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ORIGINAL RESEARCH

Relationship Between Obesity and Global Longitudinal Strain in the Pediatric Single Ventricle Fontan Population Across Ventricular Morphologies

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BACKGROUND: Obesity is associated with diminished myocardial function as measured by strain echocardiography in children and young adults with normal cardiac anatomy. Data are lacking about the effect of obesity on myocardial strain in patients with a single ventricle. In this study, the relationship between body mass index (BMI) and single ventricle myocardial strain in the Fontan population was assessed.

METHODS AND RESULTS: Thirty-eight abnormal BMI Fontan cases (21 overweight and 17 obese) and 30 normal BMI Fontan controls matched based on single ventricular morphology, age, and sex were included in the study. Ventricular morphology was categorized as single right ventricle, single left ventricle, or biventricular. Single ventricle global longitudinal peak systolic strain (GLS) and other echocardiographic measurements were performed and compared between groups, with a $P \leq 0.05$ defined as significant. The abnormal BMI group demonstrated diminished GLS (–15.7±3.6% versus –17.2±3.2%, [P=0.03]) and elevated systolic blood pressure (P=0.04) compared with the normal BMI group. On subgroup analysis of those with single right ventricle morphology, the abnormal BMI group demonstrated diminished GLS compared with controls. There was no significant difference in GLS between the abnormal BMI and control groups in the single left ventricle and biventricular subgroups. Analyzed by ventricular morphology, no other variables were statistically different in the abnormal BMI group including systolic blood pressure. Inter-reader reproducibility for GLS and strain rate were excellent for both measures.

CONCLUSIONS: Obesity has an adverse relationship with myocardial strain in the young Fontan population, with the most maladaptive response seen in the single right ventricle.

Key Words: Fontan ■ global longitudinal strain ■ obesity ■ single ventricle

The Fontan procedure provides surgical palliation for children with single ventricle congenital heart disease; most of these children are now expected to survive into adulthood.[1] However, this single ventricular physiology leaves patients with diminished cardiac reserve and increased risk of morbidity and mortality for their entire life span. Understanding the risk factors that lead to poor prognosis is paramount to improving their long-term outcome. Obesity is one such risk factor common to adult Fontan survivors (33%–41% prevalence)[2,3] that can lead to decreased aerobic capacity (VO_2 max)[3] and increased heart failure/mortality in this population.[4] Over the past decade, a link between obesity and diminished cardiac function measured by echocardiographic strain analysis has been reported in other populations with normal cardiac anatomy,

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CLINICAL PERSPECTIVE

What Is New?

- Obesity is associated with diminished single ventricular (SV) global longitudinal peak systolic strain (GLS) in patients with young Fontan, with the strongest correlation seen in those with a single right ventricle.
- SV GLS has excellent inter-reader reproducibility in this cohort.

What Are the Clinical Implications?

- The relationship between obesity and cardiac dysfunction by SV GLS in youth with Fontan emphasizes the need to optimize body mass index through lifestyle interventions.
- As SV GLS has advantages over qualitative assessment in identifying early, subtle dysfunction and can be performed across ventricular morphologies, using GLS on SV clinical echocardiograms should be considered.

Nonstandard Abbreviations and Acronyms

GLS	global longitudinal peak systolic strain
r	Pearson correlation coefficient
SBP	systolic blood pressure
SV	single ventricle

including children and young adults.[5–7] This link may provide a mechanism through which obesity affects outcomes, but this link has not yet been evaluated in the single ventricle (SV) population.

Myocardial deformation assessed using 2-dimensional speckle tracking echocardiography is increasingly being used as a quantitative marker of ventricular function in the SV population. A study of infants with hypoplastic left heart syndrome using serial strain measurements reported that reduced strain values are predictive of poor outcomes, including cardiac death.[8] Similarly, strain predicted medium-term outcomes in a pre-Glenn population of patients with hypoplastic left heart syndrome even with normal right ventricular fractional area change (RVFAC).[9] In the post-Fontan period, echocardiographic strain parameters have also been shown to be predictive of transplant-free survival.[10] The relationship between obesity and ventricular function in the SV population represents a knowledge gap in the literature. The primary objective of this study is to evaluate the effect of obesity on myocardial strain values in children and young adults with SV following Fontan operation.

