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Review article

Effect of obesity on cardiac function in children and adolescents: A review

Thomas W. Rowland
Department of Pediatrics, Baystate Medical Center, Springfield, MA, USA

Abstract
Increases in cardiac mass, ventricular dimensions, and stroke volume are typically observed in obese adults, accompanied by evidence of diminished ventricular systolic and diastolic function. Given sufficient severity and duration of excessive body fat, signs of overt congestive heart failure may ensue (cardiomyopathy of obesity). This review of cardiac findings in obese children and adolescents indicates similar anatomic features as well as early subclinical findings of ventricular dysfunction. However, cardiac functional reserve (cardiovascular fitness) appears to be preserved even in those with morbid levels of obesity.

Key words: Obesity, heart, child.

Introduction

Concern grows that the current dramatic rise of obesity among children and adolescents portends a future wave of increasing cardiovascular disease as these overweight youth reach the adult years (Olshansky et al., 2005). Although disputed by some (Gibbs, 2005), the reality of this scenario appears self-evident. Childhood obesity is highly predictive of adult obesity, and among adults, excessive body fat carries multifold risk for morbidity and premature death from coronary artery disease, hypertension, stroke, and renal vascular disease, as well as a host of non-circulatory disorders (type 2 diabetes, asthma, arthritis, certain neoplasms) (Hambdy, 2003). Even during the pediatric years, obese youngsters demonstrate a higher incidence of hypertension, peripheral vascular dysfunction (Tounian et al., 2001), and autopsy evidence of atherosclerosis (Kortelainen, 1997) compared to their nonobese peers.

The direct effects of the obese state on heart function, and the means by which excessive body fat might negatively affect cardiac health *during* the growing years, however, has received less attention. It is well-recognized that cardiac mass and chamber dimensions are increased in the obese adult, which is reflected in a greater resting stroke volume and cardiac output (Alpert and Alexander, 1998). Given sufficient duration and/or severity of obesity, this hyperkinetic state is supplanted by increasing evidence of systolic and diastolic myocardial dysfunction, which may progress to overt clinical heart failure (Alpert, 2001). This *cardiomyopathy of obesity* appears to be independent of the adverse cardiac effects of coronary artery disease, hypertension, and sleep apnea commonly observed in adults with marked obesity. The cause of this myocardial dysfunction is unclear, but chronic volume overload, insulin resistance, autonomic changes, and local metabolic derangements have all been implicated as possible etiologic factors.

Similar information is beginning to emerge regarding the effects of adiposity on cardiac health of children and adolescents. These data indicate trends of diminishing ventricular function in youth related to level of obesity; however, overt myocardial dysfunction is rare, and reserve capacity with exercise is generally preserved. It is the purpose of this review to summarize these reports which have addressed the effects of obesity on cardiac size, function, and reserve capacity ("cardiovascular fitness") in the pediatric age group. Given the marked rise in obesity in youth, an understanding of the pathophysiological implications of these effects early in the lifespan is clearly important. Such information underscores the urgency of preventive efforts and serves to help define specific management strategies.

Cardiac dimensions

Becoming obese is an anabolic event. Beside the obvious accumulation of excessive body fat, the obese child is characterized by an increase in lean body mass, acceleration of linear growth, enhanced skeletal maturation, and advanced sexual development (Forbes, 1977). An expanded circulatory system reflects this somatic growth, with increased plasma volume, hypertrophy of myocardial fibers, and cardiac chamber enlargement.

Studies in adults

Early autopsy studies of morbidly obese adults, many suffering from congestive heart failure, indicated a marked increase in heart weight, with biventricular enlargement and eccentric wall hypertrophy. Subsequent investigations utilizing echocardiography revealed that these findings 1) could be observed independent of coronary artery disease and systemic hypertension, and 2) were not simply confined to those with marked obesity but instead were evident across the range of overweight individuals (see Alpert and Alexander, 1998, for review). More specifically, measurements of left ventricular mass, chamber dimensions, and wall thickness have been observed to relate directly to both severity and duration of obesity. For example, among a group of adults with morbid obesity, Alpert et al. found an increase in average left ventricular end diastolic dimension from 4.8 cm in those with obesity of 5 years' duration to 6.5 cm after 20 years (Alpert et al., 1995). Subsequent information from magnetic resonance imaging (MRI) studies has substantiated these findings (Danias et al., 2003).

Further confirming this anabolic effect of obesity, heart mass and chamber size are observed to diminish

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following therapeutic weight reduction. Decreases in left ventricular mass, wall thickness, and chamber diastolic dimension have been reported not only in the morbidly obese following bariatric surgery (Alpert et al., 1994) but also after dietary weight reduction programs for those who are initially mild to moderately overweight (MacMahon et al., 1986).

Studies in youth

Echocardiographic studies, supplemented by recent MRI investigations, have consistently indicated similar anatomic features in obese children and adolescents. Larger, thicker hearts are seen in obese subjects compared to nonobese youth (Friberg et al., 2004; Koehler et al.., 1997; Mehta et al., 2004; Rabbia et al., 2003). In these studies, those with mild-moderate obesity typically demonstrate approximately 15-20% greater values of cardiac mass (related to body height or surface area) than lean youth. Although comparisons are treacherous, the magnitude of these differences is somewhat less than the 20-40% described in studies of obese adults (presumably reflecting differences in duration of obesity) (Alpert and Alexander, 1998).

