Effects of reduced left ventricular mass on chamber architecture, load, and function: a study of anorexia nervosa

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ABSTRACT We investigated the effects of reduction in left ventricular mass on cavity geometry and function, and the role of afterload in regulating left ventricular mass and ejection fraction have been clearly demonstrated in pressure and volume overload. In addition, the magnitude and time course of regression of left ventricular hypertrophy toward normal following afterload reduction have also been well documented. However, the effects of reduction of left ventricular muscle mass to subnormal levels on cardiac mechanics and afterload have not been fully characterized in man. Patients with anorexia nervosa afford an unusual opportunity to examine the biological regulatory mechanisms involved in the left ventricular remodeling associated with reduction in muscle mass and to assess whether the same relationships exist between afterload, pump function, and myocardial mass that operate when left ventricular mass is normal or increased.

Previous studies of severe caloric deprivation in animals and man have demonstrated decreased heart size, myocardial mass, blood pressure, and heart rate with varying degrees of reversibility after refeeding. However, assessment of left ventricular contractile function has produced conflicting results — some have shown it to be supernormal and some normal, whereas others have demonstrated marked left ventricular dysfunction. Postmortem examination of hearts from animals and man dying of starvation has demon-
strated marked histologic abnormalities, including vacuolation and fragmentation of myofibrils, replacement fibrosis, and considerable loss of muscle fibers that would provide a substrate for left ventricular dysfunction.18-20

We studied patients with anorexia nervosa prospectively to assess the physiologic consequences of marked reduction of left ventricular mass on (1) left ventricular architecture and its remodeling, (2) left ventricular afterload, (3) left ventricular stress-shortening relations, (4) resting pump function, and (5) exercise performance during treadmill testing to assess cardiac reserve.

Methods

Patients with anorexia nervosa. We studied 17 female patients with anorexia nervosa, ages 16 to 37 years (mean 26). The diagnosis of anorexia nervosa was defined by the DSM III criteria, which include (1) loss of more than 25% of the original total body weight secondary to self-imposed dietary restriction and (2) absence of any coexistent physical illness that could account for such weight loss.21 Total body weight in each patient was stable and ranged from 29.7 to 42.1 kg (mean 36.4). Body surface area varied between 1.23 and 1.40 m² (mean 1.31).

No patient had any history, symptoms, or signs of heart disease or systemic hypertension. All patients were clinically and biochemically euthyroid, had normal electrolyte balance, and had normal 12-lead electrocardiograms. All patients were participants in a behavior modification program to encourage weight gain. Informed consent was obtained from each patient included in the study.

Normal subjects. We studied 10 normal female volunteers, ages 18 to 35 years (mean 27). Total body weights varied from 42.3 to 69.3 kg (mean 55.2), and body surface areas ranged from 1.47 to 1.71 m² (mean 1.60). None had any history, symptoms, or signs of cardiac disease or systemic hypertension. All had normal physical examinations, 12-lead electrocardiograms, and M mode and two-dimensional echocardiograms.

Data acquisition. The following data were recorded from each subject in the resting state: (1) Heart rate was monitored with standard electrocardiographic lead 2. (2) Cuff systolic arterial blood pressure was measured in triplicate in the left arm in each patient after 3 min of recumbency, and mean values were calculated. Cuff arterial pressure was used to represent end-systolic left ventricular pressure, with which it correlates closely as previously demonstrated,22, 23 to calculate end-systolic circumferential and meridional wall stress. Systolic blood pressure recordings were obtained simultaneously with M mode and two-dimensional echocardiograms. (3) Two-dimensionally directed M mode left ventricular echocardiograms were obtained at the level of chordae tendineae with a Varian 3400R ultrasonoscope at paper speeds of 50 to 100 mm/sec to ensure that the M mode beam sampled the same location on the left ventricular long axis in each subject (figure 1A). (4) Two-dimensional left ventricular echocardiographic images were obtained in (a) the parasternal left ventricular short-axis view at the level of the tips of the papillary muscles (figure 1B) and (b) the apical four-chamber view, so the left ventricular long axis could be measured. Approximately 20 cardiac cycles of the left ventricular short axis were recorded, and the transducer was quickly moved to the left ventricular apex to obtain 20 cardiac cycles of the four-chamber view to minimize the time interval between acquisition of orthogonal left ventricular images.

