Is There an Association Between Clinical Presentation and the Location and Extent of Myocardial Involvement of Cardiac Sarcoidosis as Assessed by 18F- Fluorodeoxyglucose Positron Emission Tomography?

McArdle et al: PET and Clinical Presentation in Cardiac Sarcoid

Brian A. McArdle, MB BCh*; David H. Birnie, MD§; Ran Klein, PhD*; Rob A. de Kemp, PhD*; Eugene Leung, MDΦ; Jennifer Renaud, MSc*; Jean DaSilva, PhD*; George A. Wells, PhD†; Rob S. Beanlands, MD*; Pablo B. Nery, MD§

§Arrhythmia Service, †Cardiac Research and Methods Center and the *National Cardiac PET Centre, Division of Cardiology, Department of Medicine, University of Ottawa Heart Institute, Division of Nuclear Medicine, Department of Medicine, The Ottawa Hospital and University of Ottawa, Ottawa, Ontario

Correspondence to
Pablo Nery, MD
Division of Cardiology
University of Ottawa Heart Institute
40 Ruskin Street, Ottawa, Ontario, K1Y 4W7
Email: pnery@ottawaheart.ca
Telephone: +16137614948
Fax: +16137614407

DOI: 10.1161/CIRCIMAGING.112.000289

Journal Subject Codes: Diagnostic testing:[32] Nuclear cardiology and PET, Diagnostic testing:[106] Electrophysiology
Abstract

Background—Positron Emission Tomography (PET) using $^{18}$F-Fluorodeoxyglucose (FDG) is an emerging modality for diagnosis of cardiac sarcoidosis (CS). We compared the location and degree of FDG uptake in CS patients presenting with either advanced atrio-ventricular block (AVB) or ventricular tachycardia (VT).

Methods and Results—We included consecutive patients who presented with either AVB or VT with a diagnosis of CS. A cohort of patients with clinically silent CS was included as controls. FDG activity was quantified as Standardized Uptake Values (SUV) and both the overall mean LV SUV as well as the Maximum Mean Segmental SUV was recorded for each patient. ROC analysis was performed to identify cutoff SUV values that best identified patients with VT.

A total of 27 patients with CS were included (13 females, Mean Age; 56 +/- 8 years, 8 VT, 12 AVB and 7 controls). Both mean LV SUV and Max SUV in CS patients presenting with VT were significantly higher compared with those with AVB (Mean SUV; VT Median 5.33, Range 4.7-9.35 vs. AVB Median 2.48, Range 0.86-8.59, p=0.016, Max SUV; VT Median 11.07, Range 9.24-14.4 vs. AVB Median 5.63, Range 3.42-15.71, p=0.005) and compared to controls. There was no significant difference in SUV values between AVB patients and controls. ROC analysis for identification of patients with VT, showed AUC’s of 0.93 and 0.895 for a Mean LV SUV of >3.42, and a Max SUV >8.56 respectively (p<0.001).

Conclusions—CS patients with VT displayed significantly higher FDG uptake when compared to those with AVB and asymptomatic controls. Further prospective studies are required to evaluate this finding.

Key Words: cardiac sarcoidosis, cardiac positron emission tomography, fluorodeoxyglucose


Abbreviations

FDG: $^{18}$F-Fluorodeoxyglucose

PET: Positron Emission Tomography

CS: Cardiac Sarcoidosis

AVB: Atrio-ventricular Block

VT: Ventricular Tachycardia

JMHW: Japanese Ministry of Health and Welfare

ROI: Region of Interest

SUV: Standardized Uptake Value

SRS: Summed Rest Score

ROC: Receiver Operator Characteristic

AUC: Area Under the Curve.
There is a broad spectrum of clinical sequelae associated with cardiac sarcoidosis (CS), a condition which accounts for 13-25% of deaths associated with sarcoidosis as a whole, but continues to present a significant diagnostic challenge. The current clinical standard for diagnosis of CS is the Japanese Ministry of health and Welfare (JMHW) Criteria, last updated in 2006 (See Figure 1), which incorporate histological findings with abnormalities on ECG and ambulatory monitoring as well as multiple imaging modalities such as Echocardiography, MRI, and nuclear imaging with Gallium, Technetium and Thallium.

Positron Emission Tomography (PET) using $^{18}$F-Fluorodeoxyglucose (FDG) in conjunction with a perfusion tracer is an imaging approach that can quantify areas of inflammation and scar secondary to CS. The majority of studies using PET have used visual image interpretation with a finding of “focal” or “focal on diffuse” uptake interpreted as diagnostic of CS. However this approach is reliant on qualitative interpretation of uptake. More recently quantitative analysis using Standardized Uptake Values (SUV’s) for FDG within the myocardium have been utilized and shown to be a sensitive means to ascertain disease activity, with higher SUV values indicating greater degrees of active inflammation.

However, the association between varying patterns and severity of FDG uptake and the clinical presentation of the patient has not yet been characterized. This has potential to improve understanding of the pathophysiological processes that result in the spectrum of clinical findings and outcomes associated with CS and may enhance the role of PET as a non-invasive means of identifying patients at higher risk of serious adverse cardiac events who may have greater benefit from ICD insertion and/or aggressive immunosuppression.

In this study we compare the extent and location of abnormalities on FDG and rest perfusion PET in patients with CS presenting with either advanced atrio-ventricular block (AVB) or
ventricular tachycardia (VT) as well as a control group of patients with clinically silent CS, i.e. extra-cardiac sarcoidosis with clinical and imaging evidence of cardiac involvement without AVB, VT, or heart failure.

Methods

Patient Population and Controls: We analyzed the records of all patients who underwent PET scanning for evaluation for possible CS at our institution from September 2007 to October 2012 from our CADRE registry data. This is a database of all patients undergoing Cardiac FDG PET in Ontario, the majority of whom were for assessment of myocardial viability in the setting of coronary artery disease, and has ethics approval from the Human Research Ethics Boards of participating centers.

