Intraindividual Comparison of Gadobutrol and Gadopentetate Dimeglumine for Detection of Myocardial Late Enhancement in Cardiac MRI

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OBJECTIVE. Gadobutrol is an extracellular macrocyclic gadolinium chelate recently introduced in MRI, and it has already been used for cardiac late enhancement imaging; however, until now it has never been compared with gadopentetate dimeglumine. The purpose of our study was to compare 0.1 mmol/kg gadobutrol to 0.2 mmol/kg gadopentetate dimeglumine for the detection of myocardial late enhancement in the same group of patients.

SUBJECTS AND METHODS. This was an exploratory single-blind parallel group study comparing gadobutrol (0.1 mmol/kg) to gadopentetate dimeglumine (0.2 mmol/kg) in 20 adult patients scheduled for cardiac late enhancement MRI with gadopentetate dimeglumine and whose MR images showed late enhancement. MR images were acquired at 10, 15, and 20 minutes after peripheral injection of gadobutrol by using a 3D turbo field echo inversion recovery T1-weighted sequence. Volume and percentage of late enhancement, number of involved segments, late enhancement localization and pattern, and late enhancement signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were compared between contrast agents.

RESULTS. Late enhancement was not significantly different with gadobutrol and gadopentetate dimeglumine both in terms of total volume of myocardium (mean ± SD, 37.8 ± 56.1 and 35.1 ± 46.7 cm^3, respectively; $p = 0.33$) and percentage of myocardial wall involvement (22.5% ± 19.1% and 22.0% ± 17.2%, respectively; $p = 0.67$). The number of segments involved was not different (138 with gadobutrol vs 134 with gadopentetate dimeglumine). Furthermore, SNR and CNR were not different (gadopentetate dimeglumine, 123.8 ± 82.9 and gadobutrol, 117.2 ± 88.6, $p = 0.58$ and gadopentetate dimeglumine, 96.2 ± 68.9 and gadobutrol, 88.4 ± 72.9, $p = 0.53$, respectively).

CONCLUSION. A single dose of gadobutrol seems to be as effective as a double dose of gadopentetate dimeglumine for the detection of late enhancement.

Keywords: cardiac MRI, comparative studies, gadobutrol, gadopentetate dimeglumine, late enhancement

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Myocardial late enhancement in contrast-enhanced cardiac MRI was described for the first time more than 15 years ago [1, 2]. Since then, the technique has rapidly evolved and it is now the reference standard for the assessment of myocardial viability in the acute and chronic phase of an infarction [1–4] and is an established tool for the detection of myocardial damage in other disorders, such as acute myocarditis and cardiomyopathies [5–12]. Late enhancement is produced by an abnormal concentration of gadolinium-based contrast agents within the areas of myocardium characterized by irreversible acute myocardial damage or fibrotic myocardial replacement [1–12]. The abnormal concentration of gadolinium within the damaged areas is revealed through the use of a T1-weighted sequence with an inversion recovery prepulse nulling the signal of normal myocardium. The cardiac MRI technique also aids in the differential diagnosis because the areas of late enhancement in nonischemic myocardial disease associated with fibrosis or inflammation usually do not correspond to the distribution territory of a coronary artery and exhibit different patterns and location compared with ischemic lesions [3–12].

The technique involves the IV administration of an extracellular gadolinium-based contrast agent. Until now, gadopentetate dimeglumine has been the most used gadolinium-based extracellular contrast agent for detection of myocardial late enhancement, and comparison studies have been published with gadobenate dimeglumine [13–16]. A double dose (0.2 mmol/kg) of gadopentetate dimeglumine is usually administered to perform late enhance-

ment imaging. Gadobutrol is an extracellular macrocyclic gadolinium chelate [17]. Its main feature is its high concentration, which is double the concentration of other contrast agents (1.0 mol/L vs 0.5 mol/L); this allows improved image quality, as shown in both human and animal MR angiography studies [18–22]. Other favorable features are its high T1 relaxivity (5.6), which improves enhancement and image quality and its low osmolality (1.6), which improves tolerability [17]. Moreover, it has been shown that gadobutrol has been successfully used in cardiac perfusion studies both at 1.5 T [23] and at 3 T [24], providing high accuracy in the detection of stress-induced myocardial ischemia.

Gadobutrol has already been used for cardiac late enhancement imaging, usually at the dose of 0.15–0.2 mmol/kg [23–25] and has never been compared with gadopentetate dimeglumine. Our hypothesis was that, because of its higher T1 relaxivity, 1-M gadolinium contrast agent administered in a single dose (0.1 mmol/kg) may provide late enhancement images comparable to those from a double dose (0.2 mmol/kg) of 0.5-M gadolinium chelate. Thus, the purpose of this exploratory study was to compare the single dose of gadobutrol to the double dose of gadopentetate dimeglumine in terms of detection and extension of late enhancement.