Treadmill exercise tests. Incremental exercise tests were performed in 10 of the patients with anorexia nervosa and in the 10 normal subjects by means of a modified Naughton protocol. This consisted of a 3 min practice period at 1 mph and 0 degree grade, followed by a constant speed of 2 mph with an increase in grade of 3.5 degrees every 3 min. Heart rate was displayed continuously throughout, blood pressure was measured at 1 min intervals, three simultaneous electrocardiographic leads were monitored continuously, and 12-lead electrocardiograms were printed out every minute.

Expansory gas flow and partial pressures of oxygen and carbon dioxide were measured by breath with the Beckman MMCI metabolic cart. Minute ventilation (VE, liters/min), oxygen consumption (VO₂, liters/min), and carbon dioxide production (VCO₂, liters/min) were recorded at baseline and after each minute of exercise. Duration of exercise was recorded.

Seven of the 17 patients with anorexia gained weight and had repeat echocardiograms, but only four had repeat treadmill exercise tests.

Data processing and analysis

M mode echocardiograms. M mode left ventricular echocardiograms containing a minimum of three cardiac cycles of similar cycle length were calibrated and digitized on a Hewlett-Packard 9821A microcomputer. End-diastolic and end-systolic left ventricular cavity diameter (LVD) and wall thickness (WT) were measured according to the convention recommended by the American Society of Echocardiography.24 From these data, end-diastolic relative wall thickness (h/R ratio = WT/LVD²), fractional left ventricular shortening, and velocity of circumferential fiber shortening (VCF) were computed and used as an index of left ventricular short-axis architecture and pump function, respectively.

End-systolic meridional wall stress was computed with the formula:25 stress σ = P × R_p/2h (1 + h/2R_p), modified in our

![FIGURE 1A. M mode left ventricular echocardiogram from a patient with anorexia nervosa. VS = ventricular septum; LV = left ventricle; PW = posterior wall; MV = mitral valve.](http://circ.ahajournals.org/)
laboratory to σ = 0.25 × 1.33 P(LVD)/WT (1 + WT/LVD) as previously reported,22, 23 where P is cuff-determined systolic arterial pressure and the constant 1.33 converts mm Hg to dyne/cm² × 10⁻¹. (We used cuff systolic pressure to calculate an approximation to “end-systolic” meridional stress, to which it correlated closely.) 7)

Two-dimensional left ventricular echocardiograms

Parasternal short-axis view. Short-axis endocardial and epicardial images of the left ventricle from five high-quality, stop-action end-diastolic and end-systolic frames were traced with their calibration factors on clear plastic overlays from a high-contrast scan converter. Tracings of endocardium and epicardium from each subject were digitized on a Hewlett Packard 9825A microcomputer to obtain: (1) total area (Aₜ) enclosed by the left ventricular epicardium and right side of the septum; (2) cavity area (Aₜ) by two previously validated methods,22, 23, 26, 27 in which the papillary muscles were regarded (a) as part of the cavity for stress determinations and (b) as the left ventricular wall for left ventricular volume and mass determinations; and (3) muscle area (Aₘ) obtained by subtracting Aₜ (including papillary muscles) from Aₜ, i.e. (Aₜ - Aₘ) for wall stress calculations.

Apical four-chamber view. Endocardial and epicardial left ventricular lengths (L) were traced from five end-diastolic and five end-systolic stop-action frames and digitized. Cavity length was defined as the distance between the apical endocardium and the midpoint of the plane of the mitral valve annulus.

The raw values for Aₜ, Aₘ, Aₗ, and L were corrected with regression equations developed in vitro for the two-dimensional echocardiographic instrument used in this study. These corrected values were used to calculate the following: (1) end-diastolic and end-systolic volumes by the short-axis area-length method;26 V = 5/6AₜL; (2) fractional shortening assessed as the percent change in left ventricular short-axis area; (3) ejection fraction; (4) left ventricular shape expressed as the ratio of short-to-long left ventricular axes √Aₗ/√L; (5) left ventricular muscle mass (LVM) calculated as LVM = 1.055 × 5/6(AₗLₐ - AₗLₘ) (the constant 1.055 is the density of myocardial muscle); (6) left ventricular end-systolic meridional wall stress (σₘ): σₘ = (1.33 × P × Aₗ)(Aₗ - Aₘ); (7) left ventricular end-systolic circumferential wall stress (σₖ): σₖ = (1.33 × P × V)/(√Aₗ√Aₘ) · 1 - (Aₗ/3L)² [(π/3L)² (√Aₗ + √Aₘ)]. The formula used to calculate circumferential wall stress was modified from Mirsky.25 The constant 1.33 is the conversion factor from mm Hg to dyne/cm² (we used cuff systolic pressure to calculate an approximation to “end-systolic” meridional and circumferential stresses); and (8) ratio of myocardial area Aₘ to cavity area Aₗ: (Aₘ/Aₗ).