We included all patients presenting with AVB or VT with diagnosed CS based on modified JMHW criteria who underwent PET scanning in this study. The original JMHW criteria include a positive Gallium scan as a major criterion but, due to its limited sensitivity, this is no longer performed at our institution. Therefore, similar to two previous studies, focal FDG uptake was used as an alternative imaging criterion. We also included rest perfusion defects on Rb-82 or 13-N-Ammonia PET as a minor criterion as an alternative to perfusion defect on Technetium or Thallium SPECT (Figure 1). Patients with significant CAD (defined as stenosis >70% in an epicardial vessel or a history of previous myocardial infarction, previous reversible perfusion defect on prior stress perfusion imaging or revascularization), or patients where there was another more plausible explanation for their cardiac condition (i.e. valve dysfunction or congenital heart disease) were excluded. In order to focus on the uptake patterns of patients with these primary presenting findings (i.e. AVB and VT) patients with heart failure or longstanding
idiopathic cardiomyopathy (>5 yrs) without VT or AVB were also excluded. The inclusion and exclusion processes are outlined in Figure 2. Patients were then grouped according to their clinical presentation in to those with either AVB or sustained VT. AVB was defined as either second or third degree AV block or trifascicular block documented on 12-lead ECG, Holter or telemetry monitoring. Patients that had a history of sustained VT documented on Holter or ECG were included in the VT cohort, irrespective of concomitant AVB.

As controls, we included a cohort of patients with biopsy proven extra-cardiac sarcoidosis and evidence of cardiac involvement on non-invasive testing and/or advanced imaging but without a history of AVB, VT, or heart failure. Again, patients with known or strongly suspected obstructive CAD or significant ongoing valve disease were excluded.

Results of all imaging studies for included patients were collected, including echocardiography, nuclear perfusion imaging, and MRI as well as ECG, and histology results. Where there was ambiguity over the diagnosis of CS or the clinical categorization of CS patients, the case was reviewed by two cardiologists (PN &DB) in conjunction with a Nuclear Medicine physician (EL) and a consensus was reached.

Imaging Protocol: All patients were instructed to adhere to a high-fat, low carbohydrate diet on the day before, and fast for a minimum of 12 hours prior to scanning. Serum glucose was measured prior to scanning, as a baseline for comparison in cases where follow-up scanning may be performed. Low dose intravenous heparin was administered to patients in whom there was no contra-indication, to increase serum free fatty acids and further suppress background myocardial glucose uptake.
Patients were positioned in the 64-slice PET/CT scanner (either Discovery RX or Discovery 690 PET/VCT; GE Healthcare, Waukesha, WI) and initially underwent rest ECG-gated perfusion scanning following the administration of either Rubidium-82 (10 MBq/kg) or $^{13}$N-Ammonia (5 MBq/kg). A low-dose CT scan was performed for attenuation correction. Following this 5 MBq/kg $^{18}$F-FDG was administered IV. Following an uptake phase of 60 minutes, a whole body scan was performed with a CT scan from the femoral region to the head for attenuation correction. This was followed by a dedicated cardiac scan from which the myocardial SUV values were measured.

Perfusion and FDG images were reconstructed in standard transaxial plane orientation and proper alignment of PET and CT data was assessed and corrected visually. Images were manually reoriented to standard short-axis, horizontal-long axis, and vertical long axis views and using the standard ASNC 17 segment model of the LV. Perfusion within each segment was scored visually and a total Summed Rest Score (SRS) was calculated. FDG uptake was also assessed visually within each segment and the uptake pattern was recorded as either: normal, metabolism-perfusion matched defect consistent with scar, or metabolism-perfusion mismatch defect consistent with inflammation with or without scarring. The number of abnormal segments (i.e. that were found to have either: abnormal perfusion, abnormal FDG uptake, or both) was recorded for each patient. Furthermore visual analysis was used to identify the presence or absence of RV uptake on transaxial images for all patients. Ejection fraction was estimated from gated images.

Next the FDG/CT co-registered images were analyzed visually in three orientations using hybrid imaging software and regions of interest (ROI) were used to identify the maximum activity...
within the LV and this was adjusted for decay corrected injected activity and patient weight to calculate the Max SUV (g/ml) for the LV, and this was recorded for each patient.

FDG uptake within the myocardium was also quantified using FlowQuant© automated software (Ottawa, ON)\(^1\)\(^5\), which calculated mean SUV values within each of the 17 segments. Briefly, each image volume was automatically reoriented to standard left ventricle short-axis orientation and a constrained spline model was fit to generate the LV polar map regions of interest. The resulting polar map was segmented using the ASNC 17 segment model. The mean activity in each segment was adjusted for decay corrected injected activity and patient weight to calculate a mean segmental SUV\(^1\)\(^6\)(See Figure 3). Mean overall LV SUV was calculated by averaging uptake within the 17 segments and this was recorded for each patient.

The location of the segment with the maximal mean segmental SUV value was also recorded for each patient.

In addition we determined the co-efficient of variation of SUV values for each patient, which was calculated by dividing the standard deviation of segmental SUV values by the mean overall SUV value. This parameter is an indicator of the heterogeneity of FDG uptake in the myocardium, which is expected to be higher in CS, and has been recently shown by Tahara et al to be an accurate quantitative means of identifying disease activity in patients with CS\(^8\).

**Statistical Analysis:** Mean values with 95% Confidence Intervals for baseline clinical characteristics were calculated for each patient presentation group and compared using a two-tailed t-test for Independent Samples. Nonparametric methods were used for comparing; Mean LV SUV, Max LV SUV, rest EF, summed rest score (SRS), COV, and Septal/Lateral wall SUV ratio. In particular, the Kruskal-Wallis one-way analysis of variance was used to compare all three groups simultaneously (AVB vs VT vs clinically silent CS patients), and pair wise
comparisons were conducted using the Wilcoxon rank-sum test. For the pair wise comparisons, significance was determined by comparing the p-value to the Bonferroni corrected p-value of 0.0166 to correct for multiple comparisons.

The relationship between SUV values and the number of abnormal LV segments on visual analysis as well as LVEF was evaluated using Spearman’s rank correlation coefficient for non-normally distributed data.

The diagnostic performance for predicting patients with VT, of both the Mean Overall LV SUV and the Max SUV was analyzed using receiver operator characteristic (ROC) curves, displaying sensitivity and specificity at different cutoff values. Analysis was performed using MedCalc (MedCalc Software Inc., Mariakerke, Belgium) statistical software.