Positive cross-sectional associations between body fat content and left ventricular mass, wall thickness, and chamber dimensions have been evident among cohorts of obese subjects (Humphries et al., 2002) as well as in studies in the general pediatric population (Chinali et al., 2006; Gutin et al., 1998; Kono et al., 1994; Mensah et al., 1999; Paparassiliou et al., 1996; Pfleiger et al., 1994; Yoshinga et al., 1995). As in adults, these reports describe a positive relationship between severity of obesity in youth and left ventricular size. Kono et al. (1994) reported a correlation coefficient of r=0.60 between adiposity and left ventricular mass normalized for height in 6-year old males, and Rowland and Dunbar (2007) found a correlation of r = 0.59 between body mass index and left ventricular end diastolic dimension in a group of early adolescent females with a BMI range of 14-63 $kg \cdot m^{-2}$. The average dimension was 44 mm in those with a BMI of approximately 20 $kg \cdot m^{-2}$ compared to 52 mm with a BMI of 42 $kg \cdot m^{-2}$. In the only study which has assessed cardiac features relative to duration of obesity, Rabbia et al. (2003) found that a group of 13 year old obese children had a greater average heart mass than nonobese. However, they could find no significant difference in left ventricular mass among three groups of the obese children with <4, 4-7, and >7 years duration.

Longitudinal data are limited. In the Bogalusa Heart Study, left ventricular mass (by echocardiography) and body composition measures were recorded four years apart in 67 healthy children initially 9-22 years old (Urbina et al., 1995). Stepwise multivariate regression analysis indicated that initial skinfold thickness predicted final left ventricular mass (relative to body $height^{2.7}$). However, change in skinfold thickness was not related to change in cardiac mass.

Relationship to body composition

From this information it is clear that the obese condition in both adults and children is characterized by cardiac enlargement, and the extent of increased heart size is directly related to the severity of obesity. At the same time, abundant evidence indicates that this enhancement of cardiac mass and chamber size does not actually reflect the amount of body fat but rather the excess of lean body mass that accompanies the obese state. That is, the obese individual has a larger heart than the lean not because he or she is carrying excessive fat tissue but rather because of his or her extra lean body mass. This relationship is intuitively reasonable, since lean body mass, being much more metabolically active than adipose tissue, would be expected to be closely related to the dimensions of its circulatory support. It is tempting, as well, to then speculate that heart enlargement and greater lean body mass (particularly skeletal muscle) of the obese share a common mechanistic etiology.

Using echocardiography and dual-energy X-ray absorptiometry, Whalley et al. (1997) demonstrated this cardiac-lean body mass link in a group of 106 adults, showing that fat-free mass was the only independent predictor of left ventricular mass. Similar analyses in the pediatric age group have reached the same conclusion. Daniels et al. (1995) studied 201 subjects ages 6 to 17 years using the same measurement techniques. In multiple regression analysis, lean body mass by itself explained 75% of the variance of left ventricular mass, while fat mass and systolic blood pressure accounted for only 1.5% and 0.5%, respectively.

In the Muscatine Study of 124 children 8-12 years of age, fat-free mass and sum of skinfolds in the boys accounted for 50% and 15%, respectively, of variance in left ventricular mass (Janz et al., 1995). Among the girls, fat-free mass explained 62% of the variance in ventricular mass, with no significant contribution of skinfold thickness. In a similar assessment of 62 children ages 7 to 13 years, Gutin et al. (1998) found that fat free mass was responsible for 72% of the variance in left ventricular mass. When fat mass was entered into the regression, R^2 rose to 0.78.

These reports substantiate the concept that increased cardiac size in the obese parallels the increase in their lean body mass rather than amount of excessive adipose tissue. Recognizing this link bears importance for 1) understanding etiologic mechanisms which stimulate heart growth in the obese state, and 2) uncovering the most appropriate means of expressing anatomic and physiologic variables in respect to body size and composition in overweight individuals.

Etiology

While the cardiac enlargement in obesity can be couched in terms of response to a chronically increased hemodynamic load (Chinali et al., 2006), there is need for a more precise mechanistic explanation for this expansion of the cardiovascular system. Most attention has focused on the role of the anabolic effects of hyperinsulinemia, a reflection of the insulin resistance commonly observed in obese individuals (Gidding et al., 2004; Giordano et al., 2003; Sasson et al., 1993; Wong et al., 2004). This model is particularly attractive since insulin is recognized to increase both cardiac and skeletal muscle mass through insulin-like growth factor-1 receptors (IGF-1) (Hill and Milner, 1985). Studies attempting to identify the etiologic

role of these anabolic effects of insulin on myocardial hypertrophy are hampered, however, by the fact that insulin resistance and serum insulin levels are closely linked to the obese state itself (Weiss et al., 2004).

The association of insulin resistance and hyperinsulinemia with heart mass is well-documented in adults. For example, among 40 normotensive nondiabetic obese subjects, Sasson et al. (1993) found that markers of insulin resistance accounted for 50% of the variance of left ventricular mass. Univariate correlation coefficients between indices of insulin resistance and ventricular mass ranged from r = 0.44 to 0.51. The authors suggested that hyperinsulinemia might augment heart size by a muscle growth-stimulating effect or by increasing blood volume (via of changes in renal sodium reabsorption change). In 109 obese adults, Wong et al. (2004) found insulin levels were significantly associated with both indexed left ventricular mass (r = 0.24) and wall thickness (r = 0.29).

Suggestive evidence for an etiologic role of insulin in promoting myocardial growth has been described in studies of both obese and nonobese youth. In a general population, Gutin et al. (1998) found a significant partial correlation of r = 0.25 between insulin levels and height-adjusted left ventricular mass. Giordano et al. (2003) reported a significant relationship (r = 0.53) between height-indexed left ventricular mass and insulin response to an oral glucose tolerance test. In a group of 48 morbidly obese youth (BMI > 40 $gm \cdot m^{-2}$) Gidding et al. (2004) found a mean left ventricular mass at the 80^{th} percentile of normal and elevated fasting insulin concentrations, with only 13 in the normal range.

