Sudden cardiac death (SCD) is most commonly precipitated by malignant ventricular tachyarrhythmias and readily prevented by insertion of implantable cardioverter-defibrillators (ICDs). However, our ability to identify which individuals are at highest risk for SCD and thus candidates for ICDs remains inadequate. Current clinical guidelines for selecting patients who have yet to experience clinical evidence of sustained ventricular arrhythmias target those with reduced global left ventricular (LV) function (LV ejection fraction [LVEF] < 30–35% with or without heart failure) as meeting criteria for primary prevention ICDs.1 Patients who have survived a cardiac arrest episode, in the absence of a reversible cause, generally meet criteria for secondary prevention ICDs. Patients who are at risk for SCD are not being identified as candidates for ICDs. This deficiency in risk stratification practice was articulated in a recent National Heart, Lung, and Blood Institute and Heart Rhythm Society workshop publication, which concluded that “Current methods of clinical risk prediction are inadequate and there is increasing interest in examining whether or not CMR is useful for risk stratification beyond global LV function. In the current issue of Circulation: Cardiovascular Imaging, single-center studies by White et al8 and Appelbaum et al9 lend further support to the potential value of myocardial substrate imaging by CMR when evaluating patients for SCD risk, even when LVEF is preserved.

White et al8 performed CMR imaging in 82 patients presenting to their institution with resuscitated SCD or sustained monomorphic ventricular tachycardia (VT), in the absence of an established ischemic etiology. In addition to cine imaging, both T2-weighted and delayed enhancement (DE) sequences were performed to assess for myocardial edema and scar/fibrosis. In patients suspected of having ARVD (those presenting with VT with left bundle-branch morphology), T1-weighted imaging with a double inversion recovery fast echo sequence was also performed to evaluate for intramyocardial fat. An investigator blindly adjudicated the clinical reports of all non-CMR imaging, and, based on the results, judged whether or not an etiology could be determined as causing the arrhythmia, assigning 1 of 7 predefined diagnostic categories. The same was done in a blinded fashion after review of the CMR images. In both cases, a summary of the clinical presentation and relevant ECG findings were provided for clinical context. The majorit of patients had relatively preserved LVEF (mean±SD of 51±19% for the entire cohort; 60% with LVEF ≥50%). The CMR results led to reclassification of 50% (n=41) to a new or alternative diagnosis, including 20 patients (24% of the entire cohort) in whom non-CMR imaging had shown no significant myocardial disease and 18 (22% of the entire cohort) in whom non-CMR imaging suggested an idiopathic cause. Seven patients (9%) were found to have LV dysfunction by CMR, not detected by the non-CMR imaging methods, presumably due to limitations such as inadequate acoustic windows in echocardiography. The etiologic causes...
muscle bundles, have been associated with increased arrhyth-
aLA
domes and poor cardiovascular and all-cause mortal-
ities.16 Although the presence of total scar by CMR has been
studied, and as is usually observed, LVEF was preserved in
patients with qualitative evidence of myocardial DE were
identified by CMR in the reclassified cases are listed in the
Table. In 3 cases (4%), the CMR diagnosis was incorrect.

The genetic disorder HCM has a fairly high prevalence of
1 in 500 and is the most common cause of SCD in individuals
younger than 35–40 years old,10 despite preserved LVEF.
Clinical markers of SCD risk (syncope, family history of
SCD, nonsustained VT, extreme ventricular hypertrophy,
and nonsustained VT) have relatively low predictive value, and
thus improved risk stratification is needed. The study by
Appelbaum et al9 investigated whether or not the presence of
ventricular arrhythmias and SCD,17–19 its discriminant ability as a
single risk factor has yet to be established because of the lack
of prospective studies having sufficient size and follow-up
duration.10 Nonetheless, because DE is so commonly seen in
HCM, the positive predictive value of DE presence alone is
likely to be low and may not ultimately be the best risk factor.

In 2 cases of reclassification in which the non-CMR diagnosis was coronary
tree of reclassification were due to the new diagnosis of LV dysfunction by
CMR in patients with confirmed CAD etiology by both non-CMR and CMR
findings. In 1 case of reclassification, the non-CMR diagnosis was “other”
(either Takotsubo cardiomyopathy or tetralogy of Fallot repair), whereas the
CMR diagnosis was CAD with LV dysfunction and may have been an incorrect
classification by CMR. The cause of reclassification was not clear in 1 case
(total reclassification, n=40 according to Figure 5 in White et al).5

<table>
<thead>
<tr>
<th>CMR Diagnosis</th>
<th>Normal by Non-CMR Imaging (n=20 of 40)</th>
<th>Unexplained LV Dysfunction (n=13 of 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute myocarditis</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Healed myocarditis</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Acute MI</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Healed MI</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>LV noncompaction</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>ARVD</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Sarcoid</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

CMR indicates cardiac magnetic resonance; LV, left ventricular; MI, myocar-
dial infarction; and ARVD, arrhythmogenic right ventricular dysplasia.

