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Beneficial Cardiovascular Effects of Bariatric Surgical and Dietary Weight Loss in Obesity

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Objectives We hypothesized that, in obese persons without comorbidities, cardiovascular responses to excess weight are reversible during weight loss by either bariatric surgery or diet.

Background Obesity is associated with cardiac hypertrophy, diastolic dysfunction, and increased aortic stiffness, which are independent predictors of cardiovascular risk.

Methods Thirty-seven obese (body mass index 40 ± 8 kg/m^2) and 20 normal-weight subjects (body mass index 21 ± 2 kg/m^2) without identifiable cardiac risk factors underwent cardiac magnetic resonance imaging for the assessment of the left and right ventricles and of indexes of aortic function. Thirty of the obese subjects underwent repeat imaging after 1 year of significant weight loss, achieved in 17 subjects by diet and in 13 subjects by bariatric surgery. Seven obese subjects underwent repeat imaging after 1 year of continued obesity.

Results Left and right ventricular masses were significantly increased, left ventricular diastolic function impaired, and aortic distensibility reduced in the obese. Both diet and bariatric surgery led to comparable, significant decreases in left and right ventricular masses, end-diastolic volume, and diastolic dysfunction, and an increase in aortic distensibility at all levels of the aorta, most pronounced distally (e.g., distal descending aorta 5.1 ± 1.8 mm Hg^{-1} × 10^{-3} before weight loss and 6.8 ± 2.5 mm Hg^{-1} × 10^{-3} after weight loss; $p < 0.001$). No improvements were observed in continued obesity.

Conclusions Irrespective of method, 1 year of weight loss leads to partial regression of cardiac hypertrophy and to reversal of both diastolic dysfunction and aortic distensibility impairment. These findings provide a potential mechanism for the reduction in mortality seen with weight loss. (J Am Coll Cardiol 2009;54:718–26) © 2009 by the American College of Cardiology Foundation

Obesity, defined by a body mass index (BMI) >30 kg/m^2, is associated with an increased mortality rate, and even greater risk is associated with a BMI of ≥35 kg/m^2 (1). Ventricular hypertrophy, diastolic dysfunction, and aortic stiffness are present in obesity (2,3); there is a strong relationship between left ventricular (LV) hypertrophy (4), diastolic dysfunction (5), and all-cause mortality on the one hand, and between impairment of aortic elastic function and cardiovascular events in healthy and diseased populations on the other hand (6). Therefore, increased mortality in obesity is likely to be related, at least in part, to the long-term cardiovascular sequelae of increased body weight.

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Not only is obesity related to higher death rates, but also a growing body of evidence suggests that weight loss reduces long-term mortality (7). There is, however, little information on the cardiovascular effects of weight loss in obese persons who have no other identifiable cardiovascular risk factors. To investigate this important question, we undertook a study to assess the effects of substantial weight loss, over 1 year, on the cardiovascular changes present in obesity per se, namely, in the absence of traditional cardiovascular risk factors such as hypertension, diabetes mellitus, and hypercholesterolemia. If LV hypertrophy, diastolic impair-

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ment, and aortic stiffness are indeed reversible in such persons, that would suggest that important predictors of cardiovascular risk can be positively influenced by weight loss over 1 year. Such an observation would provide a potential mechanism for the reduction in mortality associated with weight loss.

There are 2 main methods of weight loss: 1) dietary intervention; and 2) bariatric surgery. Surgical weight loss is now well established to confer better long-term weight management than dietary weight loss and has been shown to reduce long-term mortality (7). Therefore, the utilization of bariatric surgery is rapidly increasing.

Despite this, no study to date has addressed the relative beneficial effects of these different weight loss approaches on cardiac and aortic structure and function. In view of this, the secondary aim of this study was to compare the cardiovascular effects of bariatric surgery and dietary weight loss.

Methods

Ethics and study cohort. The study was approved by the local ethics committee, and informed written consent was obtained from each patient.

Fifty-seven subjects (37 obese, BMI >30 kg/m^2, and 20 normal weight controls, BMI 18.5 to 24.9 kg/m^2) were included in the study. All subjects were screened for identifiable cardiac risk factors and excluded if they had a history of cardiovascular disease, current smoking, hypertension, diabetes (fasting glucose level ≥6.7 mmol), a fasting total cholesterol level ≥6.5 mmol, or use of any medications. All subjects had a normal 12-lead electrocardiogram, normal global and regional resting cardiac function on magnetic resonance (MR) imaging, and did not perform >3 sessions (defined as 30 min) of sweat-producing exercise per week.

Blood tests. Fasting blood tests for glucose, cholesterol, leptin, insulin, free fatty acids, and C-reactive protein were taken on the day of the scan. An estimate of insulin resistance was calculated using the homeostasis model assessment of insulin resistance (HOMA-IR) equation (fasting insulin [μU/ml] × fasting glucose [mmol/l] / 22.5) (8).