"Normalizing" anatomic and physiologic variables with obesity.

Cardiovascular anatomic and physiologic variables are clearly related to body size and composition. In assessing the cardiac effects of obesity, then, it is of prime importance to adjust measurements for these influences. Only then can one make appropriate comparisons between obese and non-obese individuals, for example, or examine relationships of cardiac features to severity of obesity. Although this is critical to reaching appropriate conclusions, the best means of accomplishing such variable adjustments in the obese subject is problematic-- particularly as it may be affected by variables such as gender, age, athleticism-- and the issue is not easily resolved.

For "normalizing" cardiac mass to body size, it has been considered most appropriate to make adjustments for inter-individual differences in body stature or skeletal dimensions (which will make no allowance for adiposity). The cardiac mass of a 12 year old boy is considerably more than that of a 6-year old who has the same body composition (consider examining the latter with a magnifying glass). Consider *Z* to be a cardiac variable (ie., heart mass), and *A* the correction variable that will appropriately adjust for body stature/skeletal size. A greater value of *Z/A* in a group of obese children compared to non-obese *is consistent with* the conclusion that the obese state is responsible for a greater value of *Z* compared to the non-obese. (Other factors such as body muscularization, athleticism, gender, habitual activity, disease confounders would also have to be considered.)

Utilizing an allometric analysis, de Simone et al. (1992) concluded that for Z= cardiac mass, $height^{2.7}$ was the most appropriate value for *A* that controls for the influence of body fat in assessing heart mass. Most studies addressing left ventricular mass in obese subjects have used this normalizing factor (Chinali et al., 2006; Gutin et al., 1998; Humphries et al., 2002; Kono et al., 1994; Mensah et al., 1999; Papavassiliou et al., 1996; Pflieger et al., 1994). Other height exponents that might serve as normalizing factors for left ventricular mass have been suggested (Daniels et al., 1988). Yoshinaga et al. (1995) found that among 12-year-old Japanese children, $height^{3.1}$ and $height^{1.9}$ in boys and girls, respectively, were optimal for adjusting heart mass. They considered that racial differences might account for differences from those reported by de Simone et al. (1992).

Alternatively, one could consider whether the degree of obesity *accounts for* the difference of *Z* between the two groups. This can be assessed by utilizing another normalizing factor *B*, which will eliminate the effect of excessive body fat. Following the model above, if *Z/B* is not significantly different between the two groups, then it could be concluded that the differences in *Z* in the groups reflects the effect of obesity. One might readily conclude that the optimal *B* should be body fat content, or even body mass. However, *B* depends on the variable being studied. For instance, in respect to heart mass, the data outlined above indicate that values are most closely related to lean body mass, which would serve as an appropriate *B*. Since excessive body fat in the obese individual is greater than the excess of lean body mass (Forbes and Welle, 1983), use of body fat content or body mass as *B* in this case would result in a spurious low value of adjusted heart mass. This pitfall will be observed later particularly in the case of normalization of values of maximal oxygen uptake (VO_2max).

Hemodynamics and ventricular function at rest

Given the positive effects on heart size in the obese, it is not surprising that these individuals demonstrate greater absolute values of resting stroke volume and cardiac output than lean subjects. This is evident in studies of both children and adults, which have utilized a variety of measurement techniques (thermodilution, dye dilution, echocardiography). The review of data published in adult subjects by Alexander and Alpert indicates consistent findings of increased oxygen uptake, blood volume, cardiac output, and stroke volume which are directly related to severity of obesity (Alexander and Alpert, 1998). Among those with morbid obesity, for example, Alexander et al. (1962) reported a resting mean cardiac output of approximately 6 $L \cdot min^{-1}$ in subjects who were 60 kg overweight , while those 100 kg overweight had an average of 10 $L \cdot min^{-1}$. A decline in these hemodynamic variables is seen following weight reduction (Reisin et al., 1983).

In young adolescent females with an average BMI of 34 ± 13 $kg \cdot m^{-2}$ Rowland and Dunbar (2007) found a

significant direct association of BMI and resting cardiac output (r = 0.46) and stroke volume (r = 0.36). Giordano et al. (2003) reported resting values for cardiac output of 7.3 ± 1.9 and 5.7 ± 1.2 $L \cdot min^{-1}$ ($p < 0.05$) in obese and normal weight children, respectively. Similar findings were described in 6-15 year old subjects by Pflieger et al. (1994). Chinali et al. (2006) found a direct relationship between severity of obesity and both cardiac output and stroke volume in 14-20 year old subjects (BMI range 16 to 57$kg \cdot m^{-2}$) using Doppler echocardiography. Normal weight, overweight (BMI 85-95th percentile), and obese subjects (>95th percentile) had mean resting cardiac outputs of 4.82 ± 0.91, 5.14 ± 0.96, and 5.31 ± 1.12 $L \cdot min^{-1}$, respectively. Average values for stroke volume were 73 ± 10, 77+11, and 80 ± 13 ml.

Despite these indicators of augmented heart size and output, obese subjects often demonstrate evidence of diminished myocardial function, which is directly related to the severity and duration of their adiposity. This initially came to light in early studies of adults with longstanding morbid obesity, who demonstrated signs and symptoms of frank congestive heart failure. The hearts of these subjects were characterized by reduced left ventricular ejection fraction, chamber dilatation, and elevated end-diastolic pressures, which were often independent of effects of hypertension or coexistent coronary artery disease (Alpert, 2001).

