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CLINICAL INVESTIGATIONS

Echocardiography fails to detect left ventricular noncompaction in a cohort of patients with noncompaction on cardiac magnetic resonance imaging

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Background: Left ventricular noncompaction (LVNC) is a rare disorder characterized by increased left ventricular trabeculation, deep intertrabecular recesses, and a thin compacted myocardial layer with associated clinical sequelae. Cardiac imaging with echocardiogram and cardiac magnetic resonance (CMRI) can detect variable myocardial morphology including excessive trabeculations. Multiple CMRI and echocardiographic criteria have been offered that attempt to identify LVNC morphology. The aim of this study was to assess the utility of echocardiogram in identifying LVNC in a cohort of patients with LVNC detected on CMRI.

Hypothesis: Echocardiography fails to identify LVNC morphology in a large proportion of patients with LVNC/hypertrabeculation detected on CMRI.

Methods: There were 1060 CMRI studies collected from 2009 to 2015 at 2 institutions. The patients included in this study (n = 37) met the criteria for LVNC on CMRI and had complete CMRI and echocardiogram images Clinical and imaging data were retrospectively reviewed.

Results: Of the 37 patients with LVNC on CMRI, only 10 patients (27%) had LVNC identified on echocardiogram ($P < 0.0001$, 95% confidence interval: 25.7%-66.2%). Echocardiography and CMRI were also significantly different in terms of identification of distribution of LVNC. Although 21 of 37 patients (57%) had evidence of LVNC in either the anterior or lateral walls on CMRI, there were 0 patients with LVNC detected in the anterior or lateral walls on echocardiogram ($P = 0.019$).

Conclusions: Echocardiogram fails to detect LVNC morphology/hypertrabeculation in a significant number of a cohort of patients with LVNC on CMRI. LVNC may be missed if echocardiogram is the only imaging modality performed in a cardiac evaluation.

KEYWORDS

left ventricular noncompaction, Imaging, magnetic resonance imaging, Imaging, echocardiography

1 | INTRODUCTION

Left ventricular noncompaction cardiomyopathy (LVNC) is a rare disorder of unknown etiology that has been classified as a primary genetic cardiomyopathy under the American Heart Association classification for cardiomyopathies[1] or unclassified cardiomyopathy by the

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European Society of Cardiology.[2] The predominant morphologic characteristics are the presence of increased trabeculations in the endocardial layer, deep intertrabecular recesses, and a thin compacted layer.[3] LVNC morphology is frequently diagnosed by cardiac imaging. Echocardiography is the initial and basic tool for diagnosis in many patients.[4] There are no clear criteria for diagnosis of LVNC based on echocardiogram,[5] but a ratio of noncompacted to compacted myocardium (NC/C) ≥2.0 measured at end-systole has been frequently used as criteria for diagnosis.[4,5] The emergence of cardiac magnetic resonance (CMRI) has enabled high-resolution imaging of cardiac structures. CMRI also provides detailed functional and anatomic information such as fibrosis.[4] In a cohort of patients with hypertrabeculation on CMRI and echocardiogram, Pedersen et al proposed an NC/C ratio ≥2.3 on CMRI for diagnosis of LVNC.[6]

Because echocardiogram remains the primary modality for diagnosis of LVNC, the aim of this study was to assess the performance of echocardiography in detecting LVNC morphology or hypertrabeculation in a cohort of patients with LVNC/hypertrabeculation identified on CMRI. We hypothesize that echocardiography fails to identify LVNC morphology in a large proportion of patients with LVNC/hypertrabeculation detected on CMRI.

2 | METHODS

2.1 | Studies

There were 1060 CMR studies collected from 2009 to 2015 from imaging studies performed at 2 institutions. Thirty-seven patients had CMRI studies with evidence of morphology consistent with LVNC (using the Pedersen criteria that defines LVNC as the presence of a 2-layered structure of myocardium with a ratio of noncompacted to compacted myocardium ≥2.3).[6] These patients represent the main cohort of the study. All CMRI for the 37 patients were reviewed by the authors of the study (L.N. and C.R.). Transthoracic echocardiogram (TTE) reports and images were collected for all 37 patients. All available TTE images were reviewed by a cardiologist board certified in echocardiography (A.P.). Six of the TTE studies were considered of poor quality, in which all segments were not well visualized. Intravenous (IV) contrast (DEFINITY; Lantheus Medical Imaging, North Billerica, MA) was given in 1 of the studies. All other TTEs were reported as adequate-to-good–quality studies. Complete clinical and imaging data were collected and evaluated in retrospective fashion.