MR imaging. All MR imaging scans for the assessment of LV and right ventricular (RV) mass, volumes, ejection fraction, diastolic function, and aortic distensibility were performed on a 1.5-T MR system (Siemens, Erlangen, Germany). Images for ventricular volumes and diastolic function were acquired using a steady-state free precession sequence with an echo time of 1.5 ms, a repetition time of 3.0 ms, in plane resolution 1.5 × 1.5 mm^2, temporal resolution 47.84 ms, and a flip angle of 60°, as previously described (9). All imaging was cardiac gated and acquired during end-expiratory breath hold.

Indexes of aortic function were assessed using a retrogated steady-state free precession cine sequence with the following parameters: temporal resolution 42 ms, echo time 1.4 ms, field of view read 380 mm, in-plane resolution 1.97 mm, and slice thickness 7 mm. Aortic cine images were acquired in transverse planes at 3 levels as previously described (10); the crossing of the pulmonary arch through: 1) the ascending thoracic aorta; 2) the descending thoracic aorta; and 3) 12 cm below the right hemidiaphragm perpendicular to the orientation of the abdominal aorta. Brachial artery blood pressure was recorded during image acquisition to provide pulse pressure.

Abbreviations and Acronyms

BMI = body mass index
HOMA-IR = homeostasis model assessment of insulin resistance
LV = left ventricle/ventricular
MR = magnetic resonance
RV = right ventricle/ventricular

Visceral fat mass, body composition, and percentage excess weight. A single breath-hold, 5-slice, water-suppressed T1-weighted turbo spin echo sequence centered around L5 was acquired (11). Images were manually contoured for visceral fat volume. Percentage excess weight loss was calculated according to the formula: percent excess weight loss = (weight before − weight after [kg]/excess body weight before) where excess body weight = (total body weight − ideal body weight). Ideal body weight refers to the weight if BMI = 25 kg/m^2. Bioelectrical impedance was used to determine total body fat mass and body composition using the Bodystat 1500 analyzer (Bodystat, Douglas, Isle of Man).

Weight loss and continued obesity. Seventeen obese subjects underwent a supervised low glycemic index diet, and 13 underwent bariatric surgery (10 roux-en-Y gastric bypass, 3 laparoscopic adjustable gastric band). Follow-up was 390 ± 33 days. Neither group was enrolled in graded exercise programs. Seven additional obese subjects, initially enrolled in the low glycemic index diet, who were unsuccessful in losing weight, underwent repeat scanning after 1 year (378 ± 44 days) to determine the effects of continued obesity.

Data analysis. Image analysis for LV and RV volumes, mass, and diastolic function was performed using Siemens analytical software (ARGUS). The short-axis stack was analyzed manually, contouring endocardial and epicardial borders from base to apex at end diastole and end systole to determine LV and RV mass (g) and volumes, as described (9). Left ventricular mass was indexed to height, body surface area, and height$^{2.7}$ to enable more stringent allowance for obesity (12).

Manually contouring short-axis slices across the cardiac cycle, volume time curves, diastolic peak filling rate, and time to peak filling rate, both normalized to end-diastolic volume, were derived as described (13).

Aortic cross-sectional area in systole and diastole was calculated using semiautomated in-house software within Matlab version 6.5 (Mathworks, Natick, Massachusetts), which shows a highly reproducible assessment of distensibility (coefficient of variance 0.58%). Aortic distensibility (AD) was calculated according to the formula: AD = ([A_{max} − A_{min}]/A_{min})/(pulse pressure), where A_{max} = maximal systolic area (mm^2), and A_{min} = minimal diastolic area (mm^2). All images were analyzed blinded.

Table 1 Anthropomorphic and Serum Characteristics

Characteristic	Normal Weight (n = 20)	Obese Before Weight Loss (n = 30)	Obese After Weight Loss (n = 30)
Body mass index, kg/m^2	21.4 ± 1.6	39.7 ± 7.6*	32.2 ± 5.3†
Weight, kg	60 ± 7	113 ± 23*	92 ± 18†
Systolic blood pressure, mm Hg	115 ± 9	120 ± 10	118 ± 10
Diastolic blood pressure, mm Hg	71 ± 8	77 ± 7*	75 ± 10
Waist measurement, inches	31 ± 4	46 ± 7*	40 ± 4†
Hip measurement, inches	37 ± 3	49 ± 6*	44 ± 4†
Visceral fat mass, dm^3	2.4 ± 1.2	7.3 ± 2.9*	4.4 ± 2.4†
Total fat mass, kg	17 ± 3	50 ± 19*	35 ± 12†
Fasting glucose, mmol/l	4.9 ± 0.4	5.3 ± 0.7*	5.0 ± 0.5†
Fasting cholesterol, mmol/l	5.0 ± 0.8	5.1 ± 0.7	4.9 ± 0.8
Fasting insulin, μm/l	3.0 ± 2.8	7.8 ± 6.9*	5.5 ± 4.5
Triglycerides, mmol/l	0.7 ± 0.5	1.1 ± 0.7*	0.7 ± 0.8†
Fasting leptin, ng/ml	21 ± 29	144 ± 88*	87 ± 77†
HOMA-IR score	0.7 ± 0.6	2.0 ± 2.0*	1.2 ± 1.0
C-reactive protein, mg/l	0.17 ± 0.7	1.9 ± 3.1*	0.7 ± 1.6†
Free fatty acid levels, mmol/l	0.34 ± 0.24	0.58 ± 0.31*	0.48 ± 0.22