Clinical manifestations of this *obesity of cardiomyopathy* occur in about 10% of adult patients with a body weight >75% ideal or BMI >40 $kg \cdot m^{-2}$, and usually in those whose duration of obesity exceeds 10 years Alpert, 2001). More recent echocardiographic evidence indicates, however, that subclinical evidence of depressed myocardial function, particularly diastolic, is often observed even in adults with mild-to-moderate obesity (Alpert et al., 1998;Chakko et al., 1998). The report of Wong et al. (2004) in 142 middle-aged men and women illustrated these trends. Subjects were divided into groups of referent (BMI<25), overweight (BMI 25-30), mildly obese (BMI 30-35), and severe obesity (BMI >35). While ventricular ejection fraction was similar in all groups, systolic dysfunction was indicated by progressive declines in myocardial systolic peak velocity (as measured by tissue Doppler imaging) with increasing obesity (r=-0.59 versus BMI). Similar trends of indices of diastolic function were observed with greater obesity. Isovolumetric relaxation time and tissue Doppler e' (early diastolic tissue velocity) fell while the ratio of mitral inflow velocity E to e' rose with increasing BMI, suggesting depressed myocardial relaxation properties and increased left ventricular filling pressures.

Recent studies indicate that this trend of subclinical depression in left ventricular function among obese subjects is observed in the pediatric years. Gutin et al. (1998) reported that among 62 children ages 7 to 13 years, percent body fat correlated negatively with lower midwall ventricular shortening fraction (r = -0.37). Mensah et al. (1999) found a significant negative association between midwall shortening fraction and central adiposity in black (but not white) subjects in a group of 15-year old subjects. Chinali et al. (2006) found a significantly lower left ventricular ejection fraction in 14-20 year old obese subjects (BMI >95th percentile) compared to a non-obese group.

Rowland and Dunbar (2007) found a progressive decline in left ventricular shortening fraction with increasing BMI in 39 young adolescent females (r=-0.47). Between a BMI of 20 and 60 $kg \cdot m^{-2}$, mean shortening fraction fell from 40 to 33 percent. It is important to note that in this study, however, no subject demonstrated a shorting fraction below the lower limit of normal (28 percent). Naylor et al. (2006) found an elevated tissue Doppler E/e' in obese 12 year olds (BMI 30.8 ± 2.6) compared to non obese (8.16 ± 0.26 versus 6.86 ± 0.20 $cm \cdot sec^{-1}$, respectively), suggesting mildly elevated left ventricular filling pressure from diastolic dysfunction.

Mehta et al. (2004) compared echocardiographic findings in 10-18 year old overweight and obese children with those of normal weight. No differences in left ventricular shortening fraction or ejection fraction were observed between the groups. The ratio of E/e' was also similar, suggesting no increase in left ventricular filling pressures in the obese. However, some abnormalities in diastolic function were observed by tissue Doppler imaging among the overweight subjects, particularly a lower septal e' (indicative of impaired myocardial relaxation).

Several factors have been proposed to account for this depression of systolic and diastolic function, which appears to be clearly related to both severity and duration of excess adiposity. Myocardial fatigue in the setting of obesity may be the consequence of chronic volume overwork. This model of "high output" congestive heart failure is observed in other conditions characterized by depressed myocardial function and chamber dilatation as a consequence of longstanding elevations of cardiac output (anemia, arterial venous malformations, thyrotoxicosis).

Alternatively, metabolic derangements associated with the obese state may contribute to myocardial dysfunction. Insulin resistance can modify myocardial substrate utilization, causing an increase in myocardial fatty acid oxidation and oxygen consumption and leading to a decrease in cardiac work efficiency (Peterson et al., 2004). Buchanan et al. (2005) found in a mouse model that these metabolic changes and diminished efficiency precede the development of hyperglycemia. Leptin produced by adipose cells has been demonstrated to cause myocardial dysfunction in rats (Nichola et al., 2000).

Cardiac autonomic activity is altered by obesity in both children and adults, but the patterns of these changes have not been consistent in the research literature (Liatis et al., 2004). These variations, however, might play a role in altering myocardial function.

Cardiac functional reserve (cardiovascular fitness)

The extent that obesity affects "cardiovascular fitness" depends on the definition being considered. If fitness is considered functionally as performance on an endurance exercise event, obesity is clearly detrimental. For example, among obese children (mean percentage body fat 49%), Drinkard et al. (2001) found a correlation of r = -0.82 between BMI and distance on a 12-minute walk/run

test. In a general population of 12 year old boys, Rowland et al. (1999) reported that body fat content accounted for 32 percent of the variance on finishing times on a one-mile run. This negative influence of the obese state on field measures of cardiovascular fitness has generally been considered due to the excess "baggage" of adiposity that must be transported.

When cardiovascular fitness is considered physiologically by the traditional marker of VO_2max per kg body mass, again an adverse influence of obesity is observed. Negative correlations between maximal aerobic power expressed relative to body mass and body fat measures are typically high (r = -0.50 to -0.80) (Goran et al., 2000; Loftin et al., 2001; Rowland, 1991; Rowland et al., 1999). In this case, the most obvious explanation is the significant contribution of inert adipose tissue, which inflates the denominator ("per kg") and lowers mass-adjusted maximal aerobic power.