Results

Baseline Demographics: A total of 134 patients underwent FDG-PET scanning at our institution between September 2007 and September 2012 with the indication of evaluation for Cardiac Sarcoidosis. Of these, 90 patients were excluded, as they had no positive histological or imaging evidence of sarcoidosis.

Of the remaining 44 patients, there were 26 patients that met modified JMHW criteria for diagnosis of CS, of whom 12 had advanced AVB, while 8 had documented sustained VT. Five patients had a history of cardiomyopathy without documented AVB or VT and therefore were not included while one patient with AVB was excluded due to the finding of obstructive CAD on angiography. Six of the twenty patients in our final CS cohort were included in a prior meta-analysis of the diagnostic accuracy of FDG-PET in CS.
There were a further 18 patients with abnormal PET results. Of these, 7 patients had a histological diagnosis of extra-cardiac sarcoidosis without a history of VT, AVB, or heart failure and the control cohort was comprised of these patients.

The remaining 11 patients (4 AVB, 3 VT, 4 asymptomatic) had insufficient evidence for a diagnosis of CS and were therefore excluded. The inclusion and exclusion processes are outlined in Figure 2.

The baseline characteristics of the 27 included patients are summarized in Table 1 while their clinical criteria for diagnosis of CS are outlined in Table 2.

Overall, 10/12 AVB patients and 5/8 VT patients underwent PET scanning within 1 month of first clinical presentation. The remaining 5 patients had a prior diagnosis of CS (2 AVB, 3 VT), and underwent scanning >2 years after initial presentation to assess disease activity.

All of these patients had ICD’s in-situ at the time of scanning with device interrogation revealing no sustained VT in the AVB patients. Two of the three VT patients with secondary prevention ICD’s had received an appropriate shock from their ICD within 1 year of PET scan while the other had documented runs of non-sustained VT.

Half of the included patients were female with no significant difference in age between groups. In total 5 patients underwent cardiac biopsy, of which 4 were positive. Among the AVB and VT patients, the diagnosis of CS was made based on modified JMHW with positive cardiac biopsy (n=4) or with positive systemic biopsy (n= 10). There were 6 patients who had a clinical diagnosis of systemic sarcoidosis based on findings on chest CT who met modified JMHW criteria.

**FDG PET Results:** On visual analysis alone 27/28 patients showed evidence of “focal” or “focal on diffuse” uptake of FDG within the myocardium suggestive of active CS while 1 AVB patient
with a long standing diagnosis of CS had equivocal FDG uptake with resting perfusion defects on visual analysis. Semi-quantitative segmental analysis showed a trend towards more abnormal segments in VT patients (Mean 8.62+/−3.85 VT vs. 5.58+/−2.5 AVB vs. 4.7+/−1.8 Clinically silent CS patients) that was not statistically significant (p=0.076). There were no significant differences between VT or AVB patients in the number of segments with either; normal perfusion/focal FDG, abnormal perfusion/focal FDG, or abnormal perfusion/no FDG (See Table 1). However there were no patients with segments showing abnormal perfusion in the clinically silent CS group. Furthermore there was a significant negative correlation between the number of abnormal segments and LVEF (Spearman’s coefficient -0.61, p=0.0005).

Analysis of the whole body scan showed extra-cardiac uptake in 58% of VT/AVB patients and 72% of controls, primarily in the lungs and hilar lymph nodes.

LV SUV data: On quantitative analysis both Mean Overall LV SUV and the Maximum Mean Segmental SUV were significantly higher in patients in the VT cohort compared to those with AVB (Mean SUV; VT Median 5.33, Range 4.7-9.35 vs. AVB Median 2.48, Range 0.86-8.59, p=0.016, Max SUV; VT Median 11.07, Range 9.24-14.4 vs. AVB Median 5.63, Range 3.42-15.71,p=0.005, See Figure 4). ROC analysis showed AUC’s of 0.93 and 0.895 for a Mean LV SUV of >3.42, and a Max SUV >8.56 respectively for identification of patients with VT (p<0.001, See Figure 5) with sensitivity of 100% and specificities of 90% and 79% respectively.

Both Mean Overall SUV and Max SUV were also significantly higher in the VT cohort when compared to clinically silent CS patients (p<0.016). However there was no significant difference in either parameter between AVB patients and clinically silent CS patients (See Figure 4).

Segmental Evaluation, Regional Heterogeneity, RV uptake: Evaluation of the distribution of FDG uptake showed that uptake was highest in the basal segments in all patient groups.
Furthermore the ratio of mean septal to mean lateral wall SUV was higher in AVB and VT patients when compared to controls (1.24 +/-0.5 vs. 1.42+/-0.64 vs. 0.84+/-.05 for AVB, VT, and clinically silent CS patients respectively, p=0.04). However, this difference was no longer significant on pairwise analysis when the Bonferroni corrected p-value cutoff of 0.0166 was applied.

Maximum SUV was found in the basal septum in 7/11 AVB patients with no clear pattern in VT patients. In the clinically silent control cohort, Maximum SUV was found in the lateral wall in 6/7 patients (See Table 3). However focal FDG uptake was seen in either the septum or anterior walls in all clinically silent patients but was of lesser intensity than the lateral wall in all but 1 patient.

The COV was significantly higher in AVB and VT patients when compared to clinically silent CS patients on ANOVA testing (p=0.0269). On pair wise analysis COV was significantly higher in both AVB and VT patients when compared to clinically silent CS patients (See Figure 4).

However there was no significant difference in COV between AVB and VT patients (0.34 +/-0.13 vs. 0.35+/-0.16, P=0.9) indicating a similar degree of heterogeneity of FDG uptake between these two cohorts (Figure 4).

There was a significant correlation between Mean Overall LV SUV and the number of abnormal segments on visual analysis (Spearman’s coefficient= 0.506, p=0.006) as well as a negative correlation with resting LVEF (Spearman’s coefficient= -0.42, p=0.024).

On visual analysis RV uptake of FDG was present in 5/12 of AVB and 4/8 of VT patients. It was not observed in any of the clinically silent CS patients. There was no significant difference in mean or max mean segmental SUV’s, LVEF, or number of abnormal segments between patients
with or without RV uptake within the AVB or VT patient cohorts although the numbers for comparison were small.