*$p < 0.05$ obese versus normal. †$p < 0.05$ before versus after weight loss.
HOMA-IR = homeostasis model assessment of insulin resistance.

Statistical analysis. All statistics were performed using SPSS version 15 (SPSS, Chicago, Illinois). All results are presented as mean ± SD. All normally distributed datasets (established from Kolmogorov-Smirnov tests) were compared using paired and unpaired *t* tests; non-normally distributed datasets were compared using the Mann-Whitney *U* test and Wilcoxon signed-rank test where applicable. Differences were considered significant at $p < 0.05$. Multivariate regression of data was also performed.

Results

Anthropometric and serum characteristics. BASELINE. Normal control and obese subjects were well matched for age (43 ± 9 years vs. 44 ± 8 years), height (169 ± 6 cm vs. 169 ± 9 cm), sex (obese, 6 male and 24 female; normal weight, 5 male and 15 female), systolic blood pressure, and cholesterol (Table 1). Diastolic blood pressure was significantly higher in the obese subjects, but numerically, the difference was small and the measurements were within the normal range for both groups. Both waist and hip circumference were greater in the obese cohort, as were waist/hip ratio, total fat mass, and visceral fat mass. Serum leptin was 6.9 times higher in the obese subjects. Although fasting glucose was higher in the obese cohort, all measurements remained within the normal ranges. Fasting insulin and HOMA-IR were also higher in the obese cohort, with the average still in the insulin-sensitive range. The C-reactive protein levels were ~10-fold higher in the obese cohort.

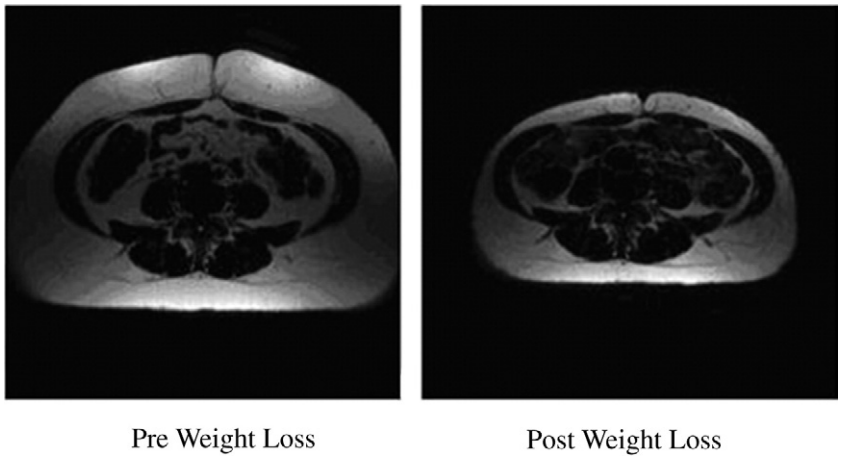

Figure 1 MR Images Before and After Weight Loss

Magnetic resonance (MR) transverse T1-weighted turbo spin echo images at the level of L5 before (Pre) and after (Post) diet-induced weight loss, demonstrating the substantial difference in both visceral and subcutaneous fat mass.

