CAIPIRINHA in Gadoxetic Acid-Enhanced Liver MRI: Can We Clarify the Hepatic Arterial Phase?

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Introduction

The arterial dominant phase has been accepted as an essential and most important phase for the characterization of focal liver lesions, especially in patients with chronic liver disease. This phase is currently achieved using 3-dimensional (3D) 'Gradient Recalled Echo' (GRE) imaging with fat suppression. Breath-hold T1-weighed volumetric GRE sequences ('Volumetric Interpolated Breath-hold Examination', VIBE) allow motion-free acquisition of diagnostic quality images within a single breath-hold period of up to 20 seconds in most patients [1, 2].

Image quality highly depends on the breath-holding capability of the patients. Therefore a short acquisition time is highly important for liver MRI. The partially parallel acquisition technique generated high-speed imaging. Among the recently developed parallel imaging techniques, 'Controlled Aliasing In Parallel Imaging Results In Higher Acceleration' (CAIPIRINHA) is a promising algorithm that allows a further reduction in image acquisition time while maintaining resolution [3, 4]. It is based on a modification of the undersampling method used in

Table 1:

	Group 1	Group 2	Group 3	Group 4
Temporal matching of data acquisition	Fixed scan (20 s delay)	Bolus triggering	Bolus triggering	Bolus triggering
Contrast injection rate	2 ml/s hand injection	1 ml/s automatic injector	1 ml/s automatic injector	1 ml/s automatic injector
MR system	3T (MAGNETOM Trio, a Tim system; Siemens Healthcare)	3T (MAGNETOM Trio, a Tim system; Siemens Healthcare)	3T (MAGNETOM Skyra; Siemens Healthcare)	3T (MAGNETOM Skyra; Siemens Healthcare)
MR parameters				
TR (ms)	3.37	3.38	3.19	4.12
TE (ms)	1.23	1.23	1.47	1.74
Flip angle (°)	10	10	11	9
Slice thickness (mm)	3, 2	3	3.3	3.5
Number of signal averages	1	1	1	1
Matrix	256 × 157	256 × 157	320 × 240	320 × 182
Field-of-view	285 × 285	278 × 278	285 × 285	348 × 350
Acceleration factor	2	2	2	4
Delta shift	NA	NA	NA	1
Acquisition time (s)	20	18	18	13
k-space	Linear	Centric-ordered	Linear	Segmented linear

Scanning method for gadoxetic acid-enhanced dynamic liver MRI of each group.

the 'GeneRalized Auto calibrating Partially Parallel Acquisition' (GRAPPA) technique.

Generally, 2-dimensional (2D) parallel imaging accelerates data acquisition in the phase- and partition-encoding directions simultaneously, whereas the commonly used 1-dimensional (1D) parallel imaging accelerates data acquisition in the phase-encoding direction. In 2D CAIPIRINHA, in addition to the standard 2D parallel imaging, the acquisition pattern is modified by shifting the sampling positions from their original locations with respect to each other in the partition-encoding direction, which is called a delta shift [3]. Shifting the sampling positions so that sensitivity variations in the receiver coil array are exploited more efficiently results in an improvement in parallel imaging reconstruction.

Therefore, the use of CAIPIRINHA provides better image quality and allows the use of higher acceleration factors. It reduces the acquisition time more effectively than the standard 1D and 2D parallel imaging techniques do and can be applied to 3D volume imaging [3, 4].

Gadoxetic acid (EOB) is now widely used for its added value during the hepatobiliary phase [5-7]. However, poor image quality has been reported on the arterial dominant phase of the dynamic liver MRI more frequently using gadoxetic acid than using other extracellular gadolinium contrast agents [8]. The lower dose of gadoxetic acid results in a short duration of injection, which leads to an abrupt change of gadolinium concentration during *k*-space filling in the hepatic arterial phase, narrowing the time window for optimal imaging. In addition, acute transient dyspnea has been reported significantly more often than with gadobenate dimeglumine [8-10]. However, in our experience, the incidence of spoiled arterial phase was different. In the period of initial use, overall 10% was developed. We have not observed any case of severely degraded arterial dominant phase of GD-EOB-DTPA-enhanced liver MRI [11].