In neither of the two aspects of fitness described above is it possible to determine the contribution of adverse effects of obesity on cardiac functional reserve itself. For the purposes of this discussion, "cardiovascular fitness" will be defined in its purist absolute sense as *the maximal capacity of the heart to generate cardiac output.* This signifies the cardiac functional reserve, and is indicated specifically by the absolute value of maximal cardiac output measured during a progressive exercise test.

Augmentation of myocardial contractility is an important requirement for normal cardiac responses to exercise (Rowland, 2005). During a progressive exercise test, increases in systemic venous return are met with a corresponding rise in heart rate, such that left ventricular filling volume and diastolic dimension are maintained stable as work and cardiac output rise. At the same time, little change is observed in stroke volume. The function of enhanced myocardial contractility, then, is to maintain stroke volume as the systolic ejection time decreases with rising heart rate. Abnormal myocardial function during exercise will be manifest by a reduction in stroke volume and lower maximal cardiac output as well as decreased values of other markers of systolic and diastolic function, including ejection or shortening fraction, peak aortic velocity, and velocity of myocardial excursion in systole and diastole (by tissue Doppler imaging) (Rowland et al., 1999).

Inter-individual differences in maximal cardiac output normally reflect variations in maximal stroke volume, as maximal heart rate is essentially independent of cardiovascular fitness. Maximal stroke volume, in turn, is a function of resting stroke volume and left ventricular end diastolic dimension. It follows, then, that the greater absolute cardiac output and stroke volume in obese versus nonobese subjects at rest should be expected to be expressed as similar higher values at maximal exercise.

Among obese adults, evidence indicates that suppression of ventricular function evident at rest is expressed also as diminished myocardial performance during exercise. As would be anticipated, this degree of limitation in functional capacity is most evident in those with morbid obesity of long-standing duration. Alpert et al. (1989) demonstrated that changes in left ventricular ejection fraction during exercise were related to heart mass in morbidly obese subjects. A normal response (+20-30%) was observed until heart mass exceeded 150-200 grams. In subjects with a heart mass above 350 grams, ejection fraction *fell* with exercise. Similar findings were described by Licata et al. (1992). They found that duration of obesity correlated inversely with percent change in ventricular ejection fraction at peak exercise (r = -0.59). Ejection fraction increased only in those with a duration of obesity less than 10 years.

Two studies have evaluated cardiac output responses to maximal exercise in obese youth. Rowland and Dunbar (2007) performed progressive cycle tests on 39 girls with a BMI ranging from 14 to 63 $kg \cdot m^{-2}$, estimating cardiac output by Doppler echocardiography. Maximal cardiac output and stroke volume were directly and linearly related to BMI, with no evidence of a decrement in this relationship at high levels of obesity. Cardiac scope (maximal value expressed as a multiple of that at rest) was approximately 2.7 for those with a BMI of 20 $kg \cdot m^{-2}$ and 3.1 for those with a BMI >40 $kg \cdot m^{-2}$ (who had been significantly obese since very early childhood). From these findings one arrives at the unexpected (but valid) conclusion that in an absolute sense, true cardiovascular fitness is superior in the obese compared to nonobese. When expressed as ability to improve cardiac function above the resting state, the two groups were similar. Importantly, these findings indicated no effect of obesity, even those of 10 years' duration with BMI>40$kg \cdot m^{-2}$, on cardiac functional capacity (i.e., true cardiovascular fitness).

Giordano et al. (2003) used the acetylene rebreathing method to compare cardiac responses to peak treadmill exercise in 24 obese males (mean age 11.9 ± 2.1 years, BMI 32.4 ± 5.8 $kg \cdot m^{-2}$) and age matched lean control subjects. No difference was observed in absolute values of maximal cardiac output for the two groups (obese 11.5 ± 4.1 $L \cdot min^{-1}$, lean 10.8 ± 3.5 $L \cdot min^{-1}$), and values were also similar when adjusted for $height^{1.83}$.

More information is available from studies, which have assessed VO_2max in obese youth, which can be interpreted as a surrogate of maximal cardiac output. Reflecting the larger diastolic dimension, stroke volume, and cardiac output at rest, absolute values of VO_2max are greater in obese compared to nonobese subjects. Rowland (1991) described a close correlation (r = 0.72) between VO_2max ($L \cdot min^{-1}$) during treadmill testing and skinfold sum in 27 obese adolescent females. When VO_2max was expressed relative to body mass the reverse trend was observed (r = -0.49).

Other researchers have mimicked these findings. Maffeis et al. (1994) showed that obese children had a significantly greater absolute VO_2max compared to nonobese subjects (1.55 ± 0.29 and 1.23 ± 0.22 $L \cdot min^{-1}$, respectively), but this difference was eliminated when values were expressed relative to fat free mass. Similarly, Goran et al. (2000) reported higher absolute VO_2max in obese versus nonobese children during treadmill exercise (1.56 ± 0.40 versus 1.24 ± 0.27 $L \cdot min^{-1}$) but the two groups had no significance difference when VO_2max was expressed relative to fat free mass (59.2 ± 4.9 and 57.9 ±

5.8 ml·kg·FFM^{-1}). Similar findings have been reported in obese youth by Ekelund et al. (2004), Treuth et al. (1998), and Marinov et al. (2003).

These data are consistent with the conclusion offered by Goran et al. (2000): VO_2max is most closely related to lean body mass but not fat mass; the lower VO_2max in obese subjects is a expression of metabolically inert fat mass in the per kg denominator. Consequently, the negative correlation observed between VO_2max per kg and degree of obesity does not reflect cardiac dysfunction. In fact, to the contrary, this research information suggests no significant impairment of myocardial functional reserve capacity in obese youth.