In 3 cases (4%), the CMR diagnosis was incorrect.

The current work by Appelbaum et al9 shows that the extent
of DE, both intermediate and high SI, was higher in patients
with ventricular arrhythmias, consistent with the results of a
prior study using high SI only.20 Moreover, the diagnostic
performance of intermediate SI was the highest (area under
the curve, 0.72) compared with high SI (area under the curve,
0.65) and total SI (area under the curve, 0.68).

Although the findings of both these studies highlight the
diagnostic potential of CMR, the authors note as important
limitations that they did not examine whether the CMR
results led to significant changes in the clinical management
of these patients or predicted prognosis, which are essential
questions when assessing comparative effectiveness of imag-
ing strategies. Moreover, future studies will need to address
the issue of cost effectiveness of adding CMR to SCD risk
stratification algorithms and this may require targeting CMR
to distinct cohorts in a tiered approach. The data from White
al5 suggest that it may have a vital role in 2 particular
subgroups who present with ventricular arrhythmias, those
of patients in whom non-CMR imaging suggests a structurally
normal heart or an idiopathic etiology. In these 2 subgroups,
CMR changed the diagnosis in 57% of cases and could affect
the subsequent management. As is evident by the CMR-
determined etiologies (Table), tailoring of the CMR exami-
nation to include specific sequences based on pretest clinical
suspicion will be critical, such as when ARVD is suspected
from the morphology of the presenting VT, other ECG
abnormalities, and/or evidence of right ventricular abnormal-
ities by non-CMR imaging. In fact, current guidelines for the
diagnosis of ARVD already incorporate specific CMR find-
ings into the major and minor criteria.21 Also in support of a
tiered diagnostic approach, CMR imaging with DE was
recently added to HCM guidelines as a class IIb indication10:
“In selected patients with known HCM, when SCD risk
stratification is inconclusive after documentation of the con-
ventional risk factors, CMR imaging with late gadolinium
enhancement may be considered in resolving clinical
decision-making.”

Standardized methods of quantifying DE and the impor-
tance of differentiating intermediate from high SI regions
remain unresolved issues in CMR. The mere presence versus
absence of DE is unlikely to be adequate as a single risk
stratifier, and quantification of DE probably is needed to
improve diagnostic performance. Pathophysiologically, scar
characteristics do contribute to how arrhythmogenic a heart
will be, and spatial heterogeneity in terms of admixtures of
normal myocytes with collagen bundles are what support
reentrant ventricular arrhythmias rather than densely conflu-
ent fibrosis. Thus, using regional differences in CMR SI
(presumably reflecting different contrast volumes of distribu-
tion and kinetics) to evaluate for areas of tissue heterogeneity
and distinguish them from homogeneously scarred regions
make sense. Validation of SI thresholds for defining myocar-
dial heterogeneity remains a challenge, particularly since
there is a limited histopathologic basis in nonischemic etiol-
ogies such as HCM, but at the minimum, any method should correlate visually with what is observed. The “best” thresholds may be those that predict outcomes with the highest diagnostic accuracy and will need to be demonstrated in large, adequately powered, prospective studies.

Finally, the results of these 2 studies support the hypothesis that myocardial scar may be a potential predictor of SCD over and above that of LVEF because it directly defines the abnormal substrate associated with increased SCD risk. Although it did not assess SCD or cardiac mortality, a recent multicenter, largely retrospective, observational study\(^\text{22}\) of 1560 consecutive patients referred for cardiac CMR (cine and DE) found that both CMR LVEF and the amount of DE were independent predictors of all-cause mortality at a median of 2.4-year follow-up. Notably, even among the 721 patients with LVEF $\leq 50\%$, DE measuring above the median value predicted increased all-cause mortality. Thus, the unique ability and strength of CMR to characterize myocardial tissue are increasingly evident and deserving of continued investigation. The full potential of CMR with DE as a clinical tool for SCD risk stratification has yet to be realized, and, while changing current paradigms will be difficult, the rate of return may be high.

**Acknowledgments**

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**Disclosures**

None.

**References**


6. de Bakker JM, van Capelle FJ, Janse MJ, Wilde AA, Coronel R, Becker AE, Dingemans KP, van Hemel NM, Hauer RN. Reentry as a cause of...


**Key Words:** Editorials ■ arrhythmia ■ cardiac magnetic resonance imaging ■ delayed enhanced MRI ■ hypertrophic cardiomyopathy
Assessing Risk for Ventricular Tachyarrhythmias and Sudden Cardiac Death: Is There a Role for Cardiac MRI?

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