Subjects and Methods

This exploratory single-blind intraindividual study compared gadobutrol at 0.1 mmol/kg body weight (Gadovist, Bayer Schering Pharma) to gadopentetate dimeglumine at 0.2 mmol/kg body weight (Magnevist, Bayer Schering Pharma) for evaluation of late enhancement in cardiac MRI. The study was conducted in accordance with good clinical practice requirements at our department from August 2008 to March 2010. It was approved by the local ethics committee, and all patients signed the informed consent form after the protocol and purpose of the study had been explained to them.

Patient Population

The patient population consisted of 20 subjects (14 men and six women; mean [± SD] age, 53 ± 14.7 years; age range, 20–81 years) who had undergone cardiac MRI with the conventional extracellular contrast agent, gadopentetate dimeglumine, for clinical reasons in the previous 48 hours to 2 weeks and whose cardiac MRI images showed the presence of late enhancement.

The exclusion criteria were the following: history of any severe allergic reaction or allergic reaction to MR contrast media; pregnancy and lactation; allergy (hypersensitivity) to the active substances or to any excipients of the contrast media under study; patients not able to lie down for at least 45–60 minutes; contraindication to MRI, such as pacemaker or claustrophobia; uncooperative patient; severe renal function impairment (glomerular filtration rate < 30 mL/min/1.73 m^2); participation in another clinical trial or previous participation in this trial; arrhythmia preventing proper ECG gating; administration of another contrast medium 12 hours before or 24 hours after cardiac MRI; or interventional procedure between the two cardiac MRI investigations.

On the basis of anamnestic clinical, laboratory, ECG, and imaging data, nine of 20 patients were diagnosed with myocarditis, five with chronic coronary artery disease (CAD), and the remaining six with cardiomyopathy (hypertrophic cardiomyopathy, $n = 4$; amyloidosis, $n = 1$; sarcoidosis, $n = 1$).

The mean time between the two MRI examinations was 5.35 days (range, 2–13 days). When the study population was divided into two groups—acute cases (nine myocarditis) and chronic cases (11 chronic CAD and cardiomyopathies)—the time interval between the two MRI examinations was significantly different. In fact, the range of time between the two examinations in the nine patients with myocarditis was significantly lower (2.78 days; range, 2–7 days) compared with that of the patients with chronic conditions (7.45 days; range 2–13 days) ($p < 0.01$).

Cardiac MRI Protocol

Cardiac MRI was performed with a 1.5-T whole-body scanner (Achieva Nova, release 2, Philips Healthcare) with maximum gradient strength, 33 mT/m; maximum gradient slew rate, 180 $mT/m^{-1}s^{-1}$) with a five-element cardiac phased-array coil (SENSE-Cardiac, Philips Healthcare).

Late enhancement imaging was performed in the short- and long-axis planes; the images were acquired at 10, 15, and 20 minutes after peripheral bolus injection of gadobutrol by using a 3D turbo field echo inversion recovery T1-weighted sequence (TR range/TE, 3.8–4.1/1.2; flip angle, 15°; inversion time, individually optimized to null the signal of normal myocardium; matrix, 256 × 256; and thickness, 5 mm). The short-axis images were acquired to encompass the entire left ventricle from the base to the apex with two acquisition datasets with two or three different breath-holds and were used for the automatic analysis described later. No SENSE technique was used. Total acquisition time averaged 40 minutes.

Cardiac MR Image Analysis

Cardiac MR images were evaluated on the basis of a two-point scale (presence or absence of late enhancement). For late enhancement evaluation, the myocardium was segmented on the basis of the 17-segment classification reported by the American Heart Association [26].

Image analysis was performed with an image-processing workstation (ViewForum R5.1V1L1 SP1, Philips Healthcare) using the cardiac analysis software package. Twenty contiguous short-axis late enhancement images, encompassing the entire left ventricle from the base to the apex, were semiautomatically analyzed to obtain late enhancement extension expressed both as volume and as a percentage of left ventricular mass. The semiautomatic late enhancement quantification was performed using an SD above a remote area technique. A region of interest (ROI) was traced by an operator on a region of unenhanced myocardium (remote area), and the late enhancement areas were defined as areas presenting signal intensities 6 SDs above the mean signal of the remote region according to previous studies [27, 28].

The late enhancement location and pattern (subendocardial, midwall, subepicardial, or transmural) of late enhancement were assessed. In addition, the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were measured by the signal intensities (SIs) obtained from ROIs placed in the normal myocardium, late enhancement areas, left ventricular cavity, and air outside the patient's body.

