease of the mitral valve or chordae tendineae alone, since it would seem reasonable to expect that regurgitation resulting from a mitral leaflet abnormality would become evident soon after the onset of contraction, when the leaflets are displaced passively into apposition by rapid rise in intraventricular pressure. Indeed, the common finding of an ECG abnormality in such patients which bears no relation to the presence or severity of mitral regurgitation, as well as postexercise ventricular arrhythmias, and the high incidence of sudden, presumably arrhythmia-related death in the familial form of this disorder8,9 strongly suggest the presence and even the predominance of a primary myocardial abnormality in the SCS. While pathologic studies are not available to support this hypothesis, an abnormal
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Figure 6

Cineangiographic frames exposed in the lateral projection (left) and their respective schematic representations (right) are shown at end-diastole (top) and end-systole (bottom), in a patient with the systolic click syndrome who exhibited mitral regurgitation. The mitral valve ring (MVR), inferior papillary muscle (IPM), and left atrium (LA) are indicated in the drawings.

asymmetric pattern of ventricular contraction has been described frequently in the SCS (fig. 6). Leachman\textsuperscript{17} and Criley\textsuperscript{6} recognized paradoxic expansion of the mitral valve annulus during systole, while other investigators have ascribed the unusual LV cavity contour during systole to increased contraction of the midventricular or equatorial myocardial fibers.\textsuperscript{16, 18} However, to date no systematic quantitative analysis of LV contraction has been presented to identify or characterize the myocardial abnormality in the SCS.

In each of the patients with SCS in the present study a significant reduction in the extent and mean velocity of fiber shortening was demonstrated in the mitral valve ring and proximal LV segment, or inflow tract, consistent with disease of this region of the LV myocardium. In two patients in whom the systolic click was absent or intermittently present, only MVR contraction was abnormal. Noncontraction or late-systolic expansion of the superior and lateral aspects of the MVR was observed consistently in the frontal view as well, a finding demonstrated in previous studies,\textsuperscript{17} suggesting that this myocardial abnormality involved the LV inflow tract circumferentially. Although contraction of the inflow tract myocardium was often markedly impaired, the systolic characteristics of the remainder of the left ventricle were normal in all but one patient, in whom shortening of the midventricular segment was also slightly depressed, indicating that the myocardial abnormality was localized to the inflow region in these patients. Indeed, overall ventricular performance, including end-diastolic volume, end-diastolic pressure, cardiac index, and ejection fraction, were within normal limits in the majority of patients in this study. Additional support for the presence of a primary myocardial abnormality was found in one older patient in whom multiple saccular diverticuli extending into the endomyocardium of the diaphragmatic LV wall were demonstrated angiographically (fig. 7).

It was of interest that only two patients with SCS in the present study were shown angiographically to have obvious prolapse or “ballooning” of the posterior mitral valve leaflet (fig. 6). In the three additional patients who exhibited mild mitral regurgitation we assumed that leaflet prolapse was responsible for mitral incompetence even though prolapse could not be demonstrated angiographically.

These observations suggest that in this group of patients with SCS, mitral valve dysfunction occurred as the result of a primary myocardial abnormality. The possibility that myocardial abnormality itself might account for mitral valve dysfunction is supported in addition by the finding in the present study that the inferior papillary muscle head in patients with SCS could be shown angiographically to be displaced away from its diastolic orientation in the midventricle and toward the mitral valve ring during systole. In contrast, in patients with normal LV function the papillary muscle head remained fixed in relation to the ventricular equator. This observation is consistent with failure of the inferior papillary muscle to shorten or to sustain contraction in the SCS patients, resulting in loss of support of the posterior mitral leaflet and thus mitral valve incompetence. The hypothesis that a localized abnormality of
myocardial function alone might account for mitral valve dysfunction is supported by the demonstration in the present study of a contraction abnormality and late systolic mitral regurgitation similar to that in the SCS in three patients with occlusive coronary artery disease and documented myocardial infarction.

Finally, loss of support of the posterior mitral leaflet related to inadequate contraction or failure of contraction of the inferior papillary muscle, or to inadequate support of the papillary muscle by disease of the proximal LV myocardial wall, appears to provide a plausible explanation for the delayed onset of mitral regurgitation during systole in patients with SCS.

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Figure 7
A cineangiographic frame exposed in the lateral projection at end-diastole in a patient (E.A.) with the systolic click syndrome (left), and its line representation (right), demonstrating multiple saccular excrescences of the diaphragmatic left ventricular wall.
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