Pericardial Fat and Echocardiographic Measures of Cardiac Abnormalities

The Jackson Heart Study

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OBJECTIVE—Pericardial adipose tissue (PAT), a regional fat depot adjacent to the myocardium, may mediate the complex relation between obesity and cardiac left ventricular (LV) abnormalities. We sought to evaluate the association of PAT with echocardiographic measures of LV abnormalities in the Jackson Heart Study (JHS).

RESEARCH DESIGN AND METHODS—A total of 1,414 African Americans (35% men; mean age 58 years) from the JHS underwent computed tomographic assessment of PAT and abdominal visceral adipose tissue (VAT) from 2007 to 2009 and echocardiography examination between 2000 and 2004. Echocardiographic measures of left atrial (LA) internal diameter, LV mass, LV ejection fraction (LVEF), and E-wave velocity-to-A-wave velocity ratio (E/A ratio) were examined in relation to PAT, VAT, BMI, and waist circumference (WC).

RESULTS—All adiposity measures were positively correlated with LA diameter and LV mass and negatively correlated with E/A ratio ($P = 0.02$ to 0.0001) and were not with LVEF ($P = 0.36$–0.61). In women, per 1-SD increment of PAT, we observed association with higher LV mass (9.0 ± 1.7 gm, $P = 0.0001$) and LA diameter (1.0 ± 0.1 mm, $P = 0.0001$). However, the magnitude of the association between PAT and cardiac measures was similar compared with VAT ($P = 0.65$ [LV mass]; $P = 0.26$ [LA diameter]) and was smallercompared with BMI ($P = 0.002$ [LV mass]; $P = 0.01$ [LA diameter]) and WC ($P = 0.009$ [LA diameter]).

CONCLUSIONS—PAT is correlated with echocardiographic measures of cardiac LV abnormalities, but the association is not stronger than other adiposity measures.

Diabetes Care 34:341–346, 2011

Pericardial adipose tissue (PAT) is an active endocrine organ (1). Because of the close proximity of PAT to the underlying myocardium, it has been hypothesized that PAT may have a local deleterious effect on cardiac structure and function (2–4). Several clinical studies have indicated that PAT is associated with increased left ventricular (LV) mass (5), left atrial (LA) enlargement, impaired LV diastolic filling function (6), and lower cardiac index (7). However, small sample sizes, the use of echocardiography to estimate the thickness of pericardial fat instead of direct volumetric quantification, and the lack of adjustment of important covariates limit the interpretation of these prior studies. Recent data from the Framingham Heart Study (FHS), a large population-based cohort, suggested that pericardial fat volume is correlated with LV structure and function defined by cardiac magnetic resonance (8) but not more so than other measures of adiposity, including visceral adipose tissue (VAT). However, these results from the FHS are derived predominantly from a European American population and may not be generalizable to African American populations where obesity and LV hypertrophy are highly prevalent (9).

Thus, to better understand the impact of PAT on cardiac structure and function in African Americans, we examined the association of computed tomography (CT) measures of PAT with echocardiographic measures of LV structure and function in the Jackson Heart Study (JHS) cohort.

RESEARCH DESIGN AND METHODS

Study sample

The JHS recruited 5,301 African Americans from the Jackson, MS, metropolitan area between September 2000 and March 2004. The cohort was composed of four components: *1*) ~31% of the cohort members were participants from the Atherosclerosis Risk in Communities (ARIC) study recruited to the JHS; *2*) 30% were representative community volunteers who met census-derived age, sex, and socioeconomic status eligibility criteria from the Jackson, MS, metropolitan; *3*) 17% were randomly ascertained from Jackson, MS, through methods described previously (10); and *4*) 22% were in the JHS family study. The sampling frame for the family study was participants in any one of the ARIC, random, or volunteer samples whose family size met eligibility requirements as detailed previously (10). The cohort consisted of 5,035 adults aged 35–84 years old and an additional 266 participants (251 participants aged 21–34 and 15 participants aged >85) who were added as a part of the JHS family study. This resulted in a final age range of 21 to 94 years (10). The current study included participants who underwent multidetector CT scanning from 2007 to 2009 as a part of the second JHS examination (JHS Exam 2).