SNR was calculated with the following formula: $SNR = SI_{MLE} / SD_A$, where SI_{MLE} is the signal intensity of late enhancement area and SD_A is the SD of signal in air outside the patient's body. CNR values were calculated with the following formula: $CNR_{MLE\text{-}NM} = (SI_{MLE} - SI_{NM}) / SD_A$ and $CNR_{MLE\text{-}LVC} = (SI_{MLE} - SI_{LVC}) / SD_A$, where $CNR_{MLE\text{-}NM}$ is the CNR between late enhancement and normal myocardium, $CNR_{MLE\text{-}LVC}$ is the CNR between late enhancement and the left ventricular cavity, SI_{NM} is the signal intensity in normal myocardium, and SI_{LVC} is the signal intensity in the left ventricular cavity.

Images were evaluated in consensus by two experienced radiologists with 16 and 8 years of experience with cardiac MRI who did not have knowledge of the clinical data or of the results of comparator images.

Statistical Analysis

Descriptive statistical parameters were calculated for quantitative variables: mean, SD, median, and range. All quantitative variables were normally distributed (Kolmogorov-Smirnov test). Frequency counts were calculated by category for qualitative variables. The efficacy analysis was carried out using a Student t test for paired data. A p value of < 0.05 was considered statistically significant. Data were correlated using Pearson correlation coefficients depending on their distribution pattern and Bland-Altman analysis. A

per-segment comparison was performed with the McNemar test.

Results

Extension and Quality of Late Enhancement

Late enhancement was not significantly different with gadobutrol and gadopentetate dimeglumine, both in terms of total volume of myocardium (37.8 ± 56.1 and 35.1 ± 46.7 cm^3, respectively; $p = 0.33$) and percentage of involvement of the myocardial wall (22.5 ± 19.1% and 22.0% ± 17.2%, respectively; $p = 0.67$). Individual patient data and late enhancement results are presented in Table 1. To differentiate the performance of gadobutrol in the evaluation of different pathophysiology, we divided the study population in three different subgroups: one composed of patients with acute myocarditis, the second composed of patients with CAD, and the third of patients with cardiomyopathy. In the three different groups, the results of gadobutrol for detection of late enhancement were not significantly different from those obtained with gadopentetate dimeglumine. Late enhancement was not significantly different with gadobutrol and gadopentetate dimeglumine, in terms of total volume of myocardium and percentage of involvement of the myocardial wall in the myocarditis group (21.8 ± 23.5 and 21.8 ± 21.3 cm^3, respectively; $p = 0.99$; 19.9% ± 12.2% and 18.0% ± 12.0%, respectively; $p = 0.52$), in the CAD group (37.9 ± 29.8 cm^3 and 36.6 ± 30.3 cm^3, respectively; $p = 0.63$; 25.3 ± 15.2% and 24.2 ± 14.9%, respectively; $p = 0.45$) and in the cardiomyopathy group (61.7 ± 96.0 cm^3 and 54.4 ± 77.8 cm^3, respectively; $p = 0.40$; 27.7 ± 28.8% and 26.4 ± 25.8%, respectively; $p = 0.48$).

To avoid results above the point of 200 cm^3, corresponding to amyloidosis, analysis of the Pearson correlation of late enhancement volume and late enhancement percentage was performed without this point, showing a strong significant correlation between gadopentetate and gadobutrol values in terms of late enhancement volume ($R = 0.97$; $p < 0.001$) and late enhancement percentage ($R = 0.95$; $p < 0.001$) (Fig. 1). Bland-Altman analysis showed very good agreement in the comparison between gadobutrol and gadopentetate dimeglumine in detection of late enhancement volume and late enhancement percentage (Fig. 2).

The number of left ventricular segments involved was not different (138 with gadopentetate dimeglumine vs 134 with gadobutrol; *p*, not significant); differences were recorded in