Table 2 Left and Right Ventricular Characteristics

Characteristic	Normal Weight (n = 20)	Obese Before Weight Loss (n = 30)	Obese After Weight Loss (n = 30)
LV mass, g	87 ± 20	134 ± 29*	121 ± 16†
LV mass indexed BSA, g/m^2	50 ± 10	59 ± 10*	58 ± 10
LV mass:volume ratio	0.75 ± 0.17	0.89 ± 0.16*	0.86 ± 0.15
LV end-diastolic volume, ml	117 ± 21	152 ± 21*	141 ± 21†
LV end-diastolic volume indexed height, ml/m	69 ± 12	89 ± 11*	83 ± 11†
LV end-systolic volume, ml	37 ± 10	47 ± 12*	42 ± 10†
LV stroke volume, ml	80 ± 15	104 ± 13*	99 ± 14†
LV ejection fraction, %	69 ± 5	69 ± 5	71 ± 4
Cardiac output, l/min	5.0 ± 1.0	6.9 ± 1.0*	6.3 ± 1.2†
RV mass, g	25 ± 17	55 ± 9*	33 ± 7†
RV mass indexed height, g/m	15 ± 4	33 ± 6*	20 ± 3†
RV end-diastolic volume, ml	132 ± 26	161 ± 22*	153 ± 23†
RV end-diastolic volume indexed height, ml/m	78 ± 15	95 ± 11*	90 ± 11†
RV end-systolic volume, ml	51 ± 14	58 ± 14*	56 ± 12
RV stroke volume, ml	76 ± 19	102 ± 15*	98 ± 15
RV ejection fraction, %	61 ± 6	64 ± 5	64 ± 5

*$p < 0.05$ obese versus normal. †$p < 0.05$ obese before weight loss versus obese after weight loss.
BSA = body surface area; LV = left ventricular; RV = right ventricular.

AFTER WEIGHT LOSS. After 1 year of weight loss (21 kg, 53% excess weight loss) (see Fig. 1 for example of cross-sectional images), both visceral fat mass (by 40%) and total fat mass (by 30%) were reduced (pooled data from both weight-loss groups). Waist and hip measures were reduced, and there was a 43% decrease in leptin. Systolic and diastolic blood pressure were unchanged and so were fasting glucose, insulin, HOMA-IR values, and cholesterol. The C-reactive protein was reduced by 63%. Comparing surgical and dietary methods, weight loss was higher in the surgical group (33 ± 13 kg vs. 12 ± 7 kg, $p < 0.01$). However, the percentage excess weight loss was similar for both groups (surgical 61 ± 22% vs. diet 48 ± 42%, $p = 0.32$).

CONTINUED OBESITY. After 1 year of continued obesity, there was no significant change in BMI, fat mass, glucose, cholesterol, or blood pressure (data not shown).

LV and RV characteristics. BASELINE. As expected, LV and RV masses and end-diastolic volume, both in absolute and height-indexed terms, were greater in obesity (Table 2). The LV mass/end-diastolic volume ratio and end-systolic and stroke volumes were also higher. The LV and RV ejection fractions were unchanged.

AFTER WEIGHT LOSS. After weight loss, there was a 10% reduction in absolute LV mass (Table 2) and indexed LV mass (data not shown). The LV mass indexed to body surface area did not change, namely, LV mass decreased in proportion to body surface area after weight loss. The LV end-diastolic volume (absolute and indexed) was also significantly lower after weight loss. The LV mass/end-diastolic volume ratio was unchanged and remained higher than in controls. The LV end-systolic volume, stroke volume, and cardiac output were reduced after weight loss, but heart rate and LV ejection fraction remained unchanged.

On pooled analysis, there was a 40% reduction in RV mass (absolute and height-indexed). The RV end-diastolic volume was also significantly lower after weight loss, but changes in

Table 3 A Comparison of the Effects of Dietary and Surgical Weight Loss

	Absolute Values		Normalized to Percent Excess Weight Loss ($\times 10^{-2}$)	
	Bariatric Cohort (n = 13)	Diet Cohort (n = 17)	Bariatric Cohort (n = 13)	Diet Cohort (n = 17)
Change in LV mass, g	19 ± 12*	10 ± 11*†	2.7 ± 3.7	2.9 ± 2.5
Change in LV EDV, ml	13 ± 14*	9 ± 9*	1.7 ± 3.2	3.4 ± 4.2
Change in RV mass, g	25 ± 12*	19 ± 8*	6.9 ± 5.1	4.9 ± 3.4
Change in RV EDV, ml	4 ± 17	10 ± 18	0.3 ± 3.2	4.8 ± 10
Change in ascending AD, mm Hg$^{-1} \times 10^{-3}$	1.2 ± 2.7	0.7 ± 2.3	2.1 ± 4.0	2.6 ± 11
Change in proximal descending AD, mm Hg$^{-1} \times 10^{-3}$	1.9 ± 1.9*	0.1 ± 1.5*†	3.0 ± 3.0	0.1 ± 6.0
Change in abdominal AD, mm Hg$^{-1} \times 10^{-3}$	1.5 ± 2.0*	1.8 ± 1.8*	2.5 ± 3.0	7.2 ± 10
Change in ventricular filling rate, ml/s	0.78 ± 0.77*	0.77 ± 0.84*	1.4 ± 1.0	2.5 ± 3.0

*$p < 0.05$ before versus after weight Loss. †$p > 0.05$ surgical versus dietary weight loss.
AD = aortic distensibility; EDV = end-diastolic volume; LV = left ventricular; RV = right ventricular.