METHODS

Retrospective data collection and analysis were performed after institutional review board approval was obtained. Informed consent was not required because this is a retrospective analysis. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Study Participants

Between January 2013 and October 2020, 257 children and young adults post-Fontan (aged 6–25 years) received an echocardiogram at a single institution. After categorizing by body mass index (BMI), 51 overweight and obese Fontan patients were identified. Those with poor apical images on their echocardiogram(s) were excluded before attempting strain analysis, leaving 39 subjects for analysis in the abnormal BMI group. We aimed to find controls to best match the abnormal weight subjects based on ventricular morphology, age range (within 2 years), and sex. Based on the matching criteria, 30 SV Fontan controls with normal BMI from the 206 non-obese subjects were identified and included in the study. As per criteria set by the Centers for Disease Control and Prevention, BMI was categorized as normal (BMI 5th–85th percentile for age 6 to 19 years, and BMI between 18.5 and 24.9 kg/m^2 for >19 years), overweight (BMI 85th–95th percentile for age 6–19 years and BMI 25–29.9 kg/m^2 for age >19 years), or obese (BMI >95th percentile for ages 6–19 years or BMI >30 kg/m^2 for age >19 years).[11] Age-specific BMI percentiles were calculated using the Centers for Disease Control and Prevention's BMI Percentile Calculator for Child and Teen. Retrospective data collection and analysis were performed after institutional review board approval was obtained.

Echocardiogram

Transthoracic echocardiogram(s) were reviewed by a single observer (N.M.), and the most recent study with adequate apical images was analyzed. Studies had been performed on the Philips ultrasound system IE33," "Epic 7," or the GE "Vivid E95," using age- and weight-appropriate 2-dimensional transducers. Data were collected on ventricular morphology, ventricular function, atrioventricular valve regurgitation, semilunar valve regurgitation, and mean gradient across the aortic arch. Ventricular morphology was categorized into single right ventricle (RV), single left ventricle (LV), or biventricular type (Figure 1). Biventricular morphology was defined in those with both ventricles having significant myocardial mass communicating through a ventricular septal defect and both contributing to ejection (eg, unbalanced atrioventricular septal defect). As in other reports, qualitative ventricular function was graded as normal, mildly depressed,