Therefore, the purpose of this paper was to evaluate the feasibility and technical quality of an abdominal 3D VIBE MR examination using the new parallel acquisition technique, CAIPIRINHA, and to determine whether CAIPIRINHA technique could improve the image quality of the hepatic arterial phase of gadoxetic acid-enhanced liver MR imaging.

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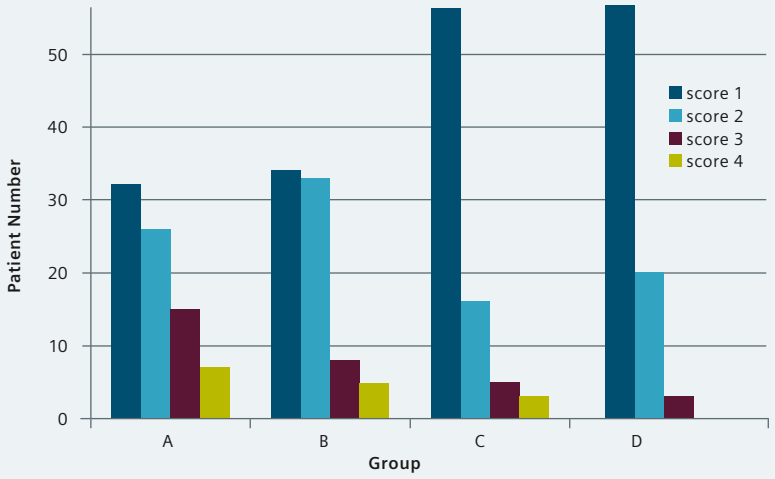


1 Frequency of image quality scores among the 4 groups.

Materials and methods

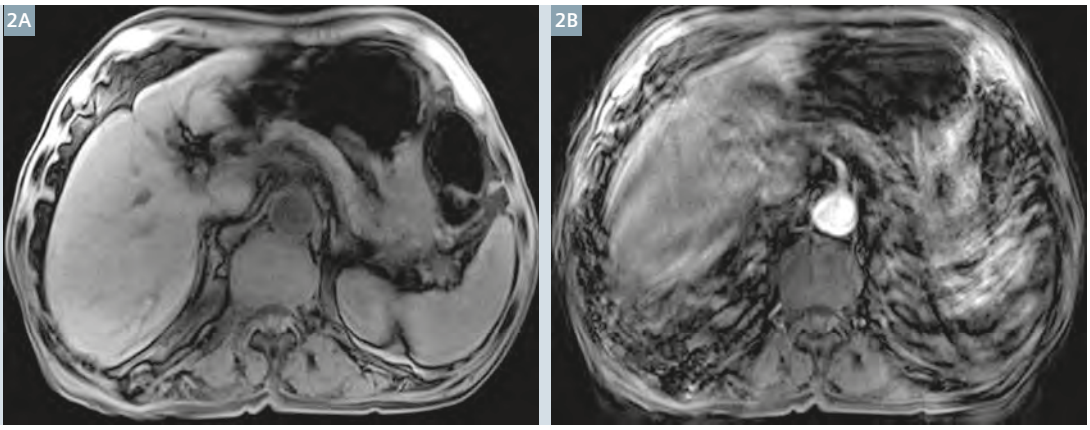
Subjects

This retrospective study was approved by the Institutional Review Board, and the requirement for informed consent was waived. We retrospectively enrolled a total of 320 eligible patients (198 men and 122 women; mean age, 58.8 ± 12.0 years; age range, 26–85 years) who underwent gadoxetic acid-enhanced liver MRI using different protocols on different systems during separate time periods. From January 2008 to March 2008, 80 patients underwent an examination using a conventional protocol on a standard 3T MRI system (group A); from July 2010 to September 2010, 80 patients underwent an examination using an optimized protocol with a standard 3T MRI system (group B); during July 2012, 80 patients underwent an examination using an optimized protocol and a newer 3T MRI system (group C); and during January 2013, 80 patients underwent an examination using a combination of an optimized protocol and the CAIPIRINHA technique on a newer 3T MRI system (group D).