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RV end-systolic and stroke volumes did not reach significance, likely due to higher variability of RV measurements. The RV ejection fraction was unchanged.

To assess the major determinants of the change in LV mass with weight loss, single linear regression analysis was first performed. Changes in the following parameters significantly correlated with LV mass reduction: BMI ($R = 0.73$, $p < 0.001$), body surface area ($R = 0.67$, $p < 0.001$), percentage excess weight loss ($R = 0.59$, $p < 0.001$), visceral fat mass ($R = 0.58$, $p < 0.001$), end-diastolic volume ($R = 0.45$, $p = 0.016$), and leptin ($R = 0.38$, $p = 0.02$). Stepwise multiple linear regression analysis of all data was then performed using a forced entry technique for the independent variables. The multivariate model consisted of LV mass as the dependent variable and of independent variables that had significant relationships (taken here as $p < 0.05$) with a change in LV mass on simple regression. This analysis revealed change in BMI ($\beta = 0.54$, $p = 0.01$) and change in LV end-diastolic volume ($\beta = 0.31$, $p = 0.013$) as the only independent predictors of change in LV mass with weight loss (overall $R^2 = 0.81$, $p < 0.001$).

DIET VERSUS SURGERY. Both surgical and dietary groups showed reductions in LV and RV mass (Table 3, Fig. 2). Reduction in absolute LV mass was greater for the surgical group, but when normalized to percentage excess weight loss, it was similar for both groups. The RV mass and LV end-diastolic volume reductions were similar between the 2 groups. The RV end-diastolic volume was only reduced in the diet group ($p = 0.03$); changes after surgery did not reach significance (Fig. 2B), again likely because of the greater variability of RV analysis.

CONTINUED OBESITY. After 1 year of continued obesity (Fig. 2C), there was a 7% increase in absolute and height-indexed LV mass. The RV mass and LV and RV end-diastolic, end-systolic, and stroke volume were unchanged with continued obesity.

Diastolic function. EFFECT OF OBESITY AND WEIGHT LOSS. Obesity subjects showed a 26% lower peak LV diastolic filling rate compared with controls (3.6 ± 0.8 ml/s vs. 4.6 ± 1.0 ml/s, $p = 0.001$) (Fig. 3A), and time to peak filling rate was 22% longer (196 ± 40 ms vs. 161 ± 44 ms, $p = 0.001$). On pooled group analysis, after weight loss, there was a 19% increase in peak diastolic filling rate (3.6 ± 0.8 ml/s vs. 4.3 ± 0.8 ml/s, $p = 0.001$) and a 9% reduction in the time to peak filling rate (178 ± 28 ms vs. 196 ± 40 ms, $p < 0.05$) (Fig. 3A). Heart rate was similar between the normal weight and obese subjects before (63 ± 7 beats/min vs. 66 ± 9 beats/min) and after weight loss (64 ± 9 beats/min). On linear regression analysis, only the reduction in LV mass was a predictor of improvement in peak diastolic filling rate ($R^2 = 0.2$, $p = 0.016$). Both means of weight loss resulted in similar improvements in diastolic function (Table 3, Fig. 4). There was no difference in diastolic filling rate after 1 year of continued obesity (Fig. 4).