In addition we compared (1) the end-systolic meridional and circumferential stress-shortening relationships and (2) the relationships among end-systolic meridional and circumferential wall stresses and ejection fraction in patients with anorexia nervosa and in normal subjects. The reproducibility and interobserver variability of left ventricular volume and mass determinations by two-dimensional echocardiography has been previously reported by our laboratory.23, 26, 27

Statistical methods. The significance of differences in measured and derived parameters of left ventricular function and exercise performance between patients with anorexia nervosa and normal control subjects was assessed by unpaired Student t tests. Paired t tests were used to compare within-population differences after gain in body weight.

Results

Resting heart rates in patients with anorexia nervosa varied over a similarly wide range as those of the age- and sex-matched normal subjects, whereas resting systolic and diastolic blood pressures were consistently lower than those in normal subjects (table 1).

End-diastolic and end-systolic left ventricular cavity diameters and end-diastolic posterior wall thicknesses measured from two-dimensionally directed M mode echocardiograms were all significantly smaller than normal (table 1). End-diastolic and end-systolic volume indexes determined by two-dimensional echocardiography were also significantly reduced in patients.
TABLE 1
Comparison of resting heart rate, blood pressure, and left ventricular size and function between patients with anorexia nervosa and age- and sex-matched normal subjects

<table>
<thead>
<tr>
<th></th>
<th>Resting heart rate (beats/min)</th>
<th>Resting blood pressure (mm Hg)</th>
<th>LV diameter (cm)</th>
<th>LV wall thickness-diastrate (cm)</th>
<th>Shape ratio short/long axis</th>
<th>VCE (circumferential fiber shortenings/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normals (n = 10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>69 ± 13</td>
<td>110 ± 9</td>
<td>74 ± 9</td>
<td>4.4 ± 0.5</td>
<td>0.7 ± 0.1</td>
<td>0.32 ± 0.05</td>
</tr>
<tr>
<td>Anorexia nervosa (n = 17)</td>
<td>63 ± 16</td>
<td>93 ± 8^A^</td>
<td>65 ± 8^A^</td>
<td>3.9 ± 0.3^A^</td>
<td>0.6 ± 0.1^B^</td>
<td>0.31 ± 0.04</td>
</tr>
</tbody>
</table>

LV = left ventricular; VCF = velocity of circumferential fiber shortening.

Statistical comparisons: ^p < .01; *p < .02.

with anorexia nervosa (49 ± 11 vs 65 ± 17 ml/m², p < .005; 14 ± 5 vs 19 ± 4 ml/m², (p < .025) (figure 2). Left ventricular mass indexes were 53 ± 15 g/m² compared with 79 ± 18 g/m² in normal subjects (p < .005) (figure 3), which represented a reduction of between 30% and 50%.

The reduction in left ventricular mass in patients with anorexia nervosa was not accompanied by changes in left ventricular chamber shape; the short/long left ventricular axis ratio at end-diastole was 0.63 ± 0.04, similar to that in the normal control subjects (0.62 ± 0.05) (table 1). End-diastolic relative wall thickness (h/R ratio) determined by M mode echocardiography did not differ significantly from normal (0.31 ± 0.04 vs 0.32 ± 0.05, table 1) and left ventricular mass-to-volume ratio determined by two-dimen-

sional echocardiography in patients with anorexia was indistinguishable from that in normal subjects (1.20 ± 0.20 vs 1.33 ± 0.24, figure 3), indicating that left ventricular architecture in patients with anorexia nervosa was normal.