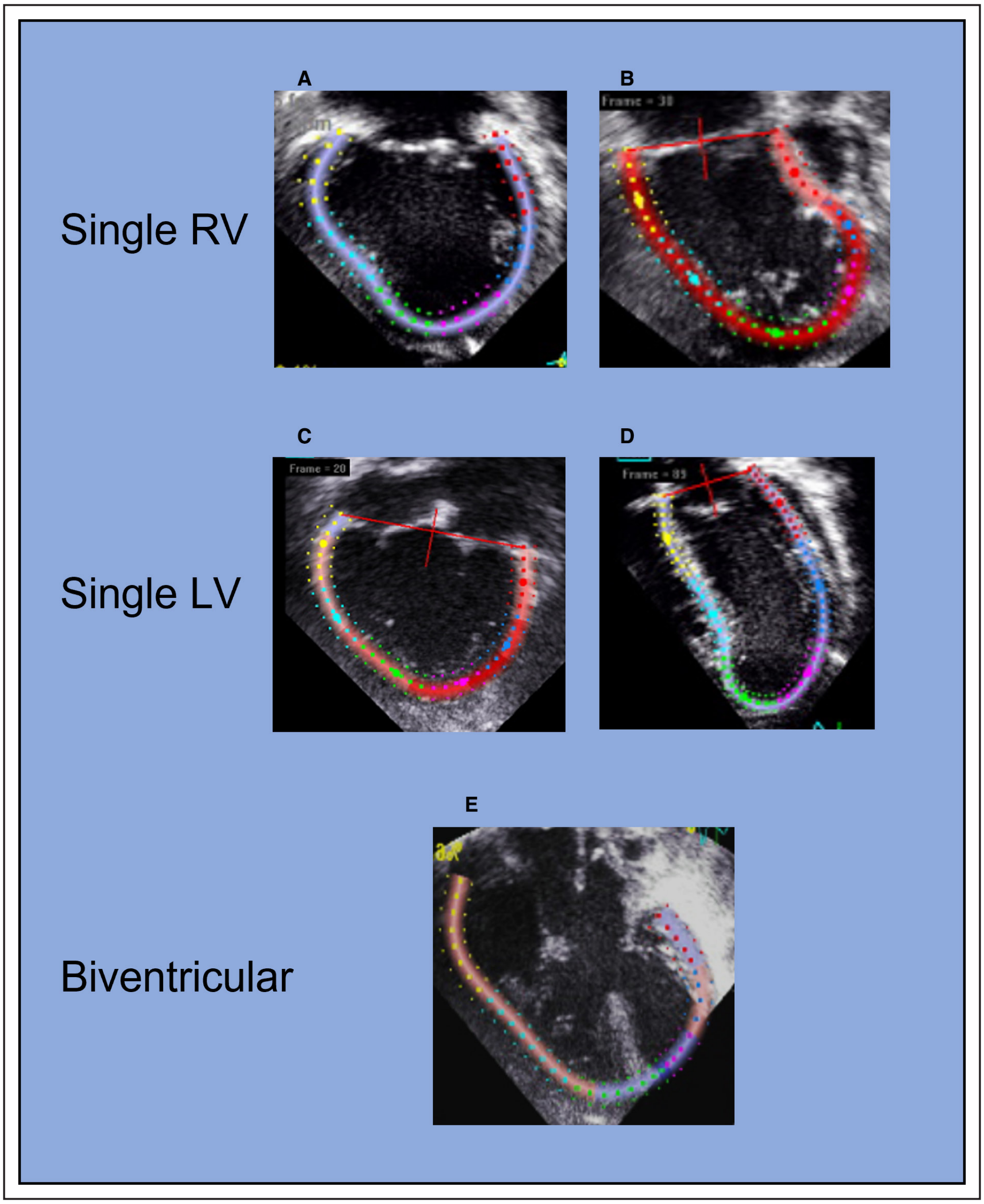

Figure 1. Ventricular morphology subtypes and corresponding strain tracking.
A, Single right ventricle morphology with no identifiable left ventricle and **B**, hypoplastic left ventricle with no ventricular septal defect and no outflow. **C**, Single left ventricle morphology with double inlet left ventricle and **D**, pulmonary atresia intact ventricular septum. **E**, Biventricular morphology with right dominant unbalanced atrioventricular canal defect. LV indicates left ventricle; and RV, right ventricle.

mild to moderately depressed, moderately depressed, moderate to severely depressed, or severely depressed.[12] In the single RV morphology group, right ventricular fractional area change (RVFAC), and in the single LV morphology group, left ventricular ejection fraction using the 5/6 area×length method, were assessed according to published guidelines.[13,14] Among the biventricular morphology group, quantitative assessment of ventricular function outside of strain analysis was not attempted given that no standard echocardiographic guidelines on how to perform them are reported in literature. Valvar regurgitation was qualitatively graded as none, mild, mild to moderate, moderate, moderate to severe, or severe. If 2 atrioventricular or semilunar valves were present, then the worst regurgitation of the 2 was recorded.

Strain Analysis

Two-dimensional echocardiogram images were converted to Digital Imaging and Communications in

Medicine format and imported into Tomtec Version 2.31 (Cardiac Performance Analysis Software, Siemens Medical Solutions, Mountain View, CA). The best single cardiac cycle from an apical 4-chamber image was identified. Using the Cardiac Performance Analysis Software, a single observer (N.M) traced the region of interest along the endocardial side of the myocardium at end systole (end of T wave on EKG). Tracings were drawn based on the ventricular morphology (Figure 1). The software automatically tracked the myocardium through the selected cardiac cycle. Tracking was then manually adjusted, if necessary, based on visual inspection. Similar methods have been published previously by other groups to evaluate single ventricular strain in a mixed morphology Fontan population.[15–18] As per European Association of Cardiovascular Imaging and American Society of Echocardiography task force recommendations, global longitudinal peak systolic strain (GLS) was calculated using the change in the length of the line method.[19] Strain analysis was repeated de novo on 15 randomly selected patients (9 cases, 6 controls) by a second observer (D.F.) blinded to the first analysis for inter-observer reproducibility.

Blood Pressure

Systolic and diastolic blood pressure (BP) was obtained in the right arm by trained medical care assistants on all patients before the echocardiogram using the oscillometric method on a calibrated machine with standard measurement practices and an appropriately sized cuff. BP was categorized into normal, elevated BP, stage 1 hypertension, or stage 2 hypertension per the current pediatric clinical practice guideline.[20] BP was analyzed as a categorical variable to account for variability across the different age groups and body sizes in the study.