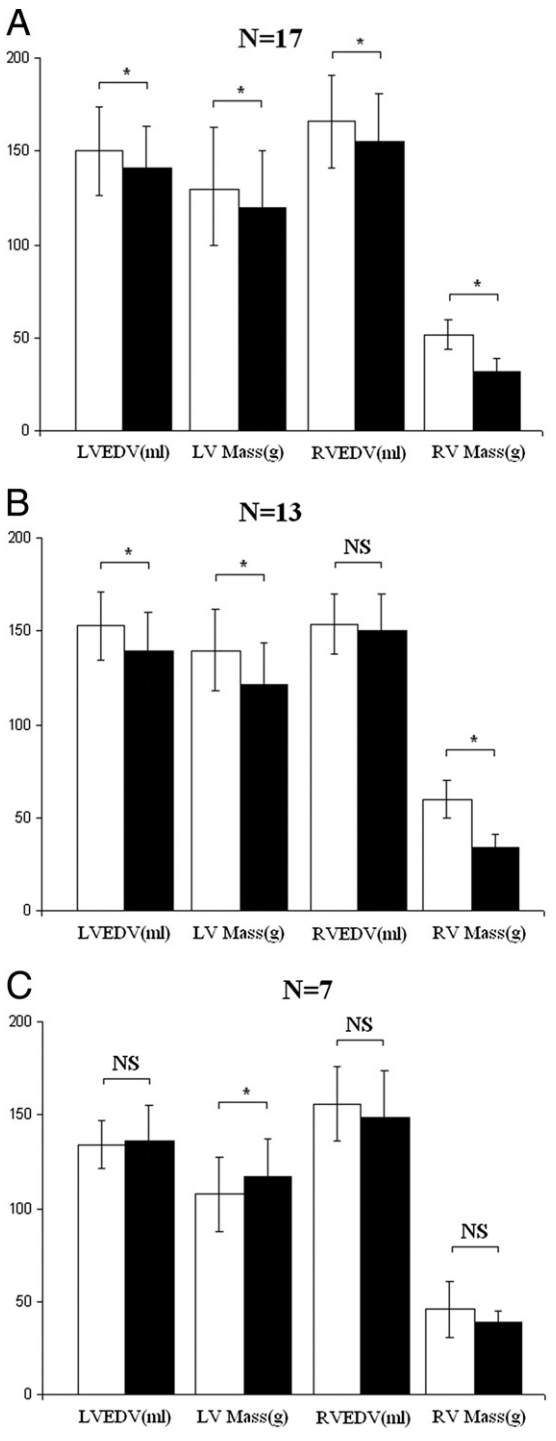

Figure 2 Ventricular Structure

Ventricular structure of **(A)** dietary weight loss, **(B)** bariatric surgery, and **(C)** continued obesity. **Open bars** = pre-intervention; **solid bars** = post-intervention. *$p < 0.05$. LV = left ventricle; LVEDV = left ventricular end-diastolic volume; NS = not significant ($p > 0.05$); RV = right ventricle; RVEDV = right ventricular end-diastolic volume.

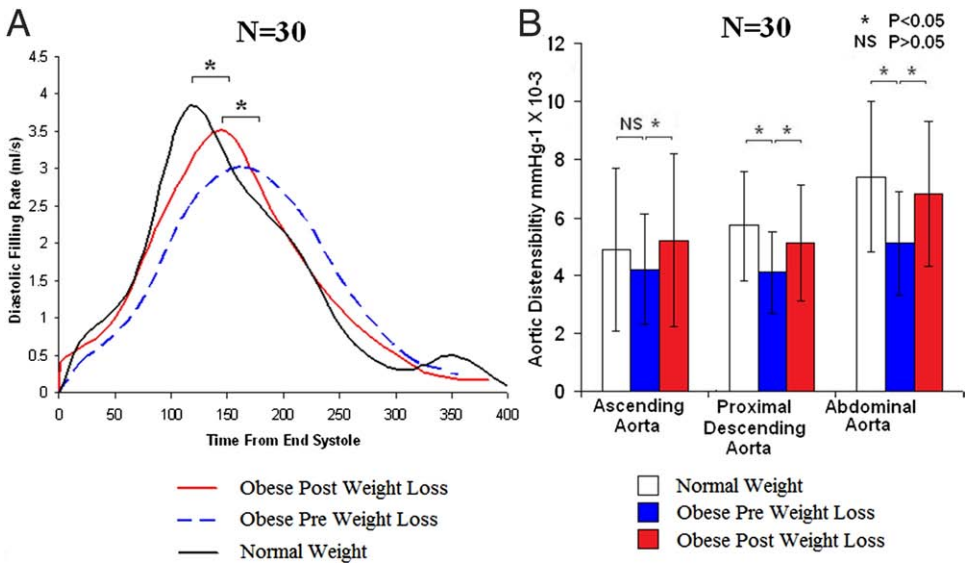

Figure 3 **Beneficial Effect of Weight Loss**

Pooled analysis for both dietary and surgical weight loss: **(A)** left ventricular diastolic function (**red solid line** = obese after weight loss; **blue dashed line** = obese before weight loss; **black solid line** = normal weight); and **(B)** aortic distensibility (**white bars** = normal weight; **blue bars** = obese before weight loss; **red bars** = obese after weight loss). NS = not significant.

Aortic elastic function. BASELINE. Confirming our previous study of baseline changes in obesity, performed on a different cohort (14), obese subjects had lower aortic distensibility at the level of the descending thoracic aorta (4.2 ± 1.4 mm $Hg^{-1} \times 10^{-3}$ vs. 5.7 ± 1.9 mm $Hg^{-1} \times 10^{-3}$, $p = 0.002$) and the abdominal aorta (5.1 ± 1.8 vs. 7.4 ± 2.6, $p = 0.001$ (Fig. 3B). Distensibility of the ascending aorta was not significantly different (4.2 ± 1.9 mm $Hg^{-1} \times 10^{-3}$ vs. 4.9 ± 2.8 mm $Hg^{-1} \times 10^{-3}$, $p = 0.29$). Thus, more distal aortic regions were associated with relatively larger reductions in aortic distensibility.