MR imaging

All patients underwent MRI on one of two kinds of 3T MR systems. A standard 3T MRI machine (MAGNETOM Trio a Tim System; Siemens Healthcare, Erlangen, Germany) with a standard 6-channel body matrix coil and table-mounted 6-channel spine matrix coil had been employed for groups A and B; a newer 3T MRI machine (MAGNETOM Skyra; Siemens Healthcare, Erlangen, Germany) with a standard 18-channel body matrix coil and table-mounted 32-channel spine matrix coil had been employed for groups C and D.

For dynamic imaging, a T1-weighted 3D spoiled GRE sequence with fat saturation and VIBE images was acquired before and after the administration of an intravenous bolus of 0.1 ml/kg of gadoxetic acid (Primovist; Bayer Pharma AG, Berlin, Germany) through a 20- to 22-gauge antecubital venous catheter. The sequence parameters are summarized in Table 1. The hepatic arterial phase was defined differently depending on the group. For group A, the arterial phase acquisition commenced after a fixed scan delay of 20 s after the hand injection of con-



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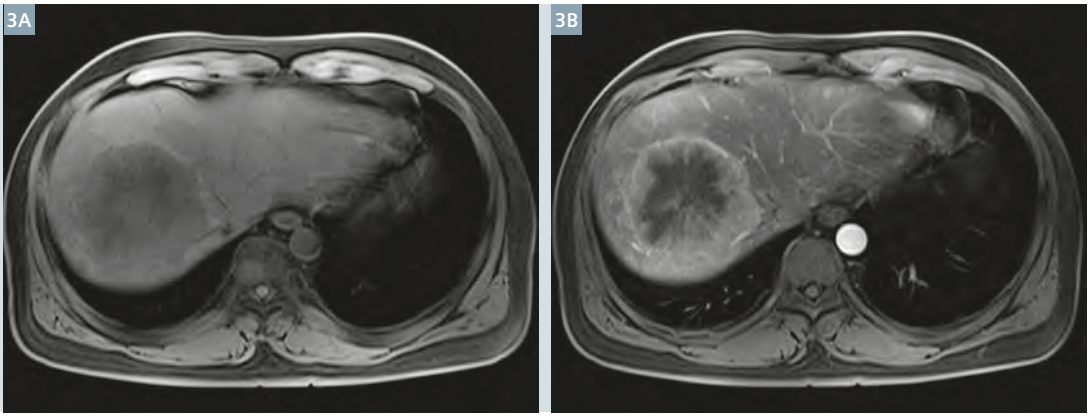
77-year-old male patient with liver cirrhosis from group C. **(2A, B)** Pre-contrast scan and hepatic arterial phase were obtained using a standard VIBE sequence during an 18 s breath-hold. Compared to the pre-contrast image, the hepatic arterial phase is degraded by severe artifacts, especially by a severe respiratory motion artifact.



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52-year-old male patient with hepatitis B from group D. **(3A, B)** Compared to the pre-contrast image, the hepatic arterial phase with CAIPIRINHA obtained during a 13 s breath-hold shows good image quality without any artifacts.

trast medium at a rate of 2 ml/s, followed by a 25 ml saline flush. For groups B–D, the arterial phase was ascertained using the bolus tracking method after the start of a mechanical contrast injection (Spectris MR; Medrad Europe, Maastricht, Netherlands) at a rate of 1 ml/s, followed by a 25 ml saline flush. Under real-time monitoring, arterial phase scanning was initiated immediately after the arrival of the contrast medium in the descending thoracic aorta for groups B and C. For group D, arterial phase scanning began immediately after the arrival of the contrast medium at the aortic arch. CAIPIRINHA-VIBE used a separate calibration scan to determine the coil sensitivity variation and to calculate the full field-of-view without aliasing, whereas the standard VIBE (GRAPPA) sequence for groups A–C used integrated calibration or autocalibration. Thus, the calibration scan for CAIPIRINHA-VIBE is separate from the acceleration scans, but requires only minimal additional time (approximately 3 s). The total breath-hold time for the hepatic arterial phase is approximately 13 s, which includes the 3 s calibration time and the 10 s acceleration time.