Statistical Analysis

Statistical analysis was performed using SPSS for Windows version 26.0 (SPSS, Inc., Chicago, IL). Categorical data are presented as frequencies and percentages. Continuous data are presented as mean±SD. We used the 2-sided Welch *t* test to compare the means between continuous variables, Mann Whitney *U* test (Wilcoxon rank sum test) to compare the medians of the ordinal data (through providing ranking of values), and Fisher exact test to compare the binary data. Pearson correlation coefficient (*r*) and linear regression were used to assess the association between continuous variables. One way test of differences in mean (ANOVA) was used to test the relationship between continuous and ordinal variables. A *P* value ≤0.05 was considered to indicate statistically significant difference. Inter-reader reproducibility for strain was calculated in a random sample of 15 subjects using 2-way, mixed effects, consistency, single-rater intraclass correlation coefficient.

RESULTS

Patient Characteristics

The prevalence of overweight and obesity across all 257 Fontan subjects aged 6 to 25 years with an echocardiogram obtained during the study period was ~20% (51 of 257). Initially, 51 overweight and obese individuals were identified, and 12 of those were excluded before strain analysis secondary to suboptimal apical imaging. A single additional patient (1 of 39) was excluded secondary to poor strain tracking. Of the 38 total subjects included in the abnormal BMI group, 21 (55%) were overweight and 17 (45%) obese. Average BMI for the patients in the abnormal BMI group was 27 kg/m^2 compared with average BMI of 20 kg/m^2 in the normal BMI group. There were no significant differences in age, sex, diastolic BP, and ventricular morphology between the abnormal BMI group and the 30 matched normal BMI controls. Systolic blood pressure (SBP) class was higher in the abnormal BMI group, with 21% classified as stage 1 or 2 hypertension versus 7% in the normal BMI group (*P*=0.04). A higher percentage of patients in the abnormal BMI group were on diuretics (*P*=0.02). There were no differences between the 2 groups with respect to presence of protein-losing enteropathy, arrhythmias, plastic bronchitis, or use of digoxin or angiotensinconverting enzyme inhibitors (Table 1).

Echocardiography

GLS was the only echocardiographic parameter that was significantly different between the 2 groups (Table 2). GLS values were diminished in the abnormal BMI group versus the normal BMI group (−15.7±3.6% versus −17.2±3.2% respectively, *P*=0.03). Across the total cohort, BMI parameters showed a weak correlation with GLS (BMI-GLS: *r*=0.13, *P*=0.3; BMI percentile (BMI%]-GLS: *r*=0.22, *P*=0.12; and BMI *Z* score (BMI Z]-GLS: *r*=0.18, *P*=0.2). There was a weak association between GLS and SBP class (*F*=2.21, *P*=0.1). Mean arch gradient, strain rate, qualitative and quantitative SV function, atrioventricular valve regurgitation, and semilunar valve regurgitation were not statistically different between the 2 groups.

Ventricular Morphology Subanalysis

GLS was compared between normal and abnormal BMI groups within each ventricular morphology subgroup (Table 3). On subanalysis of the single RV group, GLS was significantly lower in the abnormal BMI group versus the normal BMI group (−13.7±3.5%

Table 1. Demographic and Clinical Characteristics

Characteristic	Normal BMI	Abnormal BMI (overweight/obese)	*P* value
n	30	38	
Age, y	16.9±2.8	15.5±4.4	0.1
Female	13 (44%)	18 (48%)	0.79
SBP Class			0.04
Normal	18 (60%)	15 (39.5%)	
Elevated	10 (33.3%)	15 (39.5%)	
Stage I hypertension	2 (6.7%)	5 (13.1%)	
Stage 2 hypertension	0 (0.0%)	3 (7.9%)	
DBP Class			0.58
Normal	27 (90%)	35 (92.1%)	
Elevated	3 (10%)	3 (7.9%)	
Stage 1 hypertension	0 (0.0%)	0 (0%)	
Stage 2 hypertension	0 (0.0%)	0 (0%)	
Ventricular morphology			0.75
Single RV	9 (30%)	11 (29%)	
Single LV	10 (33.3%)	13 (34.2%)	
BiV	11 (36.7%)	14 (36.8%)	
Clinical characteristics			
PLE	0 (0%)	1 (2.6%)	0.37
Arrhythmias	7 (23.3%)	9 (23.6%)	0.97
Plastic bronchitis	1 (3.3%)	0 (0%)	0.44
Diuretic use	1 (3.3%)	9 (23.6%)	0.02
ACEi use	19 (63.3%)	22 (57.8%)	0.17
Digoxin use	6 (20%)	(13%)	0.16