AFTER WEIGHT LOSS AND CONTINUED OBESITY. There was an increase in aortic distensibility at all 3 levels of the aorta after weight loss (pooled analysis of both groups), with the greatest improvement seen in the abdominal section (Fig. 3B). Aortic distensibility was unchanged before and after 1 year of continued obesity (Fig. 5C).

DIET VERSUS SURGERY. Improvements in abdominal aortic distensibility were seen in both the dietary and surgical cohort (Figs. 5A and 5B). The surgical group also had significant improvements in the proximal descending aortic distensibility. Distensibility improvements of the ascending aorta did not reach statistical significance for either weight loss group alone, likely because of smaller numbers per group compared with the pooled analysis (Figs. 5A and 5B). When normalized to percentage excess weight loss, there was no difference between the distensibility improvements seen with diet and surgery (Table 3). Of note, pulse pressure was not significantly altered after weight loss in either of the weight loss groups (diet group 42 vs. 42 mm Hg, $p = 0.52$; bariatric group 45 vs. 43 mm Hg, $p = 0.56$).

Discussion

Although significant weight loss in the setting of obesity complicated by diabetes has recently been shown to be associated with a reduced myocardial triglyceride content, improved hemoglobin A1c, and improved diastolic heart function (15), this study is the first to demonstrate a beneficial effect of significant weight loss per se, in the absence of additional identifiable cardiac risk factors, on ventricular structure, myocardial relaxation, and aortic elastic function without the obscuring effects of weight loss on obesity-related comorbidities. Furthermore, we demonstrate that surgical and dietary weight loss appear to have similar beneficial effects. Thus, these findings demonstrate a mechanism that is likely to contribute to the reduction in mortality rates seen with significant weight loss.

Ventricular structure. Left and right ventricular hypertrophy and cavity dilation in obesity result from a combination of increased blood volume and (2,16) altered hormonal milieu, including hyperleptinemia (17,18), hyperinsulinemia (19), and activation of the renin-angiotensin system (20). In our study, on multivariate analysis, BMI and end-diastolic volume were the 2 main mechanisms by which weight loss causes LV mass regression. In addition, both visceral fat mass and leptin change were associated on linear regression. Thus, the reduction in ventricular mass and cavity size most likely results from a combined effect due to the partial

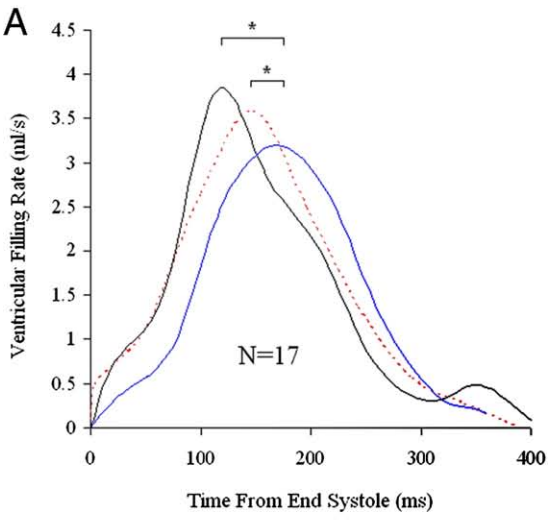

Figure 4 Diastolic Dysfunction

Mean filling curves for **(A)** dietary weight loss, **(B)** bariatric surgery, and **(C)** continued obesity. **Black solid lines** indicate normal weight; **blue solid lines** indicate obese before weight loss; **red dotted lines** indicate obese after weight loss. *$p < 0.05$. NS indicates not significant ($p > 0.05$).

reversal of the volumetric changes, a reduction in body mass, and the improved hormonal milieu. BMI and end-diastolic volume were independent predictors of LV mass regression on multivariate analysis, which may indicate that volumetric and load changes have a greater influence on LV mass regression than hormonal changes.

However, despite the improvements in LV structure, the LV mass/end-diastolic volume ratios remained unchanged and elevated after weight loss, suggesting a persistent remodeling abnormality. That finding may be explained by the relatively short 1-year follow-up period and by the obese subjects remaining in the obese BMI range even after weight loss. Longer-term studies will be needed to investigate whether LV remodeling is completely reversible with full weight normalization.

We showed that the RV hypertrophy regression appears to be greater than that of the LV. That may be a result of differential expression of leptin receptors within the myocardium, with higher levels of expression reported for the RV (21).

Aortic elastic function. We demonstrated significant improvement in aortic elastic function with weight loss. Aortic distensibility changes in obesity have been attributed to hyperleptinemia (22), physical compression from fat (23), elevated inflammatory cytokines (24), and elevated free fatty acid levels (25).