Overall, 4,200 participants attended the JHS Exam 2. Of these, 1,414 (35% men) underwent multidetector CT assessment for VAT and PAT. Of these 1,414

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Received 9 July 2010 and accepted 23 October 2010.
DOI: 10.2337/dc10-1312

participants, 1,402 had a complete covariate profile and the echocardiography measures. Thus the final sample size for analysis was 1,402. The study protocol was approved by the institutional review board of the participating institutions: the University of Mississippi Medical Center, Jackson State University, and Tugaloo College. All of the participants provided informed consent.

Multidetector CT scan protocol and data analysis

The continuous CT-imaging slices of cardiac/abdominal adipose tissue were undertaken by multidetector CT (GE Healthcare Lightspeed 16 Pro, Milwaukee, WI) at the Jackson Medical Mall and were analyzed at the CT reading center at Wake Forest University. The imaging slices consist of scout images, one electrocardiogram gated series of the entire heart that will be used for assessing PAT, and a series through the lower abdomen from L3 to S1 that were used for assessing VAT. The estimated average whole-body effective dose for the entire protocol was 4 mSv. Scanning procedure for cardiac-gated CT scans of the coronary arteries is based on the standard protocols developed as part of the National Heart, Lung, and Blood Institute (NHLBI) Multi-Ethnic Study of Atherosclerosis (MESA) and Coronary Artery Risk Development in Young Adults (CARDIA) studies (11). Nearly 44–60 continuous 2.5-mm motion-free imaging slices covering the entire heart were taken with standard CT-scanning protocol. Participants were excluded from the CT scan exam if: *1*) body weight was greater than 350 lbs (~160 kg), *2*) pregnant or pregnancy status was unknown, and *3*) female participant was <40 years of age or *4*) male participant was <35 years of age. When compared with participants who did not undergo CT scanning, those who did had lower BMI, waist circumference (WC), and LV mass; were less frequently diabetic and current smokers; and had a higher physical activity score. The Volume Analysis software tool (GE Healthcare, Waukesha, WI) was used to discern fat from the remainder of the heart with a threshold of −190 to −30 Hounsfield units. In this study, segmentation of PAT was achieved by isolating the PAT and heart from the thorax using specific anatomic landmarks. Pericardium was manually traced, and PAT was defined by any adipose tissue located in the pericardial sac (3,8,12). On a random selected sample of 60 participants, intrareader reproducibility was excellent for PAT (interclass correlation coefficient = 0.96) and for VAT (interclass correlation coefficient = 0.95).

Echocardiography assessment

Echocardiograms were performed during the baseline examination (2000–2004). All cardiac ultrasound examinations were undertaken with use of a commercially available ultrasound system (Sonos 4500, Hewlett Packard), which includes software for the acquisition of both standard ultrasound and Doppler myocardial imaging data. Standard echocardiography analyses included two-dimensional, M-mode, and Doppler flow measurement performed according to American Society of Echocardiography recommendations (13). All measurements were analyzed by experienced sonographers. LA internal diameter was measured at end-systole in the antero-posterior direction from the long-axis view. LV mass was calculated by anatomically validated Devereux's Eq (14). LV systolic function was described in terms of the LV ejection fraction (LVEF), which was calculated as percent change in LV internal diameters between systole and diastole (9,15). To estimate diastolic function, peak early E-wave and late A-wave velocities were measured from the transmitral pulsed Doppler scanning trace and ratio of peak early E-wave and late A-wave (E/A ratio) velocities were calculated.

Risk factors and covariate assessment

Risk factors were obtained from the baseline examination (2000–2004) (10). BMI was defined as weight (in kilograms) divided by the square of height (in meters). WC was measured at the level of the umbilicus; two measures of the waist were averaged to determine waist circumference for each participant. Sitting blood pressure was measured twice at 5-min intervals, and the average of two measurements was used for analysis. Estimated glomerular filtration rate (eGFR) was calculated based on serum creatinine values using the isotope dilution mass spectrometry–traceable 4-variable Modification of Diet in Renal Disease (MDRD). Study equation (GFR = 186 · [serum creatinine]$^{-1.154}$ · age$^{-0.203}$ · [0.742 if female] · [1.21 if African American]) (16). Subjects were considered to have hypertension if they were taking antihypertensive medications, self-reported a diagnosis of hypertension, and/or if their systolic pressure was ≥140 mmHg or diastolic pressure ≥90 mmHg. Diabetes was defined as a fasting plasma glucose level ≥126 mg/dL or treatment with insulin or hypoglycemic agent. Modified National Cholesterol Education Program Adult Treatment Panel III criteria were used to define the metabolic syndrome (17). Alcohol use was defined as consumption of alcoholic beverages within the past 12 months. Current smoking status was defined as smoking if the participant smoked at the time of the interview.