Continuous variables are expressed as mean±SD, and categorical variables as frequencies and percentages. ACEi indicates angiotensin-converting enzyme inhibitor; Biv, biventricular; BMI, body mass index; DBP, diastolic blood pressure; LV, left ventricle; PLE, protein losing enteropathy; RV, right ventricle; and SBP, systolic blood pressure.

versus −16.7±2.7% respectively, *P*=0.05). A moderate correlation was present between RV GLS and BMI%, and BMI Z using modeling (Table 4). Right ventricular fractional area change was feasible in 9 out of 11 (81%) patients in the abnormal BMI group and 8 out of 9 (88%) patients in the normal BMI group (0.28±0.08 versus 0.29±0.04, *P*=0.92). The biventricular subgroup, showed a tendency towards diminished GLS in the abnormal BMI group, although this did not reach statistical significance (−16.2±2.9% versus −18.0±2.2%, *P*=0.1). There was no significant correlation between GLS and BMI measures (Table 4) in the biventricular subgroup. The GLS values were similar in the LV morphology subgroup (−16.3±3.9% versus −17.0±3.8%), with no significant correlation between GLS and BMI measures (Table 4). Left ventricular ejection fraction was feasible in only 4 out 13 patients in the abnormal BMI group and 6 out 10 patients in the normal BMI group (55.4±6.8% versus 49.3±13.4%, *P*=0.32). GLS and BMI correlations based on ventricular morphology are also depicted in scatter plots (Figure 2). Differences in SBP were not significant between the normal and abnormal BMI groups when assessed within these subgroups (Table 3). GLS and SBP class did not show any statistically significant association in these subgroup analyses (RV subgroup: F=1.302 and P=0.3, LV subgroup F=0.184 and P=0.28 and biventricular subgroup; F=2.423 and P=0.11).

Reproducibility

GLS and strain rate measurements by 2 independent readers on 15 randomly chosen subjects (9 cases, 6 controls) demonstrated excellent inter-observer reproducibility with intraclass correlation coefficient of 0.95 for both measures (95% CI, 0.92–0.99, P<0.0005 for GLS and 95% CI, 0.87–0.99, P<0.0005 for strain rate).

DISCUSSION

To our knowledge, this is the first study evaluating the relationship between obesity and systolic ventricular strain values in children and young adults with SV following Fontan operation. This study has novel findings showing a negative effect of overweight and obesity on GLS across this sample of patients with SV. This adverse effect could be partly related to higher SBP (afterload) in those with higher BMI. Subgroup analysis by ventricular morphology (single LV, single RV, and biventricular) showed that the relationship between BMI and GLS seen across the total sample appears to be driven by the single RV subgroup.

Obesity in the SV Population

SV Fontan survivors are among the highest risk patient group on the congenital heart disease spectrum. In this population, growth failure secondary to low cardiac output, cyanosis, and heart failure are not infrequent; hence, SV Fontan survivors are inherently thought to be at lower risk for developing obesity compared with children with other forms of congenital heart disease. However, with improvements in care,[21,22] their functional status has improved. Concurrently, the prevalence of obesity is on the rise and similar to that found in this study.[2] Obesity in adult Fontan patients has also been shown to be associated with poor exercise capacity, increased risk of congestive heart failure, thromboembolic complications and Fontan failure resulting in death or transplantation.[3,4,23,24] Given this rise in obesity and its adverse effects on Fontan survivors, it is of paramount importance that physicians caring for these complex patients keep them and their families engaged with healthy nutrition practices.

Table 2. Echocardiographic Characteristics

Characteristic	Normal BMI	Abnormal BMI	*P* value
n	30	38	
GLS, %	−17.19±3.2	−15.67±3.56	0.03
Strain rate	0.76±0.15	0.71±0.19	0.23
Qualitative ventricular function			0.86
Normal	14 (46.7%)	21 (55.3%)	
Mildly depressed	14 (46.7%)	12 (31.6%)	
Mild–moderately depressed	1 (3.3%)	2 (5.3%)	
Moderately depressed	1 (3.3%)	3 (7.9%)	
Moderate–severely depressed	0 (0.0%)	0 (0.0%)	
Severely depressed	0 (0.0%)	0 (0.0%)	
Atrioventricular valve regurgitation			0.12
None	2 (6.7%)	6 (15.8%)	
Mild	18 (60%)	20 (52.6%)	
Mild–moderate	3 (10%)	6 (15.8%)	
Moderate	6 (20%)	4 (10.5%)	
Moderate–severe	1 (3.3%)	2 (5.3%)	
Severe	0 (0.0%)	0 (0.0%)	
Semilunar valve regurgitation			0.72
None	16 (53.3%)	23 (60.5%)	
Mild	12 (40%)	12 (31.6%)	
Mild–moderate	2 (6.7%)	3 (7.9%)	
Moderate	0 (0.0%)	0 (0.0%)	
Moderate–severe	0 (0.0%)	0 (0.0%)	
Severe	0 (0.0%)	0 (0.0%)	
Mean aortic arch gradient, mm Hg	5.5±3.4	5.5±3.4	0.99