End-systolic meridional and circumferential wall stresses in patients with anorexia nervosa varied over the same ranges as in normal subjects, and their respective mean values of 59 ± 18 vs 74 ± 19 × 10³ dyne/cm² and 170 ± 26 vs 167 ± 23 × 10³ dyne/cm² were not significantly different (figure 4). Resting left ventricular function was assessed as fractional shortening and ejection fraction, which were both normal (32 ± 4% vs 34 ± 3% and 71 ± 8% vs 71 ± 5%, respectively) (figure 5). The velocity of circumferential fiber shortening in patients with anorexia nervosa was also similar to that in normal subjects (0.98 ±
The relationships between the percent change in left ventricular diameter and end-systolic wall stress (i.e., the stress-shortening relationships) and between ejection fraction and end-systolic wall stress in patients with anorexia were within normal limits (figure 6). We plotted end-systolic circumferential wall stress against ejection fraction and percent change in left ventricular diameter, since it has been shown to relate more closely to left ventricular emptying than meridional stress because it takes into account chamber length.

Seven patients were restudied with M mode and two-dimensional echocardiography after a mean gain in total body weight of 6.3 kg. Left ventricular mass indexes and end-diastolic volume indexes increased from 61.7 ± 13.3 to 71.2 ± 17.7 g/m² (p < .02) and from 57.0 ± 7.8 to 63.4 ± 14.6 ml/m² (p < .02), respectively, but fractional shortening, ejection fraction, and end-systolic wall stresses did not change (table 2).

Exercise testing. In the 10 patients with anorexia nervosa who performed treadmill exercise tests, resting heart rate was significantly lower than that in the normal subjects (table 3), although this difference was not apparent when the population with anorexia nervosa (17 patients) was considered as a whole. Systolic blood pressures at rest were also significantly less than normal (96 ± 7 vs 119 ± 12 mm Hg; p < .01), but resting oxygen consumption values were similar (3.20 ± 0.45 vs 3.10 ± 0.60 ml/min/m²) (table 3, figure 7).

Exercise tests were terminated by fatigue in all subjects. Exercise duration in patients with anorexia nervosa was 22 ± 5 min compared with 37 ± 20 mins (p < .01) in normal subjects (table 3). Heart rate and blood pressure responses to exercise were markedly blunted in anorexia nervosa in that both were consistently less at each matched workload throughout treadmill testing. The following mean values were recorded: peak heart rate, 136 ± 19 vs 176 ± 12 beats/min (p < .01); peak systolic blood pressure, 122 ± 7 vs 164 ± 9 mm Hg (p < .01); peak oxygen consumption, 19.4 ± 4.0 vs 28.9 ± 5.3 ml/min/m² (p < .001), all significantly lower in patients with anorexia nervosa (table 3, figure 7).

Four patients underwent repeat treadmill exercise testing after a mean gain in body weight of 5.4 kg; left ventricular mass index and end-diastolic volume had increased from 58.0 ± 16.6 to 75.1 ± 23.5 g/m² (p < .05) and 56.8 ± 6.6 to 74.9 ± 15.9 ml/m² (p < .05), respectively. Exercise duration increased from a mean of 23 ± 5 to 30 ± 10 min (NS), peak heart rate from 127 ± 12 to 143 ± 5 beats/min (p < .05), peak systolic blood pressure from 125 ± 7 to 146 ± 11 mm Hg (p < .05), and peak oxygen consumption from 18.9 ± 2.0 to 22.1 ± 1.8 ml/min/m² (NS) (figure 8).

Discussion

We assessed the effects of major reduction of left ventricular muscle mass on chamber architecture and
mechanics in patients with anorexia nervosa. In addition we examined the interrelationships between left ventricular afterload, chamber function, and muscle mass when left ventricular mass was subnormal. We chose patients with anorexia nervosa as a model for three reasons. First, left ventricular muscle mass was reduced by between 30% and 50%. Second, their age and sex made the presence of coronary artery disease and associated left ventricular dysfunction extremely unlikely. Third, they were normally hydrated, in electrolyte balance, and clinically and biochemically euthyroid.

Left ventricular mass in patients with anorexia nervosa ranged between one-half and two-thirds of that in age- and sex-matched normal control subjects. This reduction in myocardial mass was disproportionately greater than the fall in total body weight; when normalized to unit body weight or unit surface area, these mass indexes remained consistently less than normal. This finding is concordant with a recent report in children with anorexia nervosa but is in sharp contrast to initial beliefs that the heart, like the brain, is spared during starvation.