Conclusions

An expanded cardiovascular system is observed in obese adults, with a direct correlation observed between degree of obesity and plasma volume, cardiac mass, ventricular wall thickness and diastolic dimension, and cardiac output. Over time, findings of myocardial diastolic and systolic dysfunction become superimposed on these features which are independent of other factors such as systemic hypertension and coronary artery disease. Given sufficient duration and severity of excess adiposity, this cardiomyopathy of obesity can eventuate in a clinical picture of congestive heart failure.

Recent studies have provided a picture of the cardiac effects of obesity in children and adolescents. These indicate certain parallels with data in adults:

1)Obese youth demonstrate similar anatomic and hemodynamic cardiac features as their adult counterparts. Cardiac enlargement, with increased heart mass and chamber dimensions, is reflected in a higher resting stroke volume and cardiac output compared to lean youngsters. As in adults, these characteristics are related to severity of obesity.

2)Clinically significant depression of myocardial function resulting from obesity is not typical of the pediatric age group. However, trends of decreasing systolic and systolic function are observed in obese children and adolescents. The findings of these antecedents of cardiomyopathy of obesity provide an impetus for vigorous efforts at early obesity prevention and treatment in the growing years.

3)Cardiac functional reserve capacity (true cardiovascular fitness) is not significantly impaired in obese youth, even in those with more marked degrees of adiposity. This observation suggests that exercise interventions for obese subjects do not need to conform to the high intensity, duration, and frequency required to improve aerobic fitness. Instead, more palatable low intensity activities designed to expend calories are appropriate.

References

Alexander, J.K. and Alpert, M.A. (1998) Hemodynamic alterations with obesity in man. In: *The heart and lung in obesity.* Eds: Alpert M.A. and Alexander J.K. Armonk, NY:Futura Publishing Company. 45-55.

Alexander, J.K., Dennis, E.W. and Smith, R.D. (1962) Blood volume, cardiac output and distribution of systemic blood flow in extreme obesity. *Cardiovascular Research Center Bulletin* **1,** 39-44.

Alpert M.A. (2001) Obesity cardiomyopathy: pathophysiology and evolution of the clinical syndrome. *American Jounral of Medical Science* **321,** 225-236.

Alpert, M.A. and Alexander, J.K. (1998) Cardiac morphology and obesity in man. In: *The heart and lung in obesity.* Eds: Alpert M.A. and Alexander, J.K. Armonk, NY:Futura Publishing Company. 25-44.

Alpert, M.A., Alexander, J.K. and Chakko S. (1998) Obesity and ventricular function in man. Systolic function. In: *The heart and lung in obesity.* Eds: Alpert, M.A. and Alexander, J.K. Armonk, NY:Futura Publishing Company. 77-94.

Alpert, M.A., Lambert, C.R. and Panayiotou H. (1995) Relationship of duration of morbid obesity to left ventricular mass, systolic function, and diastolic filling and effect of weight loss. *American Journal of Cardiology* **76,** 1194-1197.

Alpert, M.A., Lambert, C.R. and Terry, B.E. (1994) Effect of weight loss on left ventricular mass in nonhypertensive morbidly obese patients. *American Journal of Cardiology* **73,** 918-921.

Alpert, M.A., Singh, A., Terry, B.E., Kelly, D.L., Villarreal, D. and Mukerjii, V. (1989) Effect of exercise on left ventricular systolic function and reserve in morbid obesity. *American Journal of Cardiology* **63,** 1478-1482.

Buchanan, J., Mazumder, P.K., Hu, P., Chakrabarti, G., Roberts, M.W., Yun, U.J., Cooksey, R.C., Litwin, S.E. and Abel, E.D. (2005) Reduced cardiac efficiency and altered substrate metabolism precedes the onset of hyperglycemia and contractile dysfunction in two mouse models of insulin resistance and obesity. *Endocrinology* **146,** 5341-5349.

Chakko, S., Alpert, M.A. and Alexander, J.K. (1998) Obesity and ventricular function in man. Diastolic function. In: *The heart and lung in obesity.* Eds: Alpert, M.A. and Alexander, J.K. Armonk, NY: Futura Publishing Company. 57-75.

Chinali, M., de Simone, G., Roman, M.J, Lee, E.T., Best, L.G., Howard, B.V. and Devereux, R.B. (2006). Impact of obesity on cardiac geometry and function in a population of adolescents. *Journal of American College Cardiology* **47,** 2267-73.

Danias, P.G., Tritos, N.A. and Stuber, N. (2003) Cardiac structure and function in the obese: a cardiovascular magnetic resonance imaging study. *Journal of Cardiovascular Magnetic Resonance* **5,** 431-438.

Daniels, S.R., Kimball, T.R., Morrison, J.A., Khoury, P., Witt, S. and Meyer, R.A. (1995) Effect of lean body mass, fat mass, blood pressure, and sexual maturation on left ventricular mass in children and adults. *Circulation* **92,** 3249-3254.

Daniels, S.R., Meyer, R.A., Liang, Y. and Bove, K.E. (1988) Echocardiographically determined left ventricular mass index in normal children, adolescents and young adults. *Journal of the American College of Cardiology* **12,** 703-8.

de Simone, G. Daniels, S.R., Devereux, R.B., Meyer, R.A., Roman, M.J., de Divitiis, O. and Alderman, M.H. (1992) Left ventricular mass and body size in normotensive children and adults: assessment of allometric relations and impact of overweight. *Journal of the American College of Cardiology* **20,** 1251-60.