Continuous variables are expressed as mean±SD, and categorical variables as frequencies and percentages. BMI indicates body mass index; and GLS, global longitudinal peak systolic strain.

Utility of Strain to Assess the Effect of Obesity on the Fontan Population

Adverse effects of obesity on cardiac function using strain analysis have been reported previously in children with normal cardiac anatomy.[5–7] Strain analysis has also been used across the spectrum of congenital heart disease for functional and dyssynchrony analysis[25–27] with a relationship between diminished strain and poor outcomes.[8–10] In the current study, the use of GLS detected a small but statistically significant decrease in single ventricular function in the overweight/obese group compared with the matched controls with normal BMI. The small decrease in GLS is similar to that seen in the studies of pediatric patients with normal cardiac anatomy.[5–7] Additional factors can affect GLS in the Fontan population (surgical complications, residual cardiac disease, and others) that may complicate the relationship between obesity and GLS. The Fontan population has an elevated lifelong morbidity and mortality, so even if elevated BMI represents a small negative effect on GLS during adolescence, it may be an important and reversible target of lifestyle interventions. While the abnormal BMI group had relatively similar clinical characteristics to the normal BMI group (Table 1), there was increased diuretic requirement in the abnormal BMI group, potentially reflecting subtle, early evidence of heart failure that may be related to the diminished cardiac function.

Qualitative SV function did not detect this between-group difference as noted by GLS, and it was not feasible to measure left ventricular ejection fraction and/or right ventricular fractional area change in many ventricles. Since this was a mixed morphology SV group, and GLS does not require geometric assumptions or uniform ventricular anatomy, GLS has an advantage over other quantitative measures of systolic function. This method of single ventricular strain analysis across ventricular morphologies has been reported previously,[15–17] and may be usefully integrated into clinical SV echocardiograms to detect changes in systolic function, including those from abnormal BMI that may impact clinical outcomes.

Strain and Obesity by Single Ventricular Morphologic Subgroups

Fontan circulation causes an abnormal hemodynamic load and resultant remodeling of the functional SV.

Table 3. Global Longitudinal Peak Systolic Strain and Systolic Blood Pressure Values by Ventricular Morphology Between Normal and Abnormal Body Mass Index Groups

Ventricular morphology	BMI class	n	GLS (%)	*P*	SBP class (IQR)	SBP class (mean rank)	*P* value
RV	Normal	9	−16.7±2.7	0.05	0–1	7.8	0.07
	Abnormal	11	−13.7±3.5		0–1	12.7	
Biventricular	Normal	11	−18±2.2	0.1	0–1	11.5	0.4
	Abnormal	14	−16.2±2.9		0–1	14.4	
LV	Normal	10	−17.0±3.8	0.66	0–1	11.25	0.65
	Abnormal	13	−16.3±3.9		0–1	12.6	

GLS data expressed as mean±SD. IQR indicates interquartile range; LV, left ventricle; and RV, right ventricle.

Table 4. Linear Regression Analysis for Global Longitudinal Peak Systolic Strain Against the Different Body Mass Index Parameters by Ventricular Morphology

Ventricular morphology	Independent variables	*r*	r^2	Unstandardized coefficient B	Standard error	95% CI	*P* value
RV	BMI	0.45	0.17	0.34	0.17	−0.03 to 0.71	0.07
	BMI%	0.59	0.36	0.07	0.02	0.01 to 0.12	0.01
	BMI Z	0.61	0.38	1.98	0.70	0.45 to 3.50	0.01
Biventricular	BMI	0.12	0.05	0.06	0.12	−1.8 to 0.3	0.59
	BMI%	0.19	0.07	0.09	0.02	−0.35 to 0.05	0.5
	BMI Z	0.17	0.03	0.14	0.56	−1.04 to 1.32	0.8
LV	BMI	0.35	0.1	0.1	0.03	−0.31 to 0.32	0.1
	BMI%	0.38	0.09	0.002	0.03	−0.07 to 0.7	0.95
	BMI Z	0.16	0.01	0.05	0.90	−2.07 to 1.96	0.95

BMI Z indicates BMI *Z* score; BMI%, BMI percentile; LV, left ventricle; *r*, Pearson correlation coefficient; r^2, square of the Pearson correlation coefficient; and RV, right ventricle.

