Hibernating myocardium is defined as reversible left ventricular dysfunction due to chronic coronary artery disease that improves after revascularization. Patients with hibernating myocardium who are treated with revascularization rather than medical therapy have better outcomes. Recently, quantification of the transmural extent of delayed enhancement by MRI (DSMR) has been shown to predict the likelihood of recovery of myocardial function after revascularization (RECOVERY). However, in non-transmural scars (1% to 74%), only an intermediate likelihood of recovery of myocardial function after revascularization (RECOVERY) was found. The viable myocardium surrounding the scar may be normal, remodeled, hibernating, stunned, or ischemic. A dobutamine test depends on both function of viable and extent of nonviable myocardium and may therefore be superior to SCAR in predicting RECOVERY.

Although low-dose dobutamine stimulation assessed by MRI (DSMR) has been used for many years to predict hibernating myocardium, a direct comparison to SCAR as predictor of RECOVERY has not been performed in patients with chronic hibernation.

### Methods

**Patients and Study Design**

A prospective blinded within-patient comparison of DSMR and SCAR was performed in 29 patients (68±7 years, 2 women, 27 with previous infarction, 13 with previous coronary artery bypass grafting, 12 with diabetes, and 28 with hyperlipidemia). Fifty patients without contraindications for MRI were screened for the following inclusion criteria: (1) chronic coronary artery disease with stable angina; (2) ejection fraction <45% (mean, 32±8%); (3) at least 2 adjacent segments with wall motion abnormalities at rest; and (4) no infarction within the last 2 months. Definite study inclusion occurred after coronary revascularization (percutaneous coronary intervention, 25 of 50; coronary artery bypass grafting, 4 of 50 patients). The primary success of revascularization was controlled by a review of all angiograms.

DSMR and SCAR were performed 1 day before revascularization. RECOVERY was verified at 3 months after revascularization. Informed consent was obtained from all patients. The local institutional review committee approved the study.

**Magnetic Resonance Imaging**

SCAR was evaluated 10 to 15 minutes after Gd-DTPA (0.2 mmol/kg) injection (Philips ACS, NT, 1.5-Tesla system, inversion recovery turbo gradient echo sequence, prepulse-delay optimized for maximal myocardial signal suppression; TE/TR/flip: 3.6/8/15). Inversion time (200 to 250 ms) was optimized for each measurement. Transmurality of SCAR was assessed on a 5-grade scale. In borderline visual scoring, transmurality was determined by automatic segmentation.

Wall motion was assessed at rest and at the end of each dosage of dobutamine for 2-, 3-, and 4-chamber long-axis views and short-axis views at 3 levels by steady-state free precession imaging (echo time, 1.3 ms; repetition time, 2.6 ms; flip angle, 60 degrees; field of view, 350 mm; spatial resolution, 2×2×8 mm; temporal resolution, 40 ms; acquisition, 7 beats; 2 breathing cycles between 2 successive breath holds). Angulation was kept constant for short-axis and SCAR imaging to enable the use of 3D coordinates to match SCAR and wall motion images. After revascularization, only images at rest were acquired by the same technique.

Wall motion was graded as normokinesia, hypokinesia, akinesia, and dyskinesia in the 16-segment model by 2 blinded
investigators. Discordant assessments (19%) were jointly re-
viewed. An improvement of wall motion at follow-up by at least
1 grade was regarded as RECOVERY. DSMR (5 and 10 \( \mu g/kg \) per min for 3 minutes) was regarded as indicative of viability
when there was an improvement of 1 grade at either the 5- or the
10- \( \mu g/kg \) per min dose. Reviewers of DSMR, SCAR, and
RECOVERY were blinded to each other.

Statistics
We analyzed 288 of 464 (29 patient \times 16 segments) segments with
wall motion abnormalities at rest. Binary prediction of RECOV-
ERY was modeled by logistic regression. Different predictive
models were compared by receiver operating characteristic–area
under curve (ROC-AUC) statistics (SPSS 10.0).

Sensitivities, specificities, prevalences, and accuracy were calcu-
lated. Interobserver and intraobserver agreement was assessed in
15 patients (92 segments) for RECOVERY, DSMR, and SCAR
(Cohen’s \( \kappa \), 0.7 to 0.78 interobserver, 0.80 to 0.89 intraobserver).

Results

SCAR
The logistic regression model for SCAR (25% cutoff) pre-
dicted 73% of hibernating segments correctly. RECOVERY
decreased with increasing extent of scar (Figure 1).

DSMR
DSMR predicted 85% of hibernating segments correctly. The ROC
analysis in Figure 2 and the subgroup analysis in Figure 1 demonstr-
ate that accuracy of the test does not depend on the transmurality
of scar.