Resting perfusion: Abnormalities (SRS >2) were seen in 7/8 VT patients, 8/12 AVB patients, and none of the clinically silent CS patients. The majority of patients had undergone coronary angiography within 3 months of PET scanning while others had normal cardiac enzymes and no symptoms of chest pain. Mean SRS was higher in VT patients than those with AVB but this difference was not statistically significant (VT Median 7, Range 0-15 vs. AVB Median 3.5, Range 0-9, P=0.13). There was a significantly greater SRS in CS patients with VT and AVB compared to the clinically silent CS patients (p=0.0037, See Figure 4).

LV Function: Mean EF as measured on gated rest PET perfusion scanning was lower in the VT patients compared to those with AVB (VT Median 33%, Range 15-56 vs. AVB Median 51%, Range 18-71, P=0.082) and was significantly lower than clinically silent CS patients (p=0.0026). Mean EF was lower in AVB patients when compared to clinically silent CS patients but the difference was not significant when corrected for multiple comparisons (p=0.017) (See Figure 4).

Other Imaging Results: There were 12/27 patient who underwent cardiac MR scanning and of these 7 showed foci of late gadolinium enhancement suggestive of CS. MRI scanning was negative in 1 patient with AVB and 4 clinically silent CS patients (See Table 2).

Discussion

In this study we performed quantitative analysis of the uptake of FDG within the LV in patients with cardiac sarcoidosis using a semi-automated method, and related the Mean Overall SUV and Maximum Mean Segmental SUV values to the patient’s clinical presentation. While preliminary in nature, the results show that patients with episodes of sustained VT had significantly higher
FDG uptake when compared to patients presenting with AVB and to a cohort of patients with clinically silent CS.

Studies reporting correlations between abnormalities on imaging and clinical presentation in CS patients, particularly using FDG PET, are extremely limited and quantitative analysis of SUV values has not previously been utilized for this purpose. Banba et al performed Gallium scanning in 15 CS patients presenting with either AVB or VT. Interestingly, abnormal Gallium uptake was documented in 80% of AVB patients but only 14% of the VT cohort. Similar to our results EF was lower and there was a high prevalence of perfusion abnormalities in the VT cohort. The authors therefore concluded that active inflammation was not closely associated with the development of VT. This is in contrast to our results. In our study two patients presenting with VT had normal LV function and normal/mildly abnormal rest perfusion. Our data suggests that active inflammation does play a role in the development of VT and that FDG may be a sensitive means of quantifying disease activity.

In preliminary findings published in abstract form, Chung et al visually analyzed Rb-82/FDG PET scans of 55 patients meeting JMHW criteria for CS and found that 83% of patients who demonstrated scar or inflammation in >/=2 basal or mid segments had VT. In this study we found no significant difference in the number of segments showing inflammation or scar between the three patient groups although there was a trend towards more abnormal segments in the VT cohort.

Quantitative analysis of SUV’s has been used in several studies involving patients with suspected CS although not specifically to identify which patients may have AVB vs. VT. As described above Tahara et al also measured SUV’s in a 17 segment model of the LV and determined the Coefficient of Variation (COV). In this cohort we found that this parameter did
not differ significantly between patients with AVB or VT but the COV for clinically silent CS patients was significantly lower than for patients with either AVB or VT. Therefore the COV does not appear to correlate with clinical presentation amongst CS patients with either VT or AVB.

ACC/AHA/HRS guidelines give a Class IIa recommendation for ICD insertion for primary prevention in CS patients (Level of evidence C)\textsuperscript{19} but there is wide variation in clinical practice in this regard at present \textsuperscript{20,21}. Moreover, European guidelines for pacing recommend pacemaker insertion for patients with AVB secondary to CS\textsuperscript{22}. The decision regarding ICD insertion is hampered by limited tools for patient risk stratification and a lack of knowledge regarding the true prevalence of ventricular arrhythmia in this population. Programmed Ventricular Stimulation has been shown to have some utility in this regard\textsuperscript{23-25} but there are limited studies in this area and the long-term prognostic significance of a normal study remains unclear.

As the use of advanced imaging with FDG-PET and MRI in patients with sarcoidosis becomes more widespread, a significant increase in the numbers of patients diagnosed with cardiac involvement at an early stage is being seen. Although currently unproven, it is likely that CS patients with either VT, AVB, or patients with clinically silent disease do not have the same prognosis, and therefore treatment strategies will differ between groups. Therefore methods to non-invasively identify patients at higher risk of potential arrhythmia would be of significant value. The results of this study are preliminary in nature, and therefore the hypothesis that there is a relationship between the extent and severity of cardiac involvement by sarcoidosis, as assessed on FDG PET, and the risk of significant arrhythmia requires further evaluation.

LVEF was lower in the VT cohort and scar extent as quantified by SRS was also higher. These differences did not reach statistical significance when compared to AVB patients, most likely
due to low patient numbers. However it is noteworthy that all clinically silent CS patient had normal resting perfusion and there was a significant correlation between mean LV SUV and LVEF and the number of abnormal segments, suggesting that scar formation may also play a significant role in the development of arrhythmia in addition to active inflammation. However larger studies with clinical and imaging follow up to evaluate events and changes over time would be required to confirm this hypothesis.

There was no significant difference in SUV values between patients presenting with AVB and clinically silent CS patients. However the pattern of involvement appeared different in the two groups with maximal uptake localizing to the basal septum in the majority of AVB patients, and while there was focal uptake of FDG in the septum or anterior segments in all clinically silent patients, the basal lateral wall was the site of maximal uptake in 72% of these patients. This observation suggests that acute inflammation within the basal septum may predispose to the development of AVB while lateral wall involvement may be more likely to be subclinical in nature.

There are several limitations to the current study. Firstly the number of patients is small but due to the low incidence of this condition this is a common limitation of studies involving CS patients. Going forward collaborative multi-center studies are required to prospectively evaluate the hypotheses generated by this study.

The JMHW criteria, although modified in this study to include FDG PET as a criterion, may be a relatively insensitive gold standard for CS, particularly in cases of asymptomatic patients with normal LV function, or in cases of isolated cardiac involvement, where a positive endomyocardial biopsy is required to confirm the diagnosis, which is difficult to achieve in patients with limited focal disease. Our control cohort included patients who did not fully meet
the Japanese criteria but had biopsy proven extra-cardiac sarcoidosis with evidence of cardiac involvement on PET +/-MRI. Clinically it was felt that all of these patients had CS and several were commenced on steroid treatment on this basis.