Given the inherent myocardial architectural and geometric differences, it is reasonable to expect the single LV to adapt better as a systemic ventricle than the single RV or biventricular morphologies. Despite some conflicting reports, this expectation is consistent with multiple studies showing single RV morphology to be associated with increased risk of protein-losing enteropathy, heart failure, and death.[28,29] Additionally, in a recent Fontan study, the 25-year survival among single LV (75% survival) versus single RV (43% survival) versus biventricular morphology (69% survival) further suggested that the single RV subtype has the poorest outcomes.[30] When separating this current SV study population by ventricular morphology (single RV, single LV, and biventricular), a significant relationship between diminished GLS and elevated BMI was present only in the single RV group. The strength of correlation in this subgroup was moderate and was stronger than in the total study population. A prospective deformation study in infants with hypoplastic left heart syndrome demonstrated that the single RV typically adapts to function more like the LV during infancy,[31] suggesting that the native mechanics of the RV are inadequate for single ventricular physiology. Lack of this adaptation is associated with increased mechanical discoordination. It follows that the single RV may be more vulnerable to extracardiac stressors such as obesity, leading to decreased function. However, since the morphologic subgroups in this study are small and this analysis is likely underpowered, these results should be confirmed in a larger study.

Effect of Increased SBP (Afterload) on the SV

This study shows higher SBP class in the abnormal BMI group and a weak correlation between BMI class and SBP class. Being overweight/obese is expected to increase SBP and associated afterload on the SV. Since strain is a load-dependent parameter,[32] the relationship between BMI and adverse strain values may be partly explained through increased SBP. However, in the single RV subanalysis where there was a modest correlation between BMI class and GLS, the correlation between GLS and SBP class was not significant. Other factors outside of weight-related increased afterload may contribute to the RV dysfunction. Future studies should be designed to explore this possibility.

Feasibility and Reproducibility

In this retrospective study, 12 of 51 (24%) subjects with potentially abnormal BMI were excluded before analyzing strain, as their apical images were either poorly aligned (significantly foreshortened) or the imaging window was poor or absent. While a prospective imaging protocol that calls the sonographer's attention to the importance of optimizing the apical images for strain analysis may have improved this ratio, the SV population (especially as they age) will always have some with inadequate imaging windows given their abnormal BMI, cardiac lie, multiple sternotomies, and unusual anatomy. It is encouraging that of the 39 subjects with adequate apical imaging, strain was analyzable across ventricular morphologies in 38/39 (97%). The interobserver reproducibility on 15 randomly chosen studies was excellent for both GLS and strain rate and comparable with previously published pediatric studies in single and 2 ventricular anatomy populations.[33–35]

Study Limitations

With 68 total subjects, this is a medium-sized retrospective case–control study of Fontan patients who have survived into adolescence. Our results show diminished SV function by GLS in those with higher BMIs but do not establish a causal relationship between