TABLE 1: Individual Patient Data and Late Enhancement Results

Patient No.	Pathology	Time Interval (d)	Volume (cm^3)		Percentage Late Enhancement		SNR		CNR		Inversion Time (msec)	
			Gadopentetate Dimeglumine	Gadobutrol	Gadopentetate Dimeglumine	Gadobutrol	Gadopentetate Dimeglumine	Gadobutrol	Gadopentetate Dimeglumine	Gadobutrol	Gadopentetate Dimeglumine	Gadobutrol
1	Myocarditis	2	14.19	13.11	10.20	10.10	137.30	105.00	123.60	104.00	230	350
2	Myocarditis	7	9.01	10.86	11.70	14.80	73.70	112.20	43.00	92.60	270	325
3	CAD	12	44.46	55.63	30.00	36.60	213.40	217.50	169.90	121.70	260	370
4	Myocarditis	2	3.85	2.43	12.90	9.00	79.50	64.90	68.00	61.20	220	300
5	Myocarditis	3	2.28	1.36	4.60	26.00	349.00	220.00	251.00	127.40	240	310
6	CAD	7	83.20	78.46	41.70	41.00	90.00	71.10	70.50	61.50	230	290
7	Amyloidosis	5	209.62	255.57	76.00	84.50	246.90	222.40	237.30	154.50	300	460
8	Myocarditis	2	69.41	70.63	19.00	22.00	195.50	196.00	138.00	157.00	240	240
9	Myocarditis	2	12.31	12.95	17.80	19.00	72.50	73.10	44.70	45.90	280	320
10	Myocarditis	2	32.62	33.04	46.70	44.60	93.78	92.20	65.50	70.00	260	260
11	HCM	2	52.75	45.17	33.00	30.20	76.95	42.75	58.30	23.74	230	350
12	Myocarditis	3	16.66	6.08	16.00	5.00	97.00	23.00	62.00	7.00	230	340
13	CAD	9	31.40	32.43	29.60	28.60	151.00	314.00	119.80	284.70	240	240
14	HCM	13	22.14	20.93	14.50	11.50	30.70	12.30	24.70	8.20	220	270
15	HCM	6	21.49	19.41	11.80	11.00	56.00	34.40	26.50	15.50	220	340
16	Sarcoidosis	11	1.83	1.77	14.00	17.60	43.55	23.04	34.43	22.04	230	250
17	CAD	2	2.10	2.22	2.60	3.60	54.80	58.40	38.40	39.70	230	270
18	Myocarditis	2	35.80	45.84	23.00	29.00	181.63	206.60	153.40	165.17	200	270
19	CAD	8	21.59	20.85	17.00	16.90	190.00	205.00	157.00	178.00	220	320
20	HCM	7	18.34	27.31	8.80	11.50	43.50	49.40	38.20	27.75	240	350

NOTE—SNR = signal-to-noise ratio, CNR = contrast-to-noise ratio, CAD = coronary artery disease, HCM = hypertrophic cardiopathy.

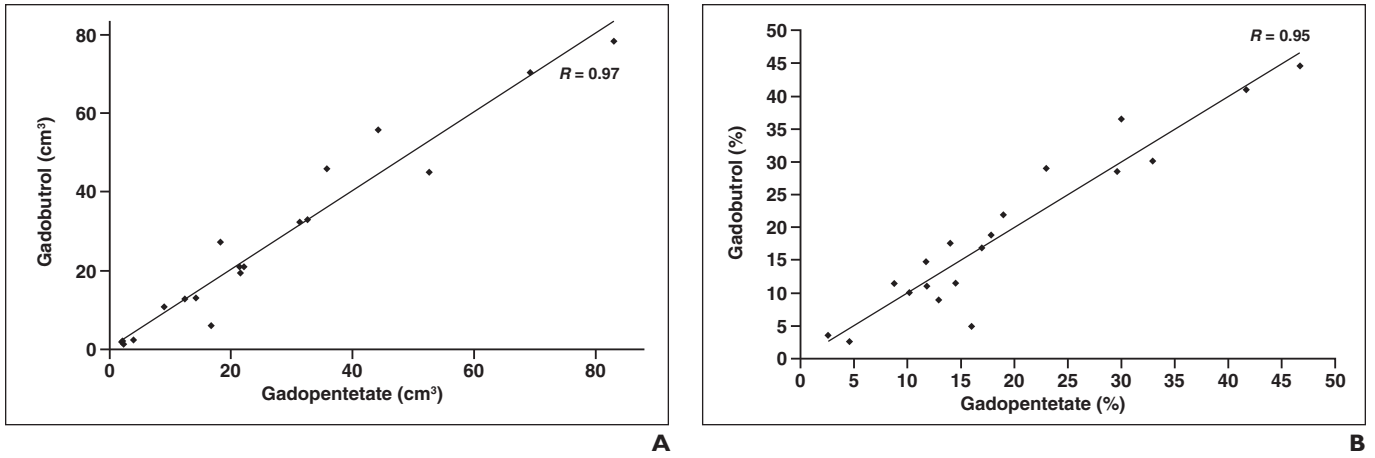

Fig. 1—Charts show correlation between myocardial late enhancement volume and percentage obtained with gadobutrol and gadopentetate. Associations between gadobutrol and gadopentetate were analyzed with Pearson correlation coefficient.
A and **B,** Correlation coefficient shows strong correlation between gadobutrol and gadopentetate late enhancement volume (**A**) ($R = 0.97$; $p < 0.001$) and gadobutrol and gadopentetate late enhancement percentage (**B**) ($R = 0.95$; $p < 0.001$).