Statistical analysis

We observed a significant interaction between sex and PAT for LVEF ($P < 0.019$); therefore, the entire analyses were stratified by sex. Age-adjusted Pearson correlation coefficients were used to assess correlations between all adiposity measures and echocardiography measures of cardiac structures and functions, including LV mass, LA diameter, LVEF, and E/A ratio. All adiposity measures, including PAT, VAT, SAT, BMI, and WC, were first standardized to a mean of 0 and a standard deviation of 1, and then the tests for the significance of the differences among BMI, WC, VAT, and PAT regression coefficients were carried out within a multivariate standardized regression to estimate the relative importance of each adiposity in association with each of the echocardiography measures. Next, a multivariable regression model was constructed with either of PAT, VAT, BMI, or WC as the independent variable and echocardiography measures as dependent variables to assess the significance of covariate-adjusted cross-sectional relations between adiposity measures and echocardiography measures. Three models were considered: *1*) age, height, smoking, alcohol, systolic blood pressure, eGFR, hemoglobin, total physical activity score, and medications for ACE inhibitors, β-blockers, hypertension, diabetes, and dyslipidemia; *2*) model 1 plus additional adjustment for VAT; and *3*) model 1 plus additional adjustment for body weight. Because of the body weight adjustment, we did not index echocardiographic measures to body surface area. Models using BMI or WC as an independent variable did not further adjust for height or VAT due to collinearity. In addition, we also performed secondary analyses. First, we limited our analysis to participants with stable BMI from exam 1 to exam 2, which was defined as a difference between $BMI_{follow\text{-}up}$ and $BMI_{baseline}$ of

<5%. Second, we focused on participants without cardiovascular disease, including coronary heart disease, heart failure, or stroke, in order to assess whether the association was still maintained in the study during the period from exam 1 to exam 2. SAS version 9.2 was used to perform all computations (SAS Institute, Cary, NC).

RESULTS—Overall, 924 women and 477 men were available for analysis. The mean age of study sample was 59 years. Men had higher mean PAT volumes than women (79.8 ± 37.1 cm^3 vs. 67.1 ± 29 cm^3, $P = 0.0001$) as well as mean VAT volumes (850.4 ± 402.5 vs. 789.5 ± 363.0, $P = 0.002$) (Table 1).

Table 1—*Clinical characteristics of study participants who underwent assessment of pericardial fat volumes*

	Women	Men
Age (years)	60 ± 11	58 ± 11
Pericardial fat (cm^3)	67.1 ± 29.0	79.8 ± 37.1
Abdominal visceral fat (cm^3)	791.3 ± 363.3	858.5 ± 409.9
BMI (kg/m^2)	32.4 ± 7.0	29.4 ± 5.1
WC (cm)	99.2 ± 16.2	100.2 ± 12.9
Height (cm)	164.2 ± 6.4	178.1 ± 6.6
Left atrial diameter (mm)	35.2 ± 4.1	37.1 ± 3.9
Left ventricle mass (gm)	135.4 ± 40.1	160.8 ± 40.2
LV ejection fraction (%)	63.0 ± 8.8	60.3 ± 9.9
E/A ratio	1.1 ± 0.3	1.1 ± 0.3
Obesity (%)	58.5	45.9
Diabetes mellitus (%)	15.6	13.5
Metabolic syndrome (%)	41.7	33.2
Hypertension (%)	62.5	59.2
Current smoking (%)	7.9	12.3
Alcohol use (%)	37.2	60.1
Physical activity score	8.3 ± 2.5	8.9 ± 2.6

Data are means ± SD unless otherwise indicated.

Correlations between adiposity measures and echocardiography measures

Age-adjusted correlations of adiposity measures with echocardiography measures are shown in Table 2. In women, all adiposity measures were positively correlated with LA diameter and LV mass and negatively correlated with E/A ratio. Significant correlations were not observed with LVEF with the exception of WC. Similar findings were also observed in men, with the exception of LA diameter, which was not correlated with PAT.