Only a minority of patients underwent cardiac MRI scanning and the majority of these were suggestive of CS. There is very limited data comparing the FDG PET and MRI in CS but previous MRI studies have shown a high sensitivity and specificity of MRI when compared to JMHW criteria. In this study 4 clinically silent CS patients and 1 AVB patient had negative MRI scans, which is higher than that observed in other studies, and may be a reflection of the low specificity of the JMHW criteria, FDG PET or both in asymptomatic patients.

From our registry there were 11 patients with a positive FDG PET who had insufficient evidence for a diagnosis of CS to be included in the analysis. While several of these patients subsequently received alternative diagnoses, it is possible that some may have CS and thus there is a possible selection bias affecting these results.

We did not assess the reproducibility of SUV values within normal subjects but this has been previously evaluated. Inglese et al evaluated a series of 49 oncology patients who underwent baseline and follow-up FDG PET scanning for cancer surveillance. They found no significant difference in maximum myocardial SUV between baseline and follow-up although they did note regional heterogeneity in uptake between scans. A further series of 47 cancer patients undergoing serial PET scanning again showed little variation in myocardial FDG uptake, although this series used visual analysis of uptake.

Sarcoidosis is a dynamic process and the interval between clinical presentation with AVB or VT and PET scanning was variable. This is a preliminary hypothesis generating study and therefore potential changes in FDG uptake on serial scanning as well as the impact of immunosuppressive
therapies were not evaluated. Ascertaining the true prognostic value of the degree and pattern of abnormalities on FDG PET scanning will require further prospective studies with long-term follow-up.

Conclusions

In this observational series, patients with Cardiac Sarcoidosis presenting with Ventricular Tachycardia showed significantly higher FDG SUV values when compared to those presenting with advanced AVB or to clinically silent CS patients. Furthermore maximal FDG uptake localized to the basal septum in the majority of patients presenting with advanced AVB. Both perfusion defect size (as measured by Summed Rest Score), and LVEF (as measured on gated PET), was lower in VT patients but did not reach statistical significance. These results suggest that there may be a relationship between the degree of FDG uptake and clinical presentation, particularly ventricular tachyarrhythmia. However larger prospective studies with longitudinal follow up and repeat scanning are required to further investigate this finding and determine if the degree of FDG uptake could potentially provide prognostic data on subsequent risk for arrhythmia.

Acknowledgments

B.M. was supervised by R.B. and P.N in this project. The authors express their gratitude to the Sarcoid registry and National Cardiac PET Centre teams including Joanne Brennan RN, Judy Etele RN, Linda Garrard RN, Karen MacDonald RN, and Ann Guo BEng, as well as the May Aung CNMT, Kym Gardner CNMT, Monique Pacquette RN and Patricia Grant RN.
Sources of Funding

This project is supported in part by the Cardiac Care Network of Ontario Working Group for Cardiac PET in collaboration with the PET Steering Committee of Ontario. This work has also been partially supported by IMAGE-HF (Imaging Modalities to Assist with Guiding Therapy and the Evaluation of Patients with Heart Failure) (Canadian Institute of Health Research team grant # CIF 99470).

Disclosures

RB is a career investigator supported by the Heart and Stroke Foundation of Ontario and Tier 1 Research Chair supported by the University of Ottawa. B.M. is supported in part by the Molecular Function and Imaging Heart and Stroke Foundation of Ontario Program Grant (#PRG6242) and The University of Ottawa Heart Institute’s Whit & Heather Tucker Endowed Research Fellowship in Cardiology Award. RSB and RdK are consultants with Jubilant DRAXImage and have received grant funding from a government/industry program (partners: GE Healthcare, Nordion, Lantheus Medical Imaging, DRAXImage). RdK and RK receive revenues from a Rubidium-82 generator technology licensed to Jubilant DRAXImage, and from sales of FlowQuant. RSB is a consultant for Lantheus Medical Imaging.

References


of nuclear cardiology: official publication of the American Society of Nuclear Cardiology. 2010;17:600-616.


**Table 1.** Baseline characteristics of patients with included in the primary analysis categorized by clinical presentation. * Denotes p-value from one-way ANOVA (Kruskal Wallis Test) indicating differences between groups