SCAR and DSMR
DSMR predicted RECOVERY better than SCAR \((P=0.05)\)
(Figure 2, A and D). The cutoff value had no impact on this
result (Figure 2D). When SCAR was performed, additional
DSMR improved accuracy of prediction, whereas the reverse
was not true (Figure 2A). The specificity of DSMR was
higher and the sensitivity comparable to SCAR.

The ROC analysis in Figure 2 (subplot C) demonstrates a
particularly low predictive value of SCAR as opposed to
DSMR in scar, with 1% to 74% transmurality.

Discussion

SCAR
Recent technical improvements and quantitative scar grading
increased the diagnostic value of delayed enhancement.\(^5,8\)
The technique delineates the extent of infarction\(^9–12\) and
assesses the likelihood of RECOVERY before revasculariza-
tion.\(^2,8,13–15\) SCAR was found to be more sensitive and to
correlate well with PET imaging, the “gold standard” for
diagnosis of viability in the past.\(^16,17\) The decreasing likeli-
hood of RECOVERY with more extensive scar found in the
present study underlines the prognostic importance of scarred
myocardium in agreement with previous studies.\(^2,8\)

SCAR accurately localizes and quantifies scarred (nonvi-
able) myocardium. If a scar is not transmural (SCAR 1% to

Figure 1. Transmurality of scar: subgroup analysis. Bars refer to
the prevalence of recovery and sensitivity, specificity, and per-
centage of correct predictions by DSMR and are subgrouped
with respect to SCAR (cutoff, 25%). The specificity of DSMR
remains high irrespective of the extent of SCAR. The test retains
a high sensitivity in 25% to 49% SCAR.

Figure 2. ROC curves. The logistic model combining SCAR and DSMR is
compared with DSMR alone and the
logistic prediction by SCAR alone. Based
on confidence intervals, the AUC values
are significantly \((P<0.05)\) higher for
DSMR than SCAR and DSMR+SCAR
than SCAR alone in all segments (sub-
plot A, cutoff 25%) and the segments
with 1% to 74% transmurality of SCAR
(subplot C, cutoff 25%). There was no
significant difference between DSMR and
SCAR in segments without scar or SCAR
transmurality \(\geq 75\%\) (subplot B, cutoff
25%). The increase of the AUC of
DSMR+SCAR compared with DSMR
alone was not significant. Subplot D
compares DSMR and SCAR with differ-
ent cutoffs (25% and 50%) in all segments.
74%), however, this technique fails to assess the functional state of the surrounding (viable) myocardium (normal, remodeled, hibernating, stunned, and ischemic).

**DSMR**

Low-dose dobutamine may improve contractile function and cellular energetics in hyperperfused myocardium and perfusion by collaterals or dynamic stenoses. Thus, the test simulates effects of revascularization. The myocardial infarction model is usually applied to assess myocardial viability, but to reduce the transmural infarct size measurement by contrast-enhanced magnetic resonance imaging. Thus, the test simulates effects of revascularization.

**SCAR and DSMR**

One recent study compares DSMR to SCAR as predictors of recovery after acute myocardial infarction. Despite protocol differences (quantitative analysis and different segmentation), the lower specificity and accuracy of SCAR compared with DSMR found in that study agrees with our results. The correlation of negative dobutamine tests with the extent of delayed enhancement implies some overlap of test information. Whereas additional DSMR, which depends on the functional reserve of viable myocardium, improved the diagnostic accuracy of SCAR, the reverse was not true (no functional reserve of scars). DSMR is very sensitive in SCAR <50% because of enhanced thickening of the inner layers of myocardium. The high specificity of the test is preserved in more transmural scars.

**Limitations**

Verification of recovery at 3 months seems sufficiently late in view of the high percentages of correct predictions. Although restenosis was not controlled invasively, noninvasive follow-up was free of symptoms or signs, indicating recurrent ischemia. Visual assessment of wall motion is a limitation of the present study. Quantitative assessment of wall motion by tagging combined with rapid postprocessing algorithms may additionally enhance sensitivity of DSMR and assessment of recovery (Fast-HARP).

**Conclusion**

Delayed enhancement and DSMR provide complementary information. Delayed enhancement localizes and quantifies scar but has impaired specificity as a predictor of recovery in nontransmural scars (1% to 74%). DSMR is superior to delayed enhancement as a predictor of recovery and does not depend on the transmurality of scar.

**References**

Magnetic Resonance Low-Dose Dobutamine Test Is Superior to Scar Quantification for the Prediction of Functional Recovery
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*Circulation*. 2004;109:2172-2174; originally published online April 26, 2004;
doi: 10.1161/01.CIR.0000128862.34201.74

*Circulation* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2004 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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