Multivariable-adjusted regression models

In women, PAT was significantly associated with LV mass after multivariable adjustment ($P < 0.0001$; Table 3). The regression coefficient per 1-SD increase in PAT for LV mass was 9.0 gm (Model 1, $P < 0.0001$). However, this regression coefficient was not different in magnitude as compared with VAT (9.1 gm, $P = 0.65$ for β-comparison) or WC (10.3 gm, $P = 0.65$ for β-comparison) but was smaller than that of BMI (10.6 gm, $P = 0.002$ for difference between PAT and BMI). The association of PAT with LV mass persisted but was attenuated after additional adjustment for VAT (4.5 gm, $P = 0.05$) or for body weight (4.1 gm, $P = 0.03$). Similar patterns of the association were also observed in men (Table 3), but the association of PAT with LV mass was not significant after additional adjustment for body weight.

PAT was associated with LA diameter in women after multivariable adjustment, but the regression coefficient per 1-SD increment of PAT (1.04 mm) was smaller as compared with BMI (1.34 mm, $P = 0.001$ for difference) or WC (1.34 mm, $P = 0.009$ for difference). The association of PAT with LA diameter remained significant after additional adjustment for VAT (0.8 mm, $P = 0.0003$) and for body weight (0.4 mm, $P = 0.03$). Among men, the association between PAT and LA diameter did not persist after additional adjustment for VAT or body weight.

We observed E/A ratio values significantly associated with per 1-SD increase in VAT, BMI, and WC but not in PAT in women. However, there were no differences in the regression coefficients among those of PAT, VAT, BMI, and WC (all $P > 0.05$). In addition, no associations were observed upon additional adjustment for VAT or body weight. In men, no significant association was found between PAT and E/A ratio except for BMI ($P = 0.04$).

In secondary analyses limited to participants with stable BMI or in participants without the presence of cardiovascular disease, the above associations between PAT and echocardiographic measures were maintained (data not shown).

CONCLUSIONS

Principal findings

In this substudy from the JHS cohort of 1,414 participants undergoing CT and echocardiography examinations, volumetric measures of PAT were correlated positively with LV mass and LA diameter and negatively correlated with E/A ratio, particularly in women. The significant association persisted with LV mass and LA diameter when additionally adjusting for VAT or body weight. There was no association observed between PAT and LVEF. However, the magnitude of the association of PAT with measures of LV

Table 2—*Age-adjusted Pearson correlation coefficients between the adiposity and echo measures*

	LV mass	*P*	LA diameter	*P*	LVEF	*P*	E/A ratio	*P*
Women								
PAT (cm^3)	0.21	0.0001	0.30	0.0001	−0.04	0.36	−0.12	0.003
VAT (cm^3)	0.23	0.0001	0.28	0.0001	−0.05	0.24	−0.10	0.019
BMI (kg/m^2)	0.31	0.0001	0.44	0.0001	−0.08	0.058	−0.15	0.0002
WC (cm)	0.30	0.0001	0.43	0.0001	−0.10	0.021	−0.18	0.0001
Men								
PAT (cm^3)	0.24	0.0001	0.11	0.065	0.03	0.61	−0.12	0.044
VAT (cm^3)	0.22	0.0003	0.11	0.07	0.01	0.84	−0.13	0.0278
BMI (kg/m^2)	0.37	0.0001	0.32	0.0001	0.05	0.36	−0.15	0.0089
WC (cm)	0.34	0.0001	0.27	0.0001	−0.01	0.87	−0.15	0.0094

Table 3—*A MV# adjusted regression coefficients between the adiposity (per 1 SD) and echocardiography measures*