Portal venous phase, equilibrium phase, and hepatobiliary phase images were acquired 70 s, 2 min, and 20 min, respectively, after the injection of contrast medium for all patients.

In our study, the CAIPIRINHA technique was used with an acceleration factor of 4 (2 × 2) and a delta shift of 1, which includes 2-fold acceleration in the phase-encoding direction, 2-fold acceleration in the partition-encoding direction, and a reordering shift of 1 corresponding to a relative shift of the 2 neighboring acquired partition-encoding lines.

Image analysis

For the evaluation of hepatic arterial phase image quality, 2 radiologists (C. H. L. and Y. S. P., with 17 and 5 years of experience in abdominal imaging, respectively) blinded to the MR technique independently reviewed the hepatic arterial phase images and assigned a numeric image quality score using a 4-point rating scale. The scoring was as follows:
1 point, no artifacts;
2 points, mild artifacts with no effect on diagnostic quality;
3 points, moderate artifacts, but without a severe effect on diagnostic quality; and
4 points, non-diagnostic images with severe artifacts.

Statistical analysis

Differences in median image quality scores on the hepatic arterial phase among the 4 groups were assessed by using a Kruskal-Wallis test followed by the Dunn procedure for multiple comparisons. Statistical analyses were performed using commercially available software (SPSS, version 20.0, SPSS, Chicago, IL, USA; MedCalc, MedCalc Software, Mariakerke, Belgium).

Results and discussion

In terms of the patients' characteristics, there were no significant differences in age, sex, or the presence of liver

cirrhosis or ascites among groups A, B, C, and D (P = 0.674, 0.213, 0.076, and 0.055, respectively).

For the image quality scores of the hepatic arterial phase, agreement between the 2 observers was robust (weighted κ = 0.847). The median image quality score was 2 in groups A and B and 1 in groups C and D. Scores of 4 points (non-diagnostic images with severe artifacts) were observed in all groups except group D: 7 in group A, 5 in group B, and 3 in group C (Fig. 1). With optimized protocols and advanced techniques, the median image quality score decreased significantly from group A to group D (P = 0.0001), indicating that image quality was improved from group A to group D (Figs. 2, 3). The median image quality score was significantly lower in group D than in groups A and B (P = 0.0001 and 0.001, respectively). Additionally, group C showed a significantly lower median score than groups A and B (P = 0.0001 and 0.003, respectively). However, the median image quality score was not significantly different between groups A and B or between groups C and D (P = 0.448 and 0.656, respectively) (Fig. 4).

Respiratory motion artifacts are one of the major causes of image degradation in the hepatic arterial phase of dynamic-enhanced liver MRI. Currently, reducing scan time seems to be the best solution for avoiding the detrimental effects of respiratory motion. Our study demonstrated that using the CAIPIRINHA technique reduced the overall acquisition time from 20 s to 13 s (up to a 35% reduction in acquisition time), and shortened the breath-holding time (up to a 35% reduction) required to obtain arterial phase imaging. Using the CAIPIRINHA technique decreased the number of non-diagnostic arterial phase images and improved the general image quality of the hepatic arterial phase, although not to a significant extent when compared with an optimized protocol on a newer scanner.

In the past, degraded hepatic arterial phase images were more frequently observed on gadoxetic acid-enhanced liver MRI than with other gadolinium-based contrast agents [8, 12]. Image degradation caused by the narrow time window for precise arterial phase timing due to the small volume of gadoxetic acid might be prevented by optimized protocols, such as the test bolus technique, the bolus tracking technique, and a lower injection rate [6, 7, 10, 13]. Despite MR protocol optimization to obtain arterial phase images of diagnostic quality, various artifacts and non-diagnostic images are still occasionally encountered in clinical practice. Recently, gadoxetic acid has been shown to provoke subjective acute transient dyspnea significantly more often than other contrast media [8]. This can disturb breath-holding and can induce respiratory motion artifacts during the hepatic arterial phase. To overcome this problem, a reduction in scanning time is of paramount importance. Although parallel imaging techniques are already used to reduce scanning time [2, 14, 15], a further reduction of acquisition time necessitates a high-performance scanner with increased numbers of coil elements [14]. We implemented a new parallel imaging technique, CAIPIRINHA, using the newest generation MR scanner, including a standard 18-channel body matrix coil and table-mounted 32-channel spine matrix coil, which reduced the acquisition time for the hepatic arterial phase by up to 13 s.