To rule out external compression from fat as a factor that improves abdominal aortic distensibility after weight loss, we simulated the effect of external compression in an additional 6 normal weight, healthy volunteers who underwent aortic MR imaging before and after the placement of a 10-kg weight on the abdomen (10 kg was chosen as the obese cohort was on average 44 kg heavier, and it was estimated that ≈25% of this weight was abdominal). There was no change in aortic distensibility at any level (e.g., distal descending aorta 7.6 ± 2.3 mm $Hg^{-1} \times 10^{-3}$ without weight vs. 8.7 ± 2.4 mm $Hg^{-1} \times 10^{-3}$ with weight, $p = 0.36$). Thus, there was no effect of external compression on aortic elastic function. This finding clearly suggests that physical compression of the aorta by excess subcutaneous fat is neither the mechanism by which obesity mediates aortic stiffness nor the mechanism by which weight loss improves aortic distensibility. Furthermore, the cholesterol profile remained unchanged and cannot be a contributing factor. Thus, it is likely that a decrease in visceral and subcutaneous fat mass with resulting reduction of both leptin and low-grade inflammation (C-reactive protein) are mediators contributing to this improvement in aortic function.

Diastolic dysfunction. Diastolic dysfunction is well recognized in obesity and has been attributed to LV hypertrophy (26). Our data suggest that weight loss results in both improved diastolic function and reduced LV mass, suggesting that the LV hypertrophic response may be at least partly responsible for the diastolic dysfunction seen in obesity and LV hypertrophy regression for the improvement in diastolic function with weight loss.

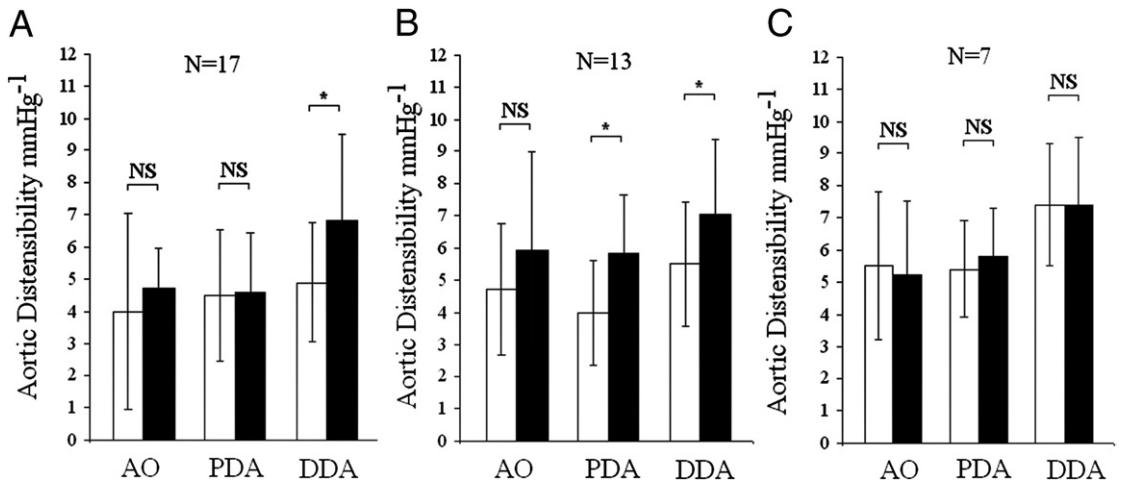

Figure 5 Aortic Elastic Function

(A) Dietary weight loss, **(B)** bariatric surgery, and **(C)** continued obesity. **Open bars** = pre-intervention; **solid bars** = post-intervention. *$p < 0.05$. NS indicates not significant ($p > 0.05$). AO = ascending aorta; DDA = distal descending aorta; PDA = proximal descending aorta.

Comparison of bariatric and dietary weight loss. To our knowledge, this is the first study investigating the relative benefits of surgical versus dietary weight loss on cardiovascular structure and function. Our data indicate that, when related to the degree of excess weight loss, diet and surgery result in similar beneficial improvements. Thus, it is the reduction in fat mass that is important to ameliorating the maladaptive ventricular hypertrophy and vascular stiffness in obesity and not the mode by which this is achieved.

Although diastolic dysfunction was greater in the surgical cohort before weight loss, as would be expected from the higher BMI, the relative improvement in diastole achieved with weight loss was the same as that achieved by the dietary cohort. Again, this finding highlights that the beneficial effects of weight loss are independent of the mode of weight loss.

Conclusions

In obesity per se, in the absence of traditional risk factors, significant weight loss irrespective of mode over a period of 1 year is associated with partial resolution of abnormal cardiovascular changes. It is likely that these beneficial effects are at least partially responsible for the reduced mortality seen with weight loss. Thus, obese persons who are able to achieve this, by whichever modality, are likely to profit from these beneficial cardiovascular effects.

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Key Words: obesity ■ weight loss ■ hypertrophy ■ aortic stiffness ■ diastole.