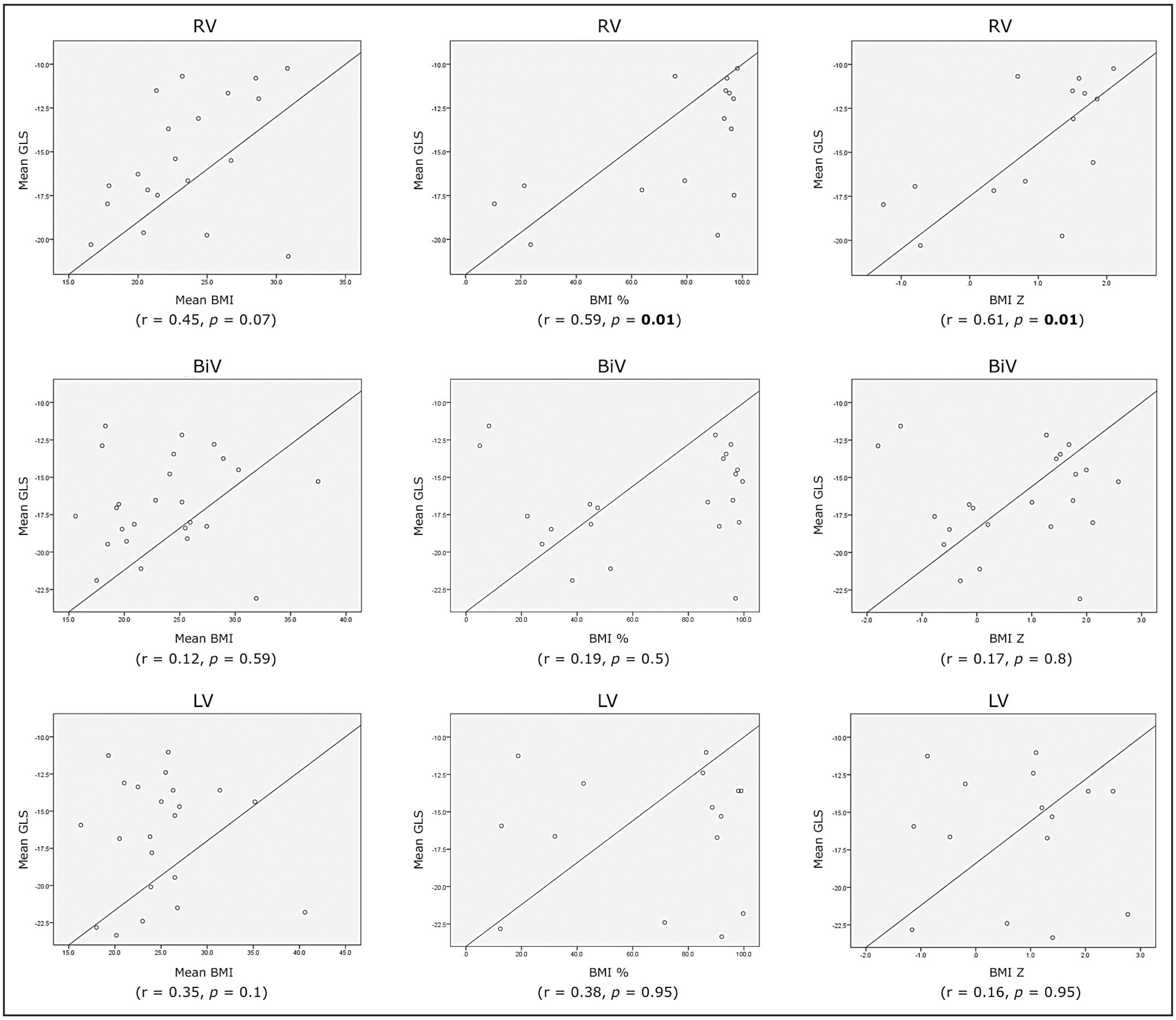

Figure 2. Scatter plots for correlations between global longitudinal peak systolic strain and body mass index parameters by ventricular morphology.

BiV indicates biventricular; BMI Z, BMI *Z* score; BMI%, BMI percentile; GLS, global longitudinal peak systolic strain; LV, left ventricle; *r*, Pearson correlation coefficient; and RV, right ventricle.

these 2 variables. The sample size limited the power, particularly for subgroup analyses. The oscillometric protocol for blood pressure may be viewed as a limitation, especially given that increase in BMI has been shown to be associated with higher BP values with automated readings when compared with manual readings.[36] But manual BP data were not collected at the time of echocardiogram. Given the retrospective nature of our study coupled with disadvantages of obesity when imaging this adolescent Fontan population, short axis ventricular imaging for circumferential strain was not feasible. Hence, circumferential strain assessments were not attempted for this study. A larger, longitudinal, and prospectively designed study with a sample size across each ventricular morphologic subgroup adequate to power multivariant regression analyses is necessary.

CONCLUSIONS

Obesity appears to have an adverse relationship with cardiac function as assessed by strain analysis in the young Fontan population, primarily impacting those with single RV morphology. This negative effect is apparent only when GLS is studied, as conventional echocardiographic parameters fail to identify this effect. Strain measures are reproducible in this Fontan population across ventricular morphologies in those with normal and abnormal BMI. Prospective longitudinal studies are required to assess the impact of diminished GLS on outcomes in obese Fontan patients.

ARTICLE INFORMATION

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