	Women					Men				
Model	MV# adjusted	*P*	MV# adjusted + VAT	*P*	MV# adjusted + body weight	MV# adjusted	*P*	MV# adjusted + VAT	*P*	MV# adjusted + body weight	*P*
LV mass (gm)											
PAT (cm^3)	9.0 ± 1.7	0.0001	4.5 ± 2.3	0.05	4.1 ± 1.8	0.03	5.5 ± 1.9	0.006	4.7 ± 2.8	0.09	2.8 ± 2.1	0.17
VAT (cm^3)‡	9.1 ± 1.6	0.0001	—	—	3.6 ± 1.8	0.05	4.5 ± 1.9	0.03	—	—	1.4 ± 2.1	0.52
BMI (kg/m^2)†	10.6 ± 1.4	0.0001	8.8 ± 1.6	0.0001			12.8 ± 2.8	0.0001	11.8 ± 3.1	0.0002	—	—
WC (cm)‡	10.3 ± 1.4	0.0001	—	—	3.1 ± 2.5	0.23	10.5 ± 2.6	0.0001	—	—	3.1 ± 4.7	0.51
LA diameter (mm)												
PAT (cm^3)	1.0 ± 0.1	0.0001	0.8 ± 0.2	0.0003	0.4 ± 0.2	0.03	0.5 ± 0.2	0.007	0.4 ± 0.3	0.17	0.3 ± 0.2	0.17
VAT (cm^3)‡	0.8 ± 0.2	0.0001	—	—	−0.04 ± 0.2	0.81	0.5 ± 0.2	0.01	—	—	0.2 ± 0.2	0.31
BMI (kg/m^2)†	1.3 ± 0.1	0.0001	1.3 ± 0.2	0.0001	—	—	1.2 ± 0.2	0.0001	1.1 ± 0.3	0.0006	—	—
WC (cm)‡	1.3 ± 0.1	0.0001	—	—	0.6 ± 0.3	0.02	1.0 ± 0.3	0.0003	—	—	−0.2 ± 0.5	0.66
LVEF												
PAT (cm^3)	−0.4 ± 0.4	0.32	−0.6 ± 0.5	0.25	−0.3 ± 0.4	0.51	0.5 ± 0.5	0.37	0.1 ± 0.8	0. 88	0.2 ± 0.6	0.72
VAT (cm^3)‡	−0.1 ± 0.4	0.85	—	—	0.1 ± 0.4	0.74	0.7 ± 0.6	0.25	—	—	0.4 ± 0.6	0.57
BMI (kg/m^2)†	−0.3 ± 0.3	0.44	−0.3 ± 0.4	0.45	—	—	1.2 ± 0.8	0.14	1.0 ± 0.9	0.26	—	—
WC (cm)‡	−0.3 ± 0.3	0.38	—	—	−0.1 ± 0.6	0.87	0.9 ± 0.8	0.27	—	—	−0.5 ± 1.4	0.72
E/A ratio												
PAT (cm^3)	−0.02 ± 0.01	0.09	−0.00 ± 0.01	0.88	−0.01 ± 0.02	0.41	−0.02 ± 0.01	0.23	0.00 ± 0.02	0.83	−0.00 ± 0.02	0.64
VAT (cm^3)‡	−0.03 ± 0.01	0.03	—	—	−0.02 ± 0.01	0.19	−0.03 ± 0.01	0.06	—	—	−0.02 ± 0.02	0.22
BMI (kg/m^2)†	−0.03 ± 0.01	0.01	−0.02 ± 0.01	0.15	—	—	−0.05 ± 0.02	0.04	−0.04 ± 0.02	0.15	—	—
WC (cm)‡	−0.03 ± 0.01	0.006	—	—	−0.03 ± 0.02	0.15	−0.04 ± 0.02	0.11	—	—	−0.00 ± 0.04	0.92

Data are regression coefficients ± SE. #MV, multivariable-adjusted for age, height, smoking, alcohol, systolic blood pressure, eGFR, hemoglobin, total physical activity score, and medications for ACE inhibitors, β-blockers, hypertension, diabetes mellitus, and dyslipidemia. †Not adjusted for height and body weight because collinearity. ‡Not adjusted for VAT or WC because collinearity.

structure and function was not stronger than other adiposity measures examined including VAT, BMI, and WC. Taken together, these results do not support a special role for PAT in association with echocardiographic measures of cardiac structure and function.

In the context of the current literature

Anatomically, PAT is divided into two layers: epicardial and paracardial fat layers. The epicardial fat layer is mainly located around major coronary arteries in the interventricular and atrioventricular grooves, with lesser amounts located around atria and right ventricles; the paracardial fat layer is situated external to the parietal layer of the pericardium within the mediastinum and has alternatively been termed mediastinal fat (12). Generally, PAT is defined as epicardial plus paracardial adipose tissue located in pericardial sac (3,4,8). As a small part of VAT, direct anatomic contact between PAT and the myocardium may impact LV structure and function via mechanical compression. Such fat depots around the heart may mechanically compress the cardiac atria and ventricles, decreasing LV compliance and affecting LV diastolic properties, consequently inducing LV hypertrophy (5,8,18), atrial enlargement, and impaired LV diastolic filling (6–8).