Drinkard, B., McDuffie, J., McCann, S., Uwaifo, G.I., Nichlson, J. and Yanovsky, J.A. (2001) Relationships between walk/run performance and cardiorespiratory fitness in adolescents who are overweight. *Physical Therapy* **81,** 1889-1896.

Ekelund, U., Franks, P.W., Wareham, N.J. and Aman, J. (2004) Oxygen uptakes adjusted for body composition in normal-weight and obese adolescents. *Obesity Research* **12,** 513-520.

Forbes, G.B. (1977) Nutrition and growth. *Journal of Pediatrics* **91,** 40-42.

Forbes, G.B. and Welle, S.L. (1983) Lean body mass and obesity. *International Journal of Obesity* **7,** 99-107.

Friberg, P., Allansdotter-Johnsson, A., Ambring, A., Arheden, H., Feamme, J., Johansson, A., Holmgren, D., Wahlander, H. and Marild, S. (2004) Increased left ventricular mass in obese adolescents. *European Heart Journal* **25,** 987-992.

Gibbs, W.W. (2005) Obesity: an overblown epidemic? *Scientific American* **292,** 70-77.

Gidding, S.S., Nehgme, R. and Heise, C. (2004) Severe obesity associated with cardiovascular deconditioning, high prevalence of cardiovascular risk factors, diabetes mellitus/hyperinsulinemia,

and respiratory compromise. *Journal of* Pediatrics **144,** 766-769.

Giordano, U., Ciampalini, P. and Turchetta, A. (2003) Cardiovascular hemodynamics: relationships with insulin resistance in obese children. *Pediatric Cardiology* **24,** 548-552.

Goran, M., Fields, D.A., Hunter, G.R., Herd, S.L. and Weinsler, R.L. (2000) Total body fat does not influence maximal aerobic capacity. *International Journal of Obesity* **24,** 841-848.

Guo, S.S., Wu, W. and Chumlea, W.C. (2002) Predicting overweight and obesity in adulthood from body mass index values in childhood and adolescence. *American Journal of Clinical Nutrition* **288,** 1728-1732.

Gutin, B., Treiber, F., Owens, S. and Mensah, G.A. (1998) Relations of body composition to left ventricular geometry and function in children. *Journal of Pediatrics* **132,** 1023-1027.

Hambdy, R.C. (2003) Obesity: an epidemic. *Southern Medical Journal* **96,** 531-532.

Hill, D.J. and Milner, D.G. (1985) Insulin as a growth factor. *Pediatric Research* **19,** 879-886.

Humphries, M.C., Gutin, B., Barbeau, P., Vemulapalli, S., Allison, J. and Owens, S. (2002) Relations of adiposity and effects of training on the left ventricle in obese youths. *Medicine and Science in Sports and Exercise* **34,** 1428-1435.

Janz, K.F., Burns, T.L. and Mahoney, L.T. (1995) Predictors of left ventricular mass and resting blood pressure in children: the Muscatine Study. *Medicine and Science in Sports and Exercise* **27,** 818-825.

Koehler, B., Malecka-Tendera, E., Drzewiecka, B., Gaysior, Z., Eackerman-Ramos, A., Majer, K., Ladarew-Lach, I., Dobrowolska-Wieiak, B., Girczys, W., Lacheta, M. and Muchacka, M. (1997) Function of the cardiovascular system in children with simple obesity. Part II. Echocardiographic assessment. *Matera Medica Polonica* **70,** 131-133.

Kono, Y., Yoshinaga, M., Oku, S., Nomura, Y., Nakamura, M. and Aihoshi, S. (1994) Effect of obesity on echocardiographic parameters in children. *International Journal of Cardiology* **46,** 7-13.

Kortelainen, M.L. (1997) Adiposity, cardiac size and precursors of coronary atherosclerosis in 5 to 15-year old children: a retrospective study of 210 violent deaths. *International Journal of Obesity and Related Metabolic Disorders* **21,** 691-7.

Liatis, S., Tentolouris, N. and Katsilambros, K. (2004) Cardiac autonomic nervous system activity in obesity. *Pediatric Endocrinology Reviews* **1 (Suppl 3),** 476-483.

Licata, G., Scaglione, R., Paterna, S., Parrinello, G., Indovina, A., Dichiara, M.A., Alaimo, G. and Merlino, G. (1992) Left ventricular function response to exercise in normotensive obese subjects: influence of degree and duration of obesity. *International Journal of Cardiology* **37,** 223-230.

Loftin, M., Sothern, M., Trosclair, L., O'Hanlon, A., Miller, J. and Udall, J. (2001) Scaling VO_2 peak in obese and non-obese girls. *Obesity Research* **9,** 290-296.

MacMahon, S.W., Wilcken, D.E.L. and MacDonald, G.J. (1986) The effect of weight reduction on left ventricular mass. A randomized, controlled trial in young overweight hypertensive patients. *New England Journal of Medicine* **314,** 334-339.

Maffeis, C., Schena, F., Zaffanello, M., Zoccante, L., Schutz, Y. and Pinelli, L. (1994) Maximal aerobic power during running and cycling in obese and non-obese children. *Acta Paediatrica* **83,** 113-116.

Marinov, B. and Kostianev, S. (2003) Exercise performance and oxygen uptake efficiency slope in obese children performing standardized exercise. *Acta Physiologica Pharmacologica Bulgaria* **27,** 9-64.

Mehta S.K., Holliday, C., Hayduk, L., Wiersma, L., Richards, N. and Younoszai, A. (2004) Comparison of myocardial function in children with body mass indexes $\geq$25 versus those <25 kg/m^2. *American Journal of Cardiology* **93,** 1567-1569.