<table>
<thead>
<tr>
<th>Patient Characteristics</th>
<th>Atrioventricular-Block (n=12)</th>
<th>Ventricular Tachycardia (n=8)</th>
<th>Controls (n=7)</th>
<th>P-Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Age</td>
<td>57 (+/- 7.1)</td>
<td>55 (+/- 11.4)</td>
<td>&gt;3 (+/- 10.2)</td>
<td>P=0.81</td>
</tr>
<tr>
<td>Females (%)</td>
<td>6 (50)</td>
<td>4 (50)</td>
<td>3 (43)</td>
<td></td>
</tr>
<tr>
<td>Known Extra-Cardiac Sarcoidosis prior to PET scan (%)</td>
<td>3 (25)</td>
<td>5 (63)</td>
<td>4 (100)</td>
<td></td>
</tr>
<tr>
<td>Cardiac Biopsy Performed (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Positive (%)</td>
<td>2 (18)</td>
<td>3 (38)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>- Negative (%)</td>
<td>0</td>
<td>3 (38)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Extra-Cardiac Biopsy Performed (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Positive (%)</td>
<td>4 (33)</td>
<td>5 (63)</td>
<td>7 (100)</td>
<td></td>
</tr>
<tr>
<td>Steroids at time of PET (%)</td>
<td>1 (9)</td>
<td>2 (25)</td>
<td>3 (43)</td>
<td></td>
</tr>
<tr>
<td>Cardiac MRI Performed (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Positive (%)</td>
<td>4 (33)</td>
<td>4 (50)</td>
<td>5 (71)</td>
<td></td>
</tr>
<tr>
<td>ICD at baseline (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prior Appropriate Shock (%)</td>
<td>0</td>
<td>4 (50)</td>
<td>1 (12)</td>
<td></td>
</tr>
<tr>
<td>Extra-Cardiac FDG- PET Report Positive (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac FDG- PET Report Positive (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Denotes p-value from one-way ANOVA (Kruskal Wallis Test) indicating differences between groups.
<table>
<thead>
<tr>
<th></th>
<th>Mean Number of Overall Abnormal LV Segments</th>
<th>Focal FDG /Normal Perfusion</th>
<th>Focal FDG /Abnormal Perfusion</th>
<th>Abnormal Perfusion/ No FDG</th>
<th>Visual RV FDG Uptake (%)</th>
<th>Mean Summed Rest Score</th>
<th>Mean Ejection Fraction (Gated-PET)</th>
<th>Mean Overall LV SUV</th>
<th>Max LV SUV</th>
<th>Co-efficient of Variation</th>
<th>Mean Septal/ Mean Lateral SUV Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.58 (+/-2.5)</td>
<td>8.62 (+/-3.85)</td>
<td>4.7 (+/-1.8)</td>
<td>P=0.076</td>
<td>5 (41)</td>
<td>4 (50)</td>
<td>0</td>
<td>5.58 (+/-1.94)</td>
<td>6.11 (+/-1.82)</td>
<td>2.81 (+/-3.7)</td>
<td>6.81 (+/-3.7)</td>
</tr>
<tr>
<td></td>
<td>3.16 (+/-1.46)</td>
<td>4.12 (+/-2.9)</td>
<td>4.7 (+/-1.8)</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>3.34 (+/-1.13)</td>
<td>11.76 (+/-2.04)</td>
<td>4.51 (+/-1.08)</td>
<td>4.12 (+/-2.9)</td>
</tr>
<tr>
<td></td>
<td>1.33 (+/-1.07)</td>
<td>2.75 (+/-1.98)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>1.35 (+/-1.16)</td>
<td>5.75 (+/-2.78)</td>
<td>0.75 (+/-1.08)</td>
<td>1.75 (+/-2.12)</td>
</tr>
<tr>
<td></td>
<td>1.5 (+/-1.08)</td>
<td>1.75 (+/-2.12)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.34 (+/-0.13)</td>
<td>0.35 (+/-0.16)</td>
<td>0.19 (+/-0.06)</td>
<td>0.84 (+/-0.05)</td>
</tr>
</tbody>
</table>

P-values: P=0.0037, P=0.0034, P=0.0019, P=0.0051, P=0.0269, P=0.0473.
Table 2. Clinical information of all included CS patients according to their clinical presentation

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Age</th>
<th>Gender</th>
<th>ECG/HOLTER Findings</th>
<th>PET Ejection Fraction</th>
<th>JMHW ECHO Criteria</th>
<th>JMHW MRI Criteria</th>
<th>CT Thorax Criteria</th>
<th>Biopsy Results &amp; Site</th>
<th>Summed Rest Score</th>
<th>Major JMHW Criteria</th>
<th>Minor JMHW Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVB</td>
<td>60</td>
<td>F</td>
<td>Complete AVB, RBBB, LAD</td>
<td>71%</td>
<td>Absent</td>
<td>Not Done</td>
<td>Positive</td>
<td>Positive</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AVB</td>
<td>48</td>
<td>M</td>
<td>Complete AVB</td>
<td>58%</td>
<td>Absent</td>
<td>Positive</td>
<td>Positive</td>
<td>Positive</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AVB</td>
<td>58</td>
<td>M</td>
<td>2nd Degree AVB, RBB, LAD</td>
<td>53%</td>
<td>Absent</td>
<td>Not Done</td>
<td>Positive</td>
<td>Positive Lung</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AVB</td>
<td>57</td>
<td>F</td>
<td>Complete AVB, LAD</td>
<td>47%</td>
<td>Absent</td>
<td>Positive</td>
<td>Positive</td>
<td>Not Done</td>
<td>7</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>AVB</td>
<td>54</td>
<td>F</td>
<td>Complete AVB</td>
<td>62%</td>
<td>Present</td>
<td>Positive</td>
<td>Positive</td>
<td>Positive Lung</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>AVB</td>
<td>56</td>
<td>M</td>
<td>Complete AVB, RBB, LAD</td>
<td>43%</td>
<td>Absent</td>
<td>Not Done</td>
<td>Positive</td>
<td>Negative Lung</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AVB</td>
<td>61</td>
<td>F</td>
<td>Complete AVB, RBB, LAD</td>
<td>39%</td>
<td>Present</td>
<td>Not Done</td>
<td>Positive</td>
<td>Not Done</td>
<td>7</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AVB</td>
<td>53</td>
<td>M</td>
<td>Complete AVB, RBB, LAD</td>
<td>50%</td>
<td>Absent</td>
<td>Not Done</td>
<td>Positive</td>
<td>Not Done</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AVB</td>
<td>65</td>
<td>F</td>
<td>Complete AVB</td>
<td>60%</td>
<td>Absent</td>
<td>Not Done</td>
<td>Positive</td>
<td>Not Done</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>AVB</td>
<td>57</td>
<td>F</td>
<td>Complete AVB, LAD</td>
<td>55%</td>
<td>Absent</td>
<td>Absent</td>
<td>Positive</td>
<td>Not Done</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>AVB</td>
<td>73</td>
<td>M</td>
<td>PACED (Complete AVB)</td>
<td>21%</td>
<td>Present</td>
<td>Not Done</td>
<td>Positive</td>
<td>Positive Lymph Node</td>
<td>9</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>AVB</td>
<td>44</td>
<td>M</td>
<td>1st Deg AVB, LAD, RBB, NSVT</td>
<td>18%</td>
<td>Present</td>
<td>Not Done</td>
<td>Positive</td>
<td>Positive Liver</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>VT</td>
<td>45</td>
<td>F</td>
<td>VT, RBBB, LAD</td>
<td>45%</td>
<td>Present</td>
<td>Positive</td>
<td>Negative</td>
<td>Positive Cardiac</td>
<td>9</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>VT</td>
<td>50</td>
<td>M</td>
<td>VT, Frequent PVC’s</td>
<td>34%</td>
<td>Present</td>
<td>Positive</td>
<td>Positive</td>
<td>Positive Lung</td>
<td>9</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>VT</td>
<td>47</td>
<td>M</td>
<td>VT, Complete AVB</td>
<td>54%</td>
<td>Absent</td>
<td>Not Done</td>
<td>Positive</td>
<td>Positive Lung</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>VT</td>
<td>65</td>
<td>M</td>
<td>VT, PACED Rhythm</td>
<td>18%</td>
<td>Present</td>
<td>Not Done</td>
<td>Positive</td>
<td>Positive Lung</td>
<td>8</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>VT</td>
<td>59</td>
<td>F</td>
<td>Complete AVB, VT</td>
<td>15%</td>
<td>Present</td>
<td>Not Done</td>
<td>Positive</td>
<td>Positive Lung</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>VT</td>
<td>75</td>
<td>F</td>
<td>VT, Frequent PVC’s</td>
<td>56%</td>
<td>Absent</td>
<td>Positive</td>
<td>Positive</td>
<td>Positive Lung</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>VT</td>
<td>46</td>
<td>M</td>
<td>PACED (Remote History of VT and VT)</td>
<td>31%</td>
<td>Present</td>
<td>Not Done</td>
<td>Positive</td>
<td>Positive Lung</td>
<td>15</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>Age</td>
<td>Diagnosis</td>
<td>AVB</td>
<td>PVC's</td>
<td>Test Site</td>
<td>Result</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>--------</td>
<td>-----</td>
<td>-----------</td>
<td>-----</td>
<td>-------</td>
<td>-----------</td>
<td>--------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT</td>
<td>F</td>
<td>56</td>
<td>VT, 1st Degree AVB</td>
<td>32%</td>
<td>Present</td>
<td>Positive Cardiac</td>
<td>6 2 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTROL</td>
<td>M</td>
<td>61</td>
<td>RBBB</td>
<td>62%</td>
<td>Absent</td>
<td>Positive Lung</td>
<td>0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTROL</td>
<td>M</td>
<td>46</td>
<td>RBBB</td>
<td>62%</td>
<td>Absent</td>
<td>Positive Lymph Node</td>
<td>0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTROL</td>
<td>F</td>
<td>53</td>
<td>Frequent PVC's</td>
<td>72%</td>
<td>Absent</td>
<td>Positive Skin</td>
<td>0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTROL</td>
<td>M</td>
<td>61</td>
<td>1st Degree AVB</td>
<td>48%</td>
<td>Absent</td>
<td>Positive Lung + Skin</td>
<td>0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTROL</td>
<td>F</td>
<td>62</td>
<td>Normal</td>
<td>61%</td>
<td>Absent</td>
<td>Positive Lung</td>
<td>0 1 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTROL</td>
<td>M</td>
<td>56</td>
<td>RBBB, LAD</td>
<td>72%</td>
<td>Absent</td>
<td>Positive Lung</td>
<td>0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTROL</td>
<td>F</td>
<td>34</td>
<td>Normal</td>
<td>62%</td>
<td>Present</td>
<td>Positive Lymph Node</td>
<td>0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Mean overall and Max LV SUV values, number of abnormal segments and number of segments with each abnormal pattern, as well as the location of the segment with the Maximal mean SUV for each patient according to clinical presentation.