2.2 | CMR imaging

Magnetic resonance imaging (MRI) was performed using either a Siemens Verio 3 T MRI (Siemens Medical Solutions USA, Malvern, PA), GE HDxt 3 T MRI (GE Healthcare, Chicago, IL), or Philips Achieva 1.5 T MRI (Philips Healthcare, Bothell, WA) before and after the IV administration of contrast medium (20–30 mL Multihance Gadolinium; Bracco Diagnostic, Monroe Township, NJ). Multiplanar, cine steady-state free precession images were obtained prior to the administration of IV contrast. The ratio of noncompacted myocardium to compacted myocardium was measured and confirmed in at least 2 orthogonal planes. Late gadolinium enhancement images were also obtained 10 minutes after the administration of IV contrast to assess for myocardial fibrosis. Measurements were made using CMRI post-processing software (CVI42; Circle Cardiovascular Imaging, Calgary, Canada).

2.3 | Echocardiographic imaging

Echocardiographic imaging was performed using either a Philips EPIQ3 or Philips iE33 (Philips Healthcare). In 1 case, IV administration of microbubble contrast agent (10 μL/kg DEFINITY, Lantheus Medical Imaging) was performed for contrast-enhanced sonography. Standard echocardiographic images including parasternal long and short axis, apical 2-, 3-, and 4-chamber views were obtained and reviewed by a cardiologist board certified in echocardiography. Color Doppler imaging was performed in all studies. All views were reviewed based on the Jenni criteria[7] of a noncompacted to compacted ratio ≥2.0 measured in parasternal short-axis images in end-systolic phase at the base, mid, and apical segments.

2.4 | Statistical analysis

Unless otherwise stated, descriptive statistics for continuous variables were presented as mean and standard deviation. Categorical variables were presented as counts followed by percentages in parentheses. Differences were evaluated by Student *t* test for continuous variables and χ^2 tests for categorical variables. The *z* test was used to calculate the difference in proportions between patients whose echocardiogram identified LVNC and those whose echocardiogram did not detect LVNC. All statistical analysis was done using SAS 9.4 (SAS Institute Inc., Cary, NC) and PHStat (Pearson Education, Upper Saddle River, NJ).

3 | RESULTS

3.1 | Main findings

Among 1060 consecutive CMRI examinations, there were 37 patients (3.6%) with LVNC detected on CMRI who also had available echocardiogram images. Baseline characteristics are listed in Table 1. Of the 37 patients with LVNC identified on CMR, echocardiogram detected LVNC morphology/hypertrabeculation in only 10 patients (27.0%) ($P < 0.0001$, 95% confidence interval: 25.7%-66.2%).

Table 2 outlines the indications for the imaging studies. There were only 7 of 37 patients who underwent CMRI for suspected LVNC. There were no patients who underwent echocardiogram for suspected LVNC/hypertrabeculation.

Table 3 compares the distribution of LVNC identified on CMRI to the distribution on echocardiogram. In both groups, left ventricular noncompaction was detected predominantly in the apex or the lateral wall. However, 21 of 37 patients (57%) also had LVNC detected on CMRI in the anterior or inferior walls (6 patients anterior, 10 patients inferior, 5 patients anterior and inferior), whereas there were no patients who had LVNC or hypertrabeculation in the anterior or inferior walls detected on echocardiography ($P = 0.019$). On

TABLE 1 Baseline characteristics (n = 37)

Characteristic	Value
Age, mean (SD), y	46.4 (15.7)
Men, no. (%)	25 (68)
Anthropometric measures, mean (SD)	
Weight, kg	89.9 (21.5)
BMI	29.7 (6.4)
BSA, m^2	2.0 (0.3)
Clinical sequelae, no. (%)	
Atrial fibrillation	11 (30)
Congestive heart failure	
NYHA class I	7 (19)
NYHA class II/III	13 (35)
TIA/stroke	3 (8)
Syncope	4 (11)
Ventricular tachycardia	5 (14)
Implantable cardioverter-defibrillator	13 (35)

Abbreviations: BMI, body mass index; BSA, body surface area; NYHA, New York Heart Association; SD, standard deviation; TIA, transient ischemic attack.