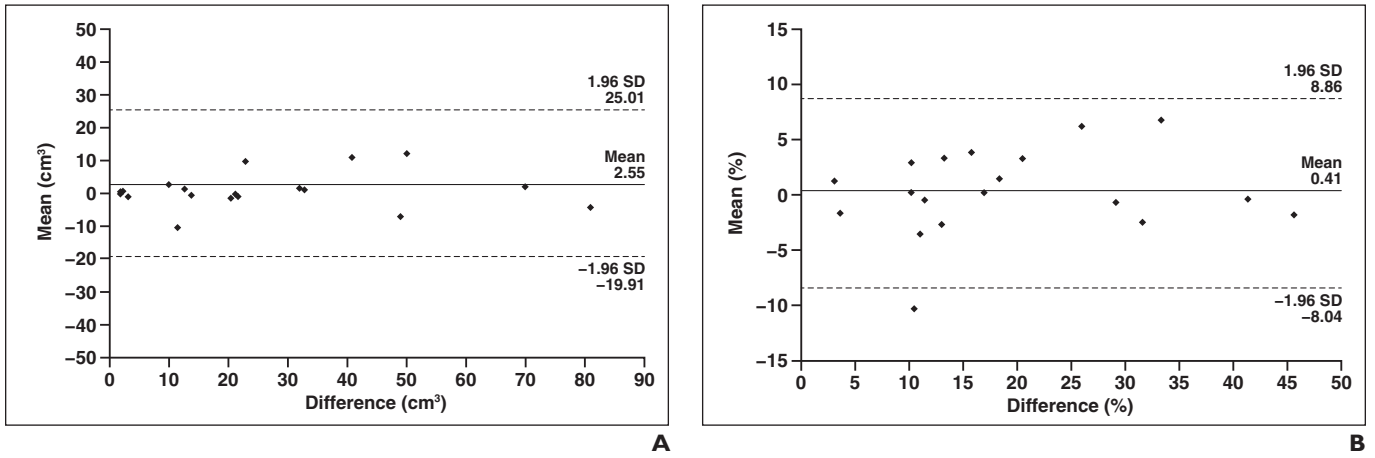

Fig. 2—Bland-Altman analysis of volume difference and percentage.
A and **B,** In Bland-Altman analysis of late enhancement volume (**A**), difference between gadobutrol volume and gadopentetate volume is drawn against mean in 19 paired measurements from study, and in Bland-Altman analysis of late enhancement percentage (**B**), difference between gadobutrol percentage and gadopentetate percentage is drawn against mean in almost all measurements in study. Solid lines indicate overall bias and dashed lines indicate 1.96 SD.

six patients (30%), which was more than one segment in only two cases (10%). Late enhancement was transmural in seven patients (35%). There was full agreement in the transmurality results achieved with the two contrast agents. The distribution pattern was linear in 11 patients, linear and nodular in five, nodular in two, widespread linear in one, and widespread in one. There was full agreement between contrast agents in all patients.

Signal Intensity Measurement

SNR was not significantly different with the two contrast agents (123.8 ± 82.9 with gadopentetate dimeglumine and 117.2 ± 88.6 with gadobutrol; $p = 0.58$) as with the CNR (96.2 ± 68.9 vs 88.4 ± 72.9; $p = 0.53$). Furthermore, CNR values between late enhancement and cavity signal were not significantly different between gadobutrol-enhanced images ($CNR_{MLE\text{-}LVC} = -14.3 \pm 33.3$) and gadopentetate-enhanced images (−26.6 ± 45.5). Bland-Altman analysis showed good agreement in the comparison between gadobutrol and gadopentetate for SNR and CNR (Fig. 3).

Inversion Time and Delay Time

The selected delay time usually was 10 or 15 minutes (13.7 ± 3.7 minutes). Inversion time ranged from 240 to 460 milliseconds (312 ± 55 milliseconds). The mean inversion time for the nulling of the signal of the normal myocardium after gadobutrol administration (311.2 ± 53.4 milliseconds) was significantly higher ($p < 0.001$) than the optimum inversion time for the gadopentetate-enhanced images (239.5 ± 23.7 milliseconds).

Discussion

Most studies using contrast-enhanced cardiac MRI for the detection of myocardial injury have been performed with gadopentetate dimeglumine [1–12]. Within the past decade, however, additional MRI contrast agents have been approved for use in imaging for different indications in routine clinical practice [13–16]. To our knowledge, no studies have ever compared the use of a double dose of gadopentetate dimeglumine with the use of a single dose of gadobutrol in the detection of late enhancement. With regard to cardiac MRI indications,