The clinical feasibility of CAIPIRINHA has been researched for the hepatobiliary phase of gadoxetic acid-enhanced MRI and liver MRI using non-hepatocyte specific contrast agents [4, 16]. They reported that for single-phase imaging of the liver, CAIPIRINHA reduced the acquisition time to a minimum of 6 s with preserved or improved spatial resolution. In a previous study, CAIPIRINHA was valuable in improving the image quality of the hepatobiliary phase [16]. However, we believe that adopting CAIPIRINHA for the hepatic arterial phase is quite different from its application in the hepatobiliary phase, because the hepatobiliary phase does not require precise timing. As opposed to GRAPPA, CAIPIRINHA uses a separate calibration scan before the acceleration scan (actual imaging), and additional time (approximately 3 s) for calibration is required in addition to the acceleration scan time (actual imaging time, approximately 10 s). For this reason, we commenced the arterial phase

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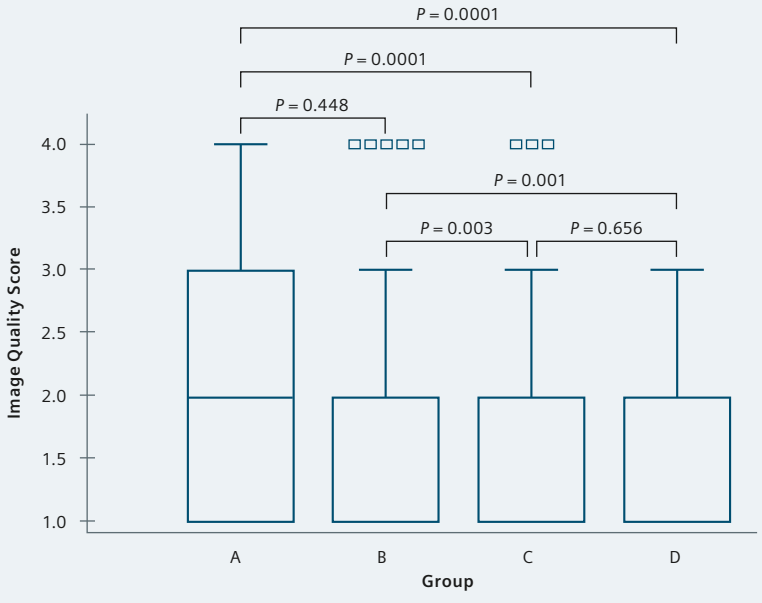

4 Box-and-whiskers plot showing the median image quality score among the 4 groups. The middle line in the box represents the median, and the lower and upper boundaries of the boxes represent the lower and upper quartiles (25th and 75th percentiles, respectively). The whiskers indicate the maximum and minimum scores.

scan immediately after detecting the arrival of the contrast media at the aortic arch, as opposed to GRAPPA, where the scan starts immediately after detecting the arrival of the contrast media in the descending thoracic aorta.

In addition, we found a significant improvement in image quality from group B to C ($P = 0.003$), even though both groups used the same optimized protocol on 3T MRI scanners. It is suspected that the increased number of coil elements in the newer MRI scanner (group C) may have accounted for the higher signal-to-noise ratio and better image quality observed. Moreover, there was no significant difference in image quality between groups A and B or between groups C and D, although a slight improvement in image quality was observed. This could explain why the type of MR scanner is a dependent factor in determining the image quality of the hepatic arterial phase, even among MR scanners of same field strength.

In conclusion, the use of the CAIPIRINHA technique reduced non-diagnostic arterial phase images and improved the image quality of the hepatic arterial phase in gadoxetic acid-enhanced liver MRI. Using CAIPIRINHA technique, the hepatic arterial phase can be clarified in gadoxetic acid-enhanced liver MRI.

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