TABLE 2 Indications for CMRI and TTE (n = 37)

	No.
Echocardiography indications	
Chest pain	10
Congestive heart failure	10
Arrhythmia/palpitations	7
Postoperative	1
Pretransplant evaluation (renal)	1
Stroke	1
Congenital heart disease	1
Syncope	2
Elevated cardiac biomarkers	1
Dyspnea	3
CMRI indications	
Congestive heart failure/cardiomyopathy	16
Arrhythmia	5
Suspected LVNC	7
Congenital heart disease	1
Valvular heart disease	3
Suspected cardiac mass/thrombus	3
Dyspnea	1
Elevated cardiac biomarkers	1

Abbreviations: CMRI, cardiac magnetic resonance imaging; LVNC, left ventricular noncompaction; TTE, transthoracic echocardiogram.

echocardiogram, there were only 3 patients with LVNC in the lateral walls and only 1 patient who had LVNC detected outside of the apex.

CMR and echocardiogram were also compared by assessment of multiple structural and functional parameters. Those variables are depicted in Table 4. There were no differences in the measurement of either ejection fraction (EF), left atrial dimension, or left ventricular end-systolic dimension between CMRI and echocardiogram. However, measurement of left ventricular end-diastolic dimension, like the presence of LVNC, was significantly different between the 2 imaging studies.

3.2 | Clinical sequelae

Table 5 demonstrates the clinical characteristics of the 10 patients with LVNC identified on echocardiogram compared to the 27 patients who did not have LVNC on echocardiogram. There were no differences in terms of medical therapy between the group with LVNC on echo compared to the group without LVNC on echo, although there was a trend toward greater use of anticoagulation among patients with LVNC detected only on CMRI (odds ratio [OR]: 4.1, $P = 0.0761$). Cardiomyopathy, defined as EF ≤50%, was more common in patients with LVNC on echo compared to patients without LVNC on echo (OR: 1.95, $P = 0.0339$), although EF itself was not different between the 2 groups (47.9% ± 16% vs 43.5% ± 16%, $P = 0.3570$). There were also no differences in terms of clinical symptoms or sequelae that could be attributed to LVNC between the echo-positive and echo-negative groups.

4 | DISCUSSION

4.1 | Main findings

Our results demonstrate that echocardiography detected LVNC morphology or hypertrabeculation only in a small minority of patients with LVNC morphology by CMR criteria. This low detection rate suggests that LVNC/hypertrabeculation may be missed when echocardiography is used as the sole imaging modality in the evaluation of patients. Although multiple authors have suggested that CMRI is superior to echocardiogram for detection of LVNC,[8] our study is one of the first to demonstrate that echocardiogram fails to detect LVNC in the majority of patients in a cohort of patients with LVNC.

A variety of factors may explain the lack of detection by echocardiography in this setting. First, the inherent limitations of echo may affect the detection of LVNC morphology. Although echocardiography may provide excellent visualization of the left ventricular cavity, thorough inspection of the myocardium and endocardium of the entire left ventricle is not always performed in the average clinical setting.[9] Six of the 37 studies were considered of poor quality, yet. additional imaging with IV contrast was only performed in 1 of the 6 studies. Three-dimensional echo and off-axis views were not

TABLE 3 Distribution of LVNC on CMR compared to echocardiogram

	Apex, No. (%)	Lateral, No. (%)	Inferior, No. (%)	Anterior, No. (%)	*P* Value for Interaction
CMR	33 (87)	31 (84)	15 (41)	11 (30)	.019
Echocardiography	9 (90)	3 (30)	0 (0)	0 (0)	

Abbreviations: CMR, cardiac magnetic resonance; LVNC, left ventricular noncompaction.

TABLE 4 Structural dimensions on TTE compared to CMRI (n = 37)

Parameter	Echo, mean (SD)	CMR, mean (SD)	*P* Value
LVEDD	56.73 (8.76)	63.34 (9.92)	0.0033
LVESD	43.72 (12.33)	49.24 (12.95)	0.0645
EF	45.45 (16.29)	46.59 (15.18)	0.7564
LA size	38.71 (5.96)	36.83 (11.47)	0.3793
LVNC present	10	37	<0.0001

Abbreviations: CMRI, cardiac magnetic resonance imaging; EF, ejection fraction; LA, left atrial; LVEDD, left ventricular end-diastolic dimension; LVESD, left ventricular end-systolic dimension; LVNC, left ventricular noncompaction; SD, standard deviation; TTE, transthoracic echocardiogram.