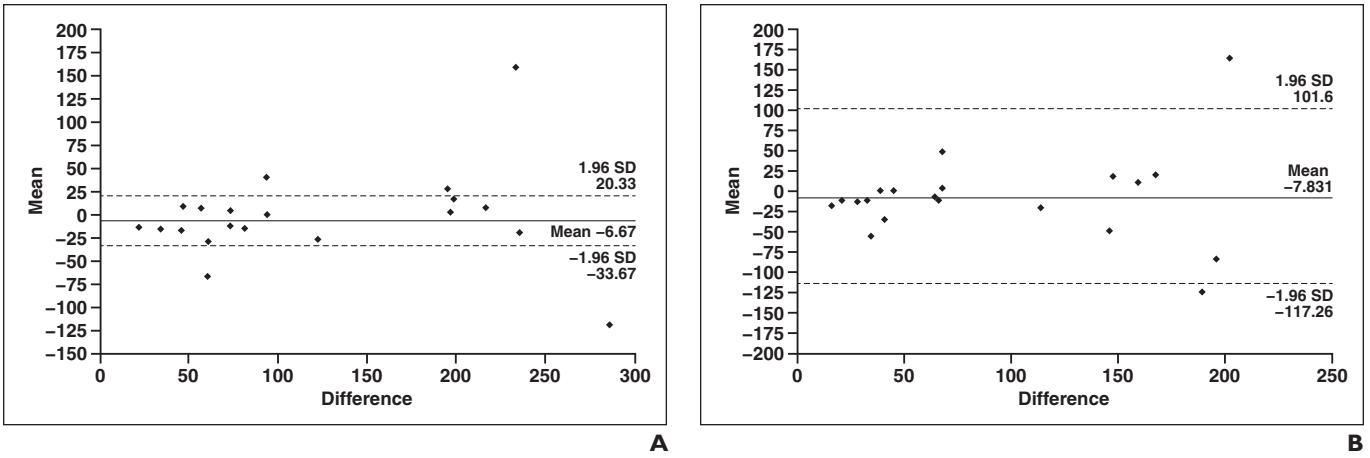

Fig. 3—Bland-Altman analysis of signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR).
A and **B,** In Bland-Altman analysis of SNR (**A**), plot estimates good agreement between difference of gadobutrol SNR and gadopentetate SNR against mean, and Bland-Altman analysis between difference of gadobutrol CNR and gadopentetate CNR (**B**) also shows good agreement against mean. Solid lines indicate overall bias and dashed lines indicate 1.96 SD.

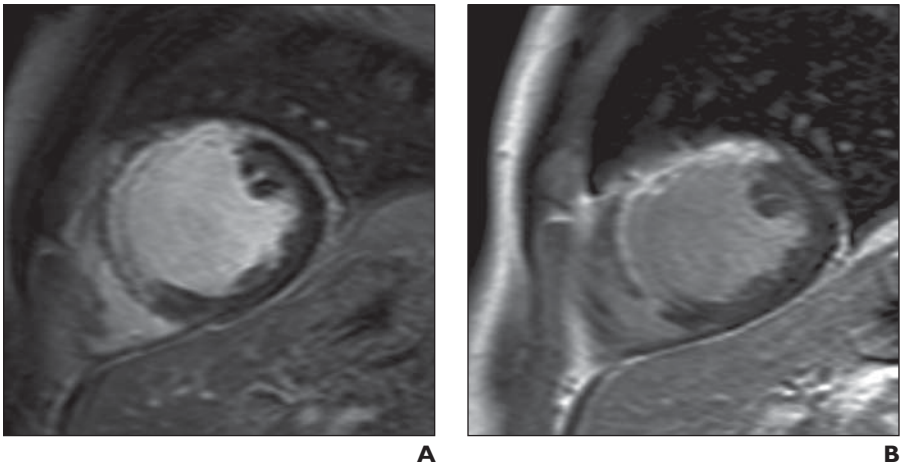

Fig. 4—Transmural anterior chronic myocardial infarction in 47-year-old man. ECG-triggered turbo field echo inversion recovery T1-weighted images were obtained in short-axis two-chamber view.
A, Gadopentetate-enhanced image shows large anterior transmural myocardial late enhancement.
B, Corresponding gadobutrol-enhanced image clearly shows same area, extension, and transmurality of infarct.