Mensah, G.A., Treiber, F.A. and Kapuku, G.K. (1999) Pattrns of body fat deposition in youth and their relation to left ventricular markers of adverse cardiovascular prognosis. *American Journal of Cardiology* **84,** 583-588.

Naylor, L., Watts, K. and Sharpe, J. (2006) Effect of resistance and circuit exercise training on left ventricular diastolic function in obese adolescents. [abstract] *Medicine and Science in Sports and Exercise* **38,** S414.

Nichola, M.W., Wold, L.E. and Colligan, P.B. (2000) Leptin attenuates cardiac contractions in rat ventricular myocytes: role of NO. *Hypertension* **36,** 501-505.

Olshansky, S.J., Passaro, D.J. and Hershow, R.C. (2005) A potential decline in life expectancy in the United States in the 21st century. *New England Journal of Medicine* **352,** 1138-1145.

Papavassiliou, D.P., Treiber, F.A., Strong, W.B., Malpass, D.G. and Davis, H. (1996) Anthropometric, demographic, and cardiovascular predictors of left ventricular mass in young children. *American Journal of Cardiology* **78,** 232-326.

Peterson, L.R., Herrero, P. and Schechtman, K.B. (2004) Effect of obesity and insulin resistance on myocardial substrate metabolism and efficiency in young women. *Circulation* **109,** 2191-2196.

Pflieger, K.L., Treiber, F.A., Davis, H., McCaffrey, F.M., Raunikai, R.A. and Strong, W.B. (1994) The effect of adiposity on children's left ventricular mass and geometry and haemodynamic responses to stress. *International Journal of Obesity* **18,** 117-122.

Rabbia, F., Silke, B., Conterno, A., Grosso, T., DeVito, B., Rabbone, J., Chiandussi, L. and Veglio, F. (2003) Assessment of cardiac autonomic modulation during adolescent obesity. *Obesity Research* **11,** 541-548.

Reisin, E., Frolich, E.D. and Messerli, F.H. (1983) Cardiovascular changes after weight loss in obesity hypertension. *Annals of Internal Medicine* **98,** 315-319.

Rowland, T. (1991) Effects of obesity on aerobic fitness in adolescent females. *American Journal of Diseases of Childhood* **145,** 764-768.

Rowland, T. (2005) Circulatory responses to exercise. Are we misreading Fick? *Chest* **127,** 1023-1030.

Rowland, T. and Dunbar, N.S. (2007) Effects of obesity on cardiac function in adolescent females. *American Journal of Lifestyle Medicine,* in press.

Rowland, T., Kline, G., Goff, D., Martell, L. and Ferrone, L. (1999) One-mile run performance and cardiovascular fitness in children. *Archives of Pediatric and Adolescent Medicine* **153,** 845-849.

Rowland, T., Potts, J, Potts. and Sandor, G. (1999) Cardiovascular responses to exercise in children and adolescents with myocardial dysfunction. *American Heart Journal* **137,** 126-133.

Sasson, Z., Rasooly, Y., Bhesania, T. and Rasooly, I. (1993) Insulin resistance is an important determinant of left ventricular mass in the obese. *Circulation* **88,** 1431-1436.

Tounian, P., Aggoun, Y. and Dubern, B. (2001) Presence of increased stiffness of the common carotid artery and endothelial dysfunction in severely obese children: a prospective study. *Lancet* **358,** 1400-1404.

Treuth M.S., Figueroa-Colon, R., Hunter, G.R., Weinsier, R.L., Butte, N.F. and Goran, M.I. (1998) Energy expenditure and physical fitness in overweight vs nonoverweight prepubertal girls. *International Journal of Obesity and Related Metabolic Disorders* **22,** 440-447.

Urbina,E.,.Gidding,S., Bao,W., Pickoff, A.S., Berdusis, K. and Berenson, G.S. (1995) Effect of body size, ponderosity, and blood pressure on left ventricular growth in children and young adults in the Bogalusa Heart Study. *Circulation* **91,** 2400-2406.

Whalley, G.A., Gamble, G.D. and Doughty R.N. (1997) Left ventricular mass correlates with fat-free mass but not fat mass in adults. *Journal of Hypertension* **17,** 569-74.

Wong, C.Y., O'Moore-Sullivan, T., Leano, R., Byrne, N., B, Eller, E. and Marwick, T.H. (2004) Alterations of left ventricular myocardial characteristics associated with obesity. *Circulation* **110,** 3081-3087.

Yoshinaga, M., Yuasa, Y., Hatano, H., Kono, Y., Nomura, Y., Oku, S., Nakamura, M., Kanekura, S., Otsubo, K., Akiba, S. and Miyata, K. (1995) Effect of total adipose weight and systemic hypertension on left ventricular mass in children. *American Journal of Cardiology* **76,** 785-787.

Weiss, R. Dziura, J. and Burgert, T.S. (2004) Obesity and the metabolic syndrome in children and adolescents. *New England Journal of Medicine* **350,** 2362-2374.

Key points

- Excessive body fat increases the work output of the heart.
- Longstanding increases in heart work result in abnormalities of heart function.
- Early findings of such changes can be observed in adolescents with severe obesity.

AUTHOR BIOGRAPHY

Thomas ROWLAND
Employment
Department of Pediatrics, Baystate Medical Center, Springfield, MA, USA
Degrees
B.S., M.D.
Research interests
Physiological responses to exercise in children, thermoregulation, cardiovascular factors in children.
E-mail: Thomas.rowland@bhs.org

✉ **Prof. Thomas Rowland**
Department of Pediatrics, Baystate Medical Center, Springfield, MA, USA