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Mean LV FDG SUV</th>
<th>Max LV FDG SUV</th>
<th>Number of Abnormal Segments</th>
<th>FDG uptake/Norm al Perfusion</th>
<th>FDG uptake/Abnormal Perfusion</th>
<th>No FDG uptake/Abnormal Perfusion</th>
<th>Max Segment Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVB</td>
<td>2.70</td>
<td>9.66</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>Basal Infero-Septum</td>
</tr>
<tr>
<td>AVB</td>
<td>2.47</td>
<td>11.07</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>Basal Infero-Septum</td>
</tr>
<tr>
<td>AVB</td>
<td>2.61</td>
<td>6.87</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>Basal Antero-Septum</td>
</tr>
<tr>
<td>AVB</td>
<td>3.42</td>
<td>7.41</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>Basal Antero-Septum</td>
</tr>
<tr>
<td>AVB</td>
<td>2.03</td>
<td>4.43</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td></td>
<td>Basal Antero-Septum</td>
</tr>
<tr>
<td>AVB</td>
<td>1.23</td>
<td>3.79</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td></td>
<td>Basal Antero-Septum</td>
</tr>
<tr>
<td>AVB</td>
<td>8.59</td>
<td>3.45</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>Mid Infero-Septum</td>
</tr>
<tr>
<td>AVB</td>
<td>2.92</td>
<td>5.21</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>Mid Antero-Septum</td>
</tr>
<tr>
<td>AVB</td>
<td>2.04</td>
<td>15.71</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>Basal Anterior</td>
</tr>
<tr>
<td>AVB</td>
<td>2.44</td>
<td>6.15</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>Basal Anterior</td>
</tr>
<tr>
<td>AVB</td>
<td>0.86</td>
<td>3.76</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>Basal Antero-Lateral</td>
</tr>
<tr>
<td>AVB</td>
<td>2.49</td>
<td>4.34</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>Basal Infero</td>
</tr>
<tr>
<td>VT</td>
<td>8.35</td>
<td>13.81</td>
<td>8</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>Basal Anterior</td>
</tr>
<tr>
<td>VT</td>
<td>9.39</td>
<td>14.4</td>
<td>8</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>Basal Infero-Septum</td>
</tr>
<tr>
<td>VT</td>
<td>4.708</td>
<td>11.87</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>Basal Antero-Lateral</td>
</tr>
<tr>
<td>VT</td>
<td>4.83</td>
<td>9.24</td>
<td>12</td>
<td>9</td>
<td>2</td>
<td>1</td>
<td>Mid Anterior</td>
</tr>
<tr>
<td>VT</td>
<td>5.82</td>
<td>10.07</td>
<td>11</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td>Basal Antero-Lateral</td>
</tr>
<tr>
<td>VT</td>
<td>6.33</td>
<td>13.68</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>Basal Antero-Septum</td>
</tr>
<tr>
<td>VT</td>
<td>4.73</td>
<td>9.5</td>
<td>15</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>Basal Infero Lateral</td>
</tr>
<tr>
<td>VT</td>
<td>4.72</td>
<td>11.54</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>Mid Inferior</td>
</tr>
<tr>
<td>CONTROL</td>
<td>2.36</td>
<td>4.12</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>Basal Infero- Lateral</td>
</tr>
<tr>
<td>CONTROL</td>
<td>1.88</td>
<td>3.94</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>Basal Infero</td>
</tr>
<tr>
<td>CONTROL</td>
<td>1.07</td>
<td>3.02</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>Basal Infero-Septum</td>
</tr>
<tr>
<td>CONTROL</td>
<td>3.29</td>
<td>8.56</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>Basal Infero- Lateral</td>
</tr>
<tr>
<td>CONTROL</td>
<td>4.06</td>
<td>10.11</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>Basal Infero-Lateral</td>
</tr>
<tr>
<td></td>
<td>CONTROL</td>
<td>0.84</td>
<td>3.58</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
<td>------</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>CONTROL</td>
<td>4.24</td>
<td>6.96</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Circulation
Cardiovascular Imaging
Journal of the American Heart Association
Figure Legends

Figure 1. Adapted Japanese Ministry of Health and Welfare Criteria for the diagnosis of cardiac sarcoidosis. Positive FDG uptake as well as perfusion defects on rest Rubidium-82 or Ammonia-13 PET have been included as major and minor criteria respectively. Adapted from Soejima et al (2) (with permission).