it has been shown that gadobutrol appears to be better suited than gadopentetate for detection of perfusion defects in MR perfusion studies [23, 24, 29, 30]. In a recent study, Fenchel et al. [23] were the first to examine gadobutrol for multislice first-pass magnetic myocardial perfusion imaging. They conducted a phantom study in which the SNR and CNR values of gadobutrol were compared with those of gadopentetate. Interestingly, they found that the determination of T1 relaxation times at the various concentrations of gadobutrol-doped phantoms yielded a significant decrease in T1 relaxation time compared with identical concentrations of gadopentetate—that is, the effect of gadobutrol on T1 was more pronounced. Furthermore, they found interesting results in 25 consecutive patients with clinically suspected CAD who underwent dynamic rest-stress MR perfusion examinations. In fact, rest-stress myocardial perfusion examinations using 0.05 mmol/kg of gadobutrol yielded high sensitivity and specificity in detection of CAD (82% and 91%, respectively). Similar results have been found more recently by Klumpp et al. [24] using high-resolution myocardial MR stress gadobutrol perfusion imaging at 3 T. In a group of 57 patients with symptoms of CAD, stress-induced hypoperfusion was found in 43 patients, yielding 95–98% sensitivity for hemodynamically relevant CAD and suggesting that high-resolution stress MR perfusion at 3 T using a 1-M contrast agent provides reliable detection of stress-induced myocardial hypoperfusion. Therefore, these reports seem to suggest that gadobutrol is a favorable contrast medium for evaluation of stress myocardial perfusion because of its high concentration and that it seems to help to overcome the well-known shortcomings of lower-concentration gadolinium-based contrast agents, that is, low SNR and CNR.

The novelty of our study is that, for the first time, we report that late enhancement obtained with single-dose gadobutrol was not inferior to that obtained with double-dose gadopentetate dimeglumine; in fact, the intraindividual comparison between the two contrast media showed full agreement in terms of late enhancement extension, location, pattern of distribution, SNR, and CNR. Therefore, we believe that, combining the high efficacy in the cardiac perfusion in previously reported studies and our results of good performance on late enhancement depiction, gadobutrol may be considered an excellent choice for cardiac MRI.

Gadopentetate dimeglumine has been the most used gadolinium-based extracellular contrast agent for detection of late enhancement; however, the use of this agent is now questioned because of reports of nephrogenic systemic fibrosis (NSF) in patients with se-

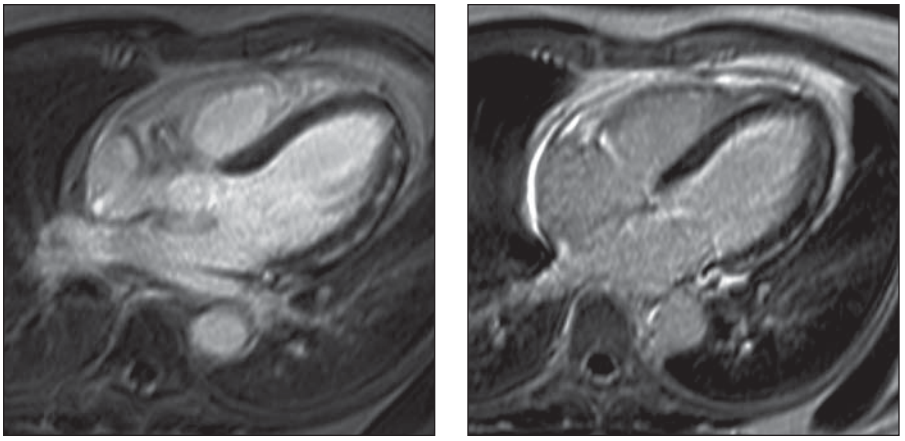

Fig. 5—Acute myocarditis in 62-year-old man. ECG-triggered turbo field echo inversion recovery T1-weighted images were obtained in long-axis four-chamber view.
A and **B,** Gadopentetate-enhanced (**A**) and gadobutrol-enhanced (**B**) images clearly show comparable subepicardial myocardial late enhancement foci and striae in lateral wall.

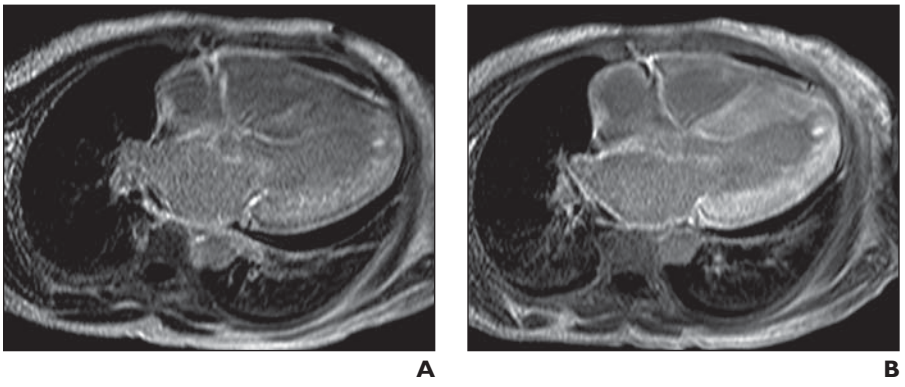

Fig. 6—Cardiac amyloidosis in 42-year-old woman. ECG-triggered turbo field echo inversion recovery T1-weighted images were obtained in long-axis four-chamber view.
A and **B,** Gadopentetate-enhanced (**A**) and gadobutrol-enhanced (**B**) images show presence of comparable diffuse myocardial late enhancement.