Major left ventricular remodeling accompanied the reduction in left ventricular mass. Left ventricular end-systolic and end-diastolic cavity diameters and volumes were significantly decreased, whereas cavity shape remained normal. The distribution of left ventricular muscle, expressed as relative wall thickness (h/R ratio) by M mode echocardiography, and the ratio of left ventricular muscle mass to end-diastolic volume determined by two-dimensional echocardiography were also both normal. Although left ventricular muscle mass was down-regulated by between 30% and

TABLE 2
Changes in left ventricular architecture, afterload, and pump function in patients with anorexia nervosa after gain in total body weight

<table>
<thead>
<tr>
<th></th>
<th>LV mass index (g/m²)</th>
<th>LV end-diastolic volume index (ml/m²)</th>
<th>% change in LV diameter</th>
<th>Ejection fraction (%)</th>
<th>End-systolic meridional stress (dyne/cm² x 10³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before weight gain (n = 7)</td>
<td>61.7 ± 13.3</td>
<td>57.0 ± 7.8</td>
<td>35 ± 5</td>
<td>72 ± 6</td>
<td>58.6 ± 7.3</td>
</tr>
<tr>
<td>After weight gain (n = 7)</td>
<td>71.2 ± 17.7</td>
<td>63.4 ± 14.6</td>
<td>36 ± 4</td>
<td>73 ± 5</td>
<td>61.3 ± 12.3</td>
</tr>
</tbody>
</table>

LV = left ventricular.

*p < .02.
50%, normal left ventricular architecture was maintained, and this was also true after the increases in muscle mass and volume that accompanied gain in total body weight.

Left ventricular afterload, which we assessed in our patients with anorexia nervosa as end-systolic meridional and circumferential wall stresses, was consistently normal and remained within normal limits even after the increases in left ventricular mass and chamber volume that accompanied gain in total body weight. Thus left ventricular remodeling in patients with anorexia nervosa occurred in such a way that circumferential and meridional wall stresses were maintained within normal limits and normal left ventricular chamber architecture was preserved.

Resting left ventricular function, expressed as percent fractional shortening, velocity of circumferential fiber shortening, and ejection fraction, was normal before and after gain in body weight. In addition, the inverse relationships between left ventricular fractional shortening or ejection fraction and end-systolic wall stress were similar to those in the normal subjects, indicating that stress-shortening relationships, in patients with anorexia nervosa were normal.

We were unable to assess myocardial contractility as the slopes of force-length lines or end-systolic stress-dimension lines in individual patients. This would have required perturbations in left ventricular loading conditions with intravenous infusions to increase systolic blood pressure, since it was already below normal at rest. This was not thought to be advisable in our patients on account of their emotional fragility. Thus to determine whether the reduction in left ventricular mass was accompanied by cardiovascular dysfunction not apparent at rest, we assessed cardiac performance during dynamic exercise by breath-by-breath analysis of oxygen uptake.

Exercise tests were terminated by fatigue in the patients with anorexia and in the normal subjects. Exercise duration in patients with anorexia nervosa was shorter than in normal subjects despite a similar degree of fatigue. However, this may have been caused by peripheral factors such as the decreased skeletal muscle mass in these patients. Heart rate and blood pressure were also significantly less than normal at each matched workload throughout the treadmill tests. Although oxygen consumption in patients with anorexia nervosa was normal at rest, it was significantly lower at peak exercise than in the normal subjects. Four patients repeated the exercise test after a 15% gain in total body weight. Peak heart rates and peak systolic blood pressures increased significantly on exercise, although the increases in exercise duration and oxygen consumption were not statistically significant.

The temporal sequence and exact mechanism of left ventricular mass reduction in patients with anorexia nervosa were not statistically significant.
nervosa could not be elucidated from our study because we assessed patients only during the long-term steady state when their body weights were stable. The decrease in left ventricular mass could theoretically have resulted from failure to deliver the metabolic requirements to the myocardium. However, this is inconsistent with the normal left ventricular chamber architecture and normal pump function. The reduction in left ventricular mass more likely resulted from alteration in left ventricular afterload. Systolic arterial pressure decreases early after the onset of fasting in experimental animals, and there is strong evidence that this is caused by decreased norepinephrine biosynthesis and turnover and reduced α-adrenergic receptor activity. This hypotensive effect of fasting also occurs in patients with anorexia nervosa. Furthermore, catecholamine metabolism is similarly decreased and the levels of norepinephrine and its active metabolites in plasma, urine, and cerebrospinal fluid in patients with anorexia nervosa are significantly lower than normal. The fall in systemic arterial pressure in the early stages of decreased caloric intake would result in a reduction in afterload and act as the stimulus for down-regulation of left ventricular mass to subnormal levels. This is the exact corollary of the increase in afterload in pressure overload that has been demonstrated to up-regulate left ventricular mass in man.