obtained in any of the patients which also may have limited the ability to detect LVNC. The fact that TTE and CMRI provide similar results on many parameters of left ventricular structure and function suggests that the 2 modalities are similar with respect to some parameters, yet they vary substantially when it comes to identification of LVNC/hypertrabeculation. Additionally, the standard echocardiographic images that are obtained on a routine study may not be optimal for the detection of LVNC.[8] Our data identified that anterior and inferior noncompaction was not found in any of the patients in this cohort, even though a substantial number of them had evidence of LVNC/hypertrabeculation in the anterior and inferior walls on CMRI, suggesting that anterior and inferior noncompaction may be frequently undetected.

In patients with poor acoustic windows, such as those with musculoskeletal abnormalities, obesity, or pulmonary disease, the reduction in image quality may result in missed diagnoses.[8] In these patients, the use of echocardiographic contrast imaging with contrast agents has been advocated.[10–12] Whereas additional echo views might enhance the detection rate of LVNC, those views might be obtained only when there is a high index of suspicion. Multiple reports have suggested that the diagnosis of LVNC is often delayed because of lack of detection on echocardiography. Often times, the diagnosis is not made until patients have undergone several echocardiograms.[13,14] Whereas advanced echocardiographic technology such as tissue Doppler-based strain analysis or 3-dimensional echocardiography may enhance detection, those techniques may not be feasible for most studies performed in a general community setting given limited time and resources. Echocardiography is often times the initial

TABLE 5 Clinical characteristics of patients with LVNC/hypertrabeculation identified on echocardiogram compared to patients who did not have LVNC/hypertrabeculation on echocardiogram

	LVNC Detected on TTE	LVNC Undetected on TTE	*P* Value
Characteristic			
Age, mean (SD), y	44.1 (16.9)	47.3 (15.5)	0.5895
Men, no. (%)	6 (60)	19 (70)	0.6065
Anthropometric measures, mean (SD)			
Weight, kg	81.99 (16.62)	92.8 (22.6)	0.1776
BMI	27.8 (3.6)	30.5 (7.1)	0.2611
BSA, m^2	1.95 (0.28)	2.07 (0.28)	0.2548
Clinical features, no. (%)			
Cardiomyopathy (EF <50%)	8 (80)	11 (41)	0.0339
Hypertension	6 (60)	12 (44)	0.4005
Diabetes mellitus	0 (0)	8 (30)	N/A
Coronary artery disease	2 (20)	5 (19)	0.9186
Chronic kidney disease	2 (20)	5 (19)	0.9186
Medications, no. (%)			
Aspirin	5 (50)	9 (33)	0.3532
β-blocker	7 (70)	17 (63)	0.6905
ACE inhibitor/ARB	6 (60)	18 (67)	0.7060
Mineralocorticoid receptor antagonist	3 (30)	9 (33)	0.8475
Anticoagulant (warfarin or NOAC)	1 (10)	11 (41)	0.0761
Clinical sequelae, no. (%)			
Atrial fibrillation	1 (10)	10 (37)	0.1101
CHF NYHA class I	1 (10)	6 (22)	0.3992
CHF NYHA class II/III	4 (40)	9 (33)	0.7060
TIA/stroke	0 (0)	3 (11)	N/A
Syncope	0 (0)	4 (15)	N/A
Ventricular tachycardia	1 (10)	4 (15)	0.7036
Implantable cardioverter-defibrillator	2 (20)	11 (41)	0.2405

Abbreviations: ACE, angiotensin-converting enzyme; ARB, angiotensin receptor blocker; BMI, body mass index; BSA, body surface area; CHF, congestive heart failure; EF, ejection fraction; LVNC, left ventricular noncompaction; N/A, not applicable; NYHA, New York Heart Association; NOAC, new oral anticoagulant; SD, standard deviation; TIA, transient ischemic attack; TTE, transthoracic echocardiogram.

and last step of evaluation. In light of this low detection rate, a high index of suspicion for LVNC may be appropriate, especially whenever a patient presents with a new nonischemic cardiomyopathy. Otherwise, many cases of LVNC may go undetected if additional imaging with CMRI is not obtained.