Figure 2. Flow diagram illustrating inclusion and exclusion criteria for patients who underwent FDG PET. Twenty-six patients met modified Japanese Ministry of Health and Welfare criteria for diagnosis of CS, of whom 20 had documented VT or AVB without exclusion criteria. There were 7 clinically silent CS patients included as controls.

Figure 3. Image examples from two CS patients. (a) Shows both Rubidium-82 resting perfusion (top row) and FDG-PET (bottom row) slices of the heart in three orientations from a 55y/o female who presented with VT and was diagnosed with CS on cardiac biopsy. There is a mild perfusion defect within the inferior, septal and anteroseptal walls with focal uptake of FDG visible in these regions. The quantitative polar map of FDG SUV’s is shown in (b) showing maximal SUV values of 10g/ml in the inferior wall. (c) Images from a 42y/o male who presented with complete AVB and was diagnosed with CS on cardiac biopsy. Rubidium-82 perfusion is normal (top row) while there is focal uptake of FDG within the basal inferoseptum (bottom row). (d) Shows the SUV polar map demonstrating a max SUV of 6g/ml in the basal inferoseptum.

Figure 4. Bar graphs illustrating differences in mean parameters between the three patient cohorts (error bars show max value). (a) & (b) Shows higher Mean and Max LV SUV values in VT patients compared to those with AVB and to control patients with clinically silent CS with no significant difference between AVB patients and control patients. (c) Shows larger perfusion...
defects in VT and AVB patients compared to controls with a trend towards larger defect in VT patients. (d) The Co-efficient of variation was higher in patients with both VT and AVB when compared to control patients with no difference between AVB and VT patients. (e) Comparison of the number of abnormal segments (I.e. segments with either visually; abnormal FDG uptake, resting perfusion, or both) shows a trend towards more abnormal segments in the VT patient that is not statistically significant when corrected for multiple comparisons. (f) LV Ejection fraction as measured on gated PET was significantly lower in VT patients compared to controls with a trend towards a lower EF than those with presenting with AVB. *denotes significant Bonferroni corrected p-value of 0.0166 to correct for multiple comparisons.

**Figure 5.** ROC curves showing cutoffs for (a) Mean LV SUV (above left) and (b) Max SUV (above right) for prediction of CS patients presenting with sustained VT (above left and right).

Histological diagnosis group:
Cardiac sarcoidosis is confirmed when endomyocardial biopsy specimens demonstrate non-caseating epithelioid cell granulomas with histological or clinical diagnosis of extracardiac sarcoidosis.

Clinical diagnosis group:
Although endomyocardial biopsy specimens do not demonstrate non-caseating epithelioid granulomas, extracardiac sarcoidosis is diagnosed histologically or clinically and satisfies the following conditions and more than one in six basic diagnostic criteria:
1. Two or more of the four major criteria are satisfied
2. One in four of the major criteria and two or more of the five minor criteria are satisfied

Major Criteria:
- Advanced AV Block
- Basal thinning of the interventricular septum
- Positive Gallium-67 (or $^{18}$F-FDG*) uptake in the heart
- Depressed EF <50%

Minor Criteria:
- Abnormal ECG findings: ventricular arrhythmias (VT or multifocal or frequent PVC’s), complete RBBB, axis deviation, or abnormal Q-waves
- Abnormal ECHO; RWMA or morphological abnormality (aneurysm or wall thickening)
- Perfusion defects on nuclear imaging: Thallium-201, Technetium 99m SPECT (or Rubidium-82 or $^{13}$N-Ammonia PET*).
- Delayed Gadolinium Enhancement on Cardiac MRI
- Interstitial fibrosis or monocyte infiltration on cardiac biopsy

*Modified Criteria to include PET results

Adapted from Soejima et al (8) with permission.
CADRE Registry of patients undergoing FDG PET in Ontario for evaluation for CS (n=134)

Excluded due to normal FDG PET (n=90)

Abnormal FDG PET (n=44)

Excluded as no proven extra-cardiac sarcoidosis & negative JMHW criteria (n=11)

Modified JMHW Criteria Positive (n=26)

Excluded due heart failure without AVB or VT (n=5)

Documented AVB or sustained VT (n=21)

Excluded due to significant CAD OR Valvular Disease (n=1)

AVB (n=12)

VT (n=8)

Clinically silent CS patients Abnormal PET + biopsy proven extra-cardiac sarcoidosis. (n=7)
Is There an Association Between Clinical Presentation and the Location and Extent of Myocardial Involvement of Cardiac Sarcoidosis as Assessed by $^{18}$F- Fluorodeoxyglucose Positron Emission Tomography?

Brian A. Mc Ardle, David H. Birnie, Ran Klein, Rob A. de Kemp, Eugene Leung, Jennifer Renaud, Jean DaSilva, George A. Wells, Rob S. Beanlands and Pablo B. Nery

_Circ Cardiovasc Imaging_. published online July 24, 2013;
_Circulation: Cardiovascular Imaging_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2013 American Heart Association, Inc. All rights reserved.
Print ISSN: 1941-9651. Online ISSN: 1942-0080

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circimaging.ahajournals.org/content/early/2013/07/24/CIRCIMAGING.112.000289

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in _Circulation: Cardiovascular Imaging_ can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to _Circulation: Cardiovascular Imaging_ is online at:
http://circimaging.ahajournals.org/subscriptions/