Increased left ventricular afterload results in increased left ventricular muscle mass, which normalizes wall stress and thereby preserves ejection function. By contrast, a decrease in afterload, achieved for example by treating systemic hypertension, can result in regression of left ventricular mass and normalization of wall stress. Normalization of systolic wall stress is thought to be the feedback signal that governs the rate and extent of ventricular hypertrophy. In patients with anorexia nervosa, end-systolic meridional and circumferential wall stresses were consistently normal. However, theoretically we could have overlooked physiologically meaningful differences in systolic wall stresses between the two populations because of our relatively small sample sizes. Although we could not establish a direct cause-and-effect relationship between afterload and the reduced left ventricular muscle mass from this study, the disproportionately greater fall in left ventricular mass than in total body weight suggests that it more likely resulted from reduction in afterload, since afterload may vary independently of body weight and surface area.

Our inability to document left ventricular dysfunction in patients with anorexia nervosa either at rest or on exercise, except for a blunted heart rate and blood pressure response, is in sharp contrast to the histologic abnormalities in the myocardium described in starvation. One possible reason for this discrepancy might be that histologic abnormalities and associated ventricular dysfunction reported in starvation develop only in the terminal stages, and our patients with an-

FIGURE 8. Plots showing the changes in peak heart rate, peak systolic blood pressure, exercise duration, peak oxygen consumption, left ventricular mass indexes, and left ventricular end-diastolic volume indexes in four patients with anorexia nervosa after gain in total body weight.
orexia nervosa had not approached this severity of caloric deprivation. An alternative explanation for the development of left ventricular dysfunction might relate to the previously reported high incidence of hypothyroidism. However, several recent studies in patients with anorexia nervosa have demonstrated that thyroxine (T₄) and thyroid-stimulating hormone (TSH) levels are normal and that tri-iodothyronine (T₃) is adaptively down-regulated in body weight, which thus spares muscle wasting and does not indicate the presence of hypothyroidism. Moreover, all our patients were both clinically and biochemically euthyroid.

We submit that the reduction in left ventricular mass to subnormal levels in patients with anorexia nervosa probably resulted from decreased left ventricular afterload. The decrease in left ventricular afterload and the blunted heart rate and blood pressure responses to exercise may well be mediated by reduced α-adrenergic receptor activity and reduced catecholamine biosynthesis. The fall in left ventricular myocardial mass was associated with major left ventricular remodeling, which occurred in such a way that (1) orthogonal meridional and circumferential wall stresses remained normal, (2) normal chamber shape and architecture were maintained, and (3) normal chamber function and stress-shortening relationships were preserved. Furthermore, these parameters remained normal after the increase in left ventricular mass and volume observed with refeeding. Thus down-regulation of left ventricular mass per se, like adaptive up-regulation of left ventricular mass, was not associated with abnormal left ventricular function.

Hitherto afterload has been shown to increase left ventricular mass only above normal levels. We examined afterload when left ventricular mass was reduced to subnormal levels. Thus these observations extend previous studies of afterload and demonstrate that the same physiologic relationships exist between afterload, left ventricular mass, and chamber function when left ventricular mass is well below normal as exist when left ventricular mass is normal or increased.

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References
17. Moodie DS, Salcedo E: Cardiac function in adolescents and young adults with anorexia nervosa. J Adolescent Health Care 4: 9, 1983
27. Helak J, Plappert T, Muhammad A, Reichek N: Two-dimensional echocardiographic imaging of the left ventricle: comparison of me-
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35. Croxson MS, Ibbertson HK: Low serum tri-iodothyroxine (T3) and hypothyroidism in anorexia nervosa. J Clin Endocrinol Metab 44: 1967, 1977
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