Second, the current criteria for diagnosis of LVNC on echocardiogram are problematic. The initial studies that established echocardiographic criteria for LVNC involved only a very small number of patients. Those studies may have focused only on patients with more extreme forms of LVNC, whereas patients with more subtle forms of LVNC may not have been included. The existing criteria for the detection of LVNC on echocardiogram also have not been prospectively tested or rigorously validated. Hence, those studies may not be generalizable to a larger population. Moreover, Kohli et al have demonstrated poor correlation among the differing criteria for identification of LVNC by echocardiogram.[15] The high interobserver and intraobserver variability of echocardiography further complicates the application of these criteria.[4]

The reproducibility of the measurement of noncompacted to compacted segment ratio on echocardiogram has also been shown to be poor.[16]

Aside from the inherent limitations of echocardiography, the clinical limitations are also worth noting. The only difference that we could identify between patients with LVNC on echocardiogram compared to patients without LVNC on echocardiogram was a higher proportion of patients with cardiomyopathy defined as EF ≤50%. When we adjusted the EF cutoff to lower numbers, this finding no longer became statistically significant, likely because cardiologists may be more prone to look for LVNC in patients with reduced EF on echocardiogram. Additionally, this study may have been underpowered to detect clinical sequelae to LVNC. That said, the detection of LVNC on CMR in patients without LVNC on echocardiogram did not appear to affect clinical management both in terms of medical therapy as well as identification of arrhythmias, thromboembolic events, or congestive heart failure. Zemrak et al have recently noted in the MESA (Multi-Ethnic Study of Atherosclerosis) cohort that hypertrabeculation on CMR may not have significant adverse clinical consequences.[17]

4.2 | Limitations

There are multiple limitations to this study. It is a retrospective analysis and is thus subject to all of the inherent limitations and confounding of retrospective analyses. Diagnoses and comorbidities were identified through physician reporting, but there was no confirmation of clinical items, because there was no communication with patients or physicians to confirm events or diagnoses. A second limitation is that the study did not assess patients with LVNC diagnosed only by echocardiogram who either did not undergo CMRI or did not have LVNC on CMRI. We suspect that this is a minor limitation because our institution orders CMRI for almost all individuals with LVNC detected on echocardiogram initially. All 10 of the patients with LVNC on echocardiogram and CMRI had LVNC identified on CMRI only after the initial echocardiogram had established a possible diagnosis. Hence, we suspect that the number of individuals with LVNC based on echocardiogram only is very small and would not affect our analysis. However, our study cannot exclude the possibility that some patients may be diagnosed with LVNC based on echo alone. A third limitation is that the relatively short duration of follow-up limits our ability to identify clinical sequelae. Some of the clinical consequences that are potentially attributable to LVNC such as arrhythmias, strokes, or changes in medical management may not have been reported or captured in our data because we were not able to follow up patients for extensive periods of time. A fourth limitation is that 6 of the 37 studies were considered of poor quality which may have affected the ability of echo to detect LVNC morphology in those patients. Although this limitation may affect our claim that echocardiography fails to detect LVNC morphology, we consider the inclusion of these poor-quality studies as 1 of the strengths of the studies because it probably reflects more accurately the clinical care in the community with respect to visualization of LVNC morphology on echo and CMRI. Since many practitioners do not routinely perform atypical views or 3-dimensional echo in patients, this reinforces the likelihood that LVNC morphology may not be detected when echocardiogram is the only imaging study performed in a community cardiology practice. Finally, a fifth limitation is that the echocardiograms were read by a large number of cardiologists, whereas all CMRI were read by only 2 physicians. To address this, all echocardiogram images were reviewed by a physician board certified in echocardiography to confirm that LVNC was not present on the echo images. That said, we consider this limitation to be a strength of the study because it likely reflects more accurately the practice in the community where echocardiograms are read by a wide variety of practicing cardiologists who may not be board certified in echocardiography. Thus, the low detection rate of LVNC in this cohort may reflect more accurately lower detection rates of LVNC by echocardiograms in general community practice.

5 | CONCLUSION

Our data indicate that echocardiography fails to identify LVNC in a large proportion of patients with LVNC detected on CMRI. Since many patients with cardiac complaints undergo echocardiogram as the only imaging for their complaints, LVNC might be underdiagnosed. A high index of clinical suspicion for LVNC may be warranted for patients who present with cardiac complaints and have an echocardiogram depicting either a nonischemic cardiomyopathy or no abnormalities. In those cases, CMRI may help unveil LVNC morphology, which can affect the patient's management. Further studies are warranted to evaluate the value of echocardiography in detecting this difficult condition.

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