In addition, PAT and the underlying cardiac myocardium share the same coronary blood supply without a separate fascia between the adipose tissue and myocardial layers. Thus the cardiac myocardium receives a dual direct supply of free fatty acid or inflammatory cytokines, including monocyte chemoattractant protein-1, interleukin (IL)-1β, IL-6, tumor necrosis factor-α, leptin, and others, from pericardial fat and circulation, which may alter myocardial energy metabolism (1,7,19–21). Atrial enlargement, diastolic dysfunction, and LV hypertrophy are common findings in morbidly obese individuals (22).

However, the pathogenic mechanisms of a local or paracrine role for PAT as compared with the predominant systemic effects of overall obesity on cardiac structure and function are not completely understood. Overall obesity is associated with higher pressure in the right side of heart, increased cardiac output, and LV volume and flow (22,23), which can lead to LV diastolic dysfunction and impairment of LV systolic function. Weight loss has been shown to

improve the cardiac performance in morbidly obese patients by improving cardiac output, LV mass, and systolic and diastolic function (24). These alternations may be due to hemodynamic changes predominantly resulting from the increased blood volume and flow required to adequately perfuse increased body mass. Given the broadly similar associations of PAT, VAT, WC, and BMI with measures of cardiac structure and function—observed primarily in our larger female subgroup—our findings support the notion that the local effects of PAT are not stronger than generalized adiposity in association with cardiac structure and function abnormality.

Implications

African Americans have been found to have greater LV mass and higher prevalence of LV hypertrophy (LVH) compared with European Americans (9,25), and PAT is hypothesized to be a potential risk factor for cardiac structure and function abnormalities because of its close anatomic contact to the underlying myocardium (5–7). In the current study, we demonstrate a significant association of PAT with LV mass and LA diameter. Nevertheless, we note that PAT is no more correlated with LV mass and LA diameter than other adiposity measures. Therefore, our results suggest that the possible mechanical and paracrine effects of PAT may not be more pronounced for measures of cardiac structure and function than the systemic effects of obesity.

Strengths and limitations

Strengths of this study include a large sample size from the population-based JHS cohort, a contemporaneous and highly reproducible volumetric quantification of PAT and VAT, and adjustment for multiple potential confounders. Limitations include *1*) the cross-sectional study design, which limits our ability to infer causality; *2*) the potential misclassification of PAT due to combined measurement of pericardial and epicardial fat inherent in our methodology; *3*) lack of tissue Doppler measures of diastolic function and low availability of deceleration time and isovolumic relaxation time in the echocardiography measures; and *4*) the potential misclassification of risk factors that exists due to the time gap between the clinical echocardiography measures and CT measures of PAT and VAT. However, the results from the secondary analyses indicate that the associations between PAT and cardiac structure and function are still maintained in this study during the time period from exam 1 to exam 2. Thus we do not expect that this time gap should impact the relative association of PAT compared with other adiposity measures with cardiac structure and function in this study.

PAT is associated with higher levels of LV mass and LA diameter, but the association is not stronger than other adiposity measures, including VAT, BMI, and WC.

Acknowledgments—The JHS is supported by the National Heart, Lung, and Blood Institute (NHLBI) and the National Center on Minority Health and Health Disparities (NCMHD). Funding for H.A.T. was provided under contracts N01-HC-95170, N01-HC-95171, and N01-C-95172 from the NHLBI and the NCMHD.

No potential conflicts of interest relevant to this article were reported.

J.L. had full access to all of the data in the study and takes responsibility for integrity of the data and accuracy of the data analysis. Study concept and design: J.L., H.A.T., and C.S.F. Acquisition of data: J.L. Analysis and interpretation of data: J.L., C.S.F., D.A.H., and H.A.T. Drafting of the article: J.L., C.S.F., and H.A.T. Critical revisions of the article for important intellectual content: H.A.T., J.L., C.S.F., W.L.M., J.D., and J.J.C. Statistical analysis: J.L. Obtained funding: H.A.T.

We thank the staff, interns, and participants in the JHS for their long-term commitment and important contributions to the study.

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