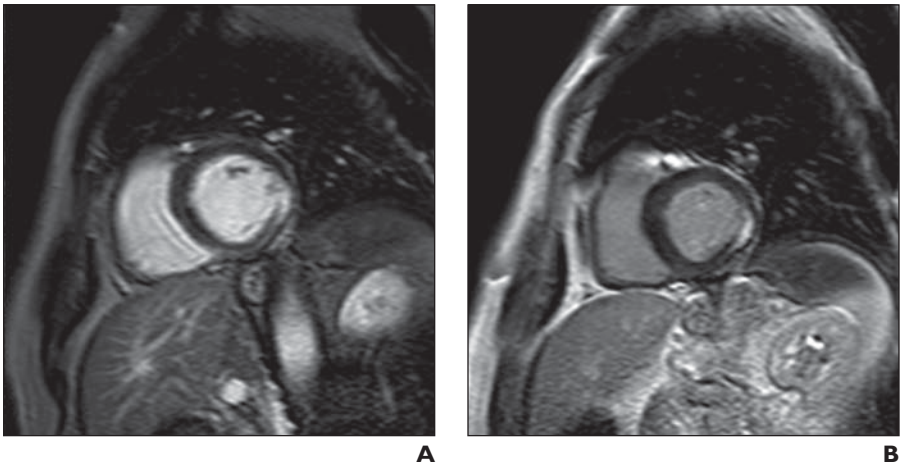

Fig. 7—Cardiac sarcoidosis in 68-year-old man. ECG-triggered turbo field echo inversion recovery T1-weighted images were obtained in short-axis two-chamber view.
A and **B,** Gadopentetate-enhanced (**A**) and gadobutrol-enhanced (**B**) images show presence of myocardial late enhancement in lateral wall.

vere renal failure. In November 2009, the European Medicines Agency (EMEA) published an assessment document in which this compound is classified among those associated with a high risk of NSF [31]. NSF is a rare, debilitating, and potentially fatal disease that causes fibrosis of the skin; musculoskeletal system; and internal organs, such as the liver, lungs, and heart in patients with severe renal disease. There is no effective treatment for NSF, making prevention essential [32, 33]. It is thought that the mechanism of action is the release of toxic gadolinium from unstable chelate [31]. Contrast agents associated with a high risk of NSF, such as gadopentetate dimeglumine, are no longer recommended in patients with renal failure. According to the EMEA categorization of gadolinium-containing contrast agents [17], gadobutrol is associated with a low risk of NSF, and macrocyclic contrast agents, such as gadobutrol, are recommended for contrast-enhanced MRI in patients at risk.

Our findings apply to a broad range of patients because the study population included both sexes; young, middle-aged, elderly, and very old patients (age range, 20–81 years); and a broad range of diagnoses (CAD, myocarditis, various types of cardiomyopathies) (Figs. 4–7).

However, the results of the study need to be interpreted critically because of some significant study limitations, including small sample size and inhomogeneity of the study population. The small sample size can be considered the major study limitation. First, only a small group of patients with CAD, myocarditis, and cardiomyopathies were examined. To prevent this inhomogeneous population from resulting in biased findings, we evaluated the performance of gadobutrol in three different subgroups: one composed of patients with acute myocarditis, the second composed of patients with CAD, and the third composed of patients with cardiomyopathies. The results of gadobutrol in detection of late enhancement were not significantly different from those obtained with gadopentetate dimeglumine; therefore, we can conclude that gadobutrol may work nicely for patients with different pathophysiology. Another main limitation is that acute CAD is missing from the population of the study, although contrast agents are used routinely for this purpose at many sites. However, in our department, the main reasons for the examinations are inflammatory myocardial diseases, viability, and cardiomyopathies as we gain experience [10, 12]. Thus, there may be a selection bias for the pathology that comes to our attention. Future work will focus on testing gadobutrol within relevant population subgroups. Despite the ability to perform intraindividual comparisons within the current study, the data need to be validated with larger patient cohorts.

Another limitation of the study could be that allowing up to 2 weeks between the examinations using the two agents could theoretically introduce time bias in the imaging of late enhancement, depending on the acuity of myonecrosis. However, if we consider patients with an acute condition (e.g., myocarditis), the range of time between the two examinations in this group of patients was low and significantly lower compared with that of the patients with chronic conditions. Therefore, we believe that this small time difference in the acute setting avoids the presence of time bias.

In conclusion, our preliminary findings suggest that single-dose gadobutrol is as effective as double-dose gadopentetate dimeglumine for the detection and quantification of myocardial late enhancement in cardiac MRI.

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