



# Influence of the reference scan and scan time on the arterial phase of liver magnetic resonance imaging

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## Abstract

The controlled aliasing in parallel imaging results in higher acceleration (CAIPIRINHA) technique can decrease scan time. The purpose of this study was to determine whether an arterial phase scan can be performed in 5 s using the CAIPIRINHA short-scan and a reference scanning technique. The generalized autocalibrating partially parallel acquisition (GRAPPA), the CAIPIRINHA routine (CAIPI-routine), and the CAIPIRINHA short-scanning (CAIPI-short) methods were compared. The scan time for each method was preset to 20 s, 15 s, and 10 s, respectively. The reference scan had a scan time of 5 s. A phantom study was used to compare the influence of artifacts during the reference scan. For comparison, the phantom was moved during the last 5 s. In the clinical studies of suspected chronic liver diseases, magnetic resonance imaging of the liver is usually performed while the patient is breath-hold. The motion artifacts of each method were compared. Artifacts were reduced in reference scans using the CAIPIRINHA method. At 5 s after initiation, the rate of change in the standard deviation value was within 30% compared to that of the original image. Motion artifacts due to the influence of the reference scan when a patient failed to hold their breath did not complicate image evaluation. The proportion of motion artifacts for each sequence was as follows: GRAPPA, 5.8%; CAIPI-routine, 1.9%; and CAIPI-short, 0.7%. The arterial phase can be scanned in 5 s using the CAIPI-short and reference scan techniques.

**Keywords** Arterial phase · CAIPIRINHA · Liver · Motion artifact · Parallel imaging · Reference scan

## Abbreviations

ABH	All-breath-hold methods	CAIPI-routine	CAIPIRINHA routine method
AF	Acceleration factor	CAIPI-short	CAIPIRINHA short-scanning method
BHS	Breath-hold shortening methods	DCE	Dynamic contrast material-enhanced
BMI	Body mass index	GRAPPA	Generalized autocalibrating partially parallel acquisition
CAIPIRINHA	Controlled aliasing in parallel imaging results in higher acceleration	MRI	Magnetic resonance imaging
		ROI	Region of interest
		SD	Standard deviation
		SENSE	SENSitivity encoding
		SMASH	Simultaneous acquisition of spatial harmonics
		SNR	Signal-to-noise ratio
		TSM	Transient severe motion
		VIBE	Fat-suppressed 3D-volume interpolated breath-hold examination
		3D	Three-dimensional

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## 1 Introduction

The detection, characterization, and diagnosis of liver tumors are traditionally achieved through magnetic resonance imaging (MRI). For specific determination of the presence or absence of tumor vascularity, dynamic contrast material-enhanced (DCE) imaging is necessary [1–3]. Breath-hold DCE and hepatobiliary phase sequences are the key sequences required for performing an MRI of the liver. The image quality of the arterial phase of DCE can be significantly compromised by respiratory motion artifacts caused by incomplete breath-hold. According to previous reports, artifacts render the imaging results non-diagnostic at a rate ranging from 4.8 to 18% [4–8]. In previous studies, these probabilities were reduced [9].

Simultaneous acquisition of spatial harmonics (SMASH) and SENSitivity encoding (SENSE) are both parallel imaging techniques that have facilitated marked reductions in scan times [10, 11]. Generalized autocalibrating partially parallel acquisition (GRAPPA) was developed as a more progressive type of SMASH [12, 13]. GRAPPA uses an autocalibration signal by collecting more data in k-space, with improved accuracy and signal-to-noise ratio (SNR). Based on these improvements, the technique of controlled aliasing in parallel imaging results in higher acceleration (CAIPIRINHA) was developed [14, 15]. CAIPIRINHA samples data points in k-space while creating a shift that suppresses the increase in g-factor. Thus, even when using a high parallel factor during three-dimensional (3D) imaging, it is possible to suppress artifacts.

CAIPIRINHA is used in MRI examinations of the liver and allows for shorter scanning times [16]. This new parallel imaging technique has been used at various anatomical sites in previous studies [17, 18]. CAIPIRINHA allows for a shorter breath-hold time than does GRAPPA. Scan

times and aliasing artifacts can be reduced with parallel imaging by setting a high acceleration factor (AF). In this approach, a reference scan is first conducted, and with experience, CAIPIRINHA can obtain good images with this technique without requiring a set breath-hold time during the reference scan. This fact is unknown in many hospitals. To determine whether the use of a reference scan technique with the CAIPIRINHA method facilitates shortening of breath-hold time, we conducted both phantom and clinical studies.

## 2 Materials and methods

This retrospective study was approved by our institutional review board, who waived the requirement for obtaining informed consent.

### 2.1 Phantom study

All MR images were acquired using a 1.5-T system (Magnetom Avanto Dot VD13, Siemens Healthcare, Erlangen, Germany) with a phased-array matrix coil (anterior) and a spine matrix coil (posterior) for signal reception. Scan parameters are shown in Table 1. The liver phantom was a cylinder with a diameter of 150 mm and a length of 150 mm. To produce hepatic  $T1$  values, contrast material and agar was used in the phantom ( $T1$ -value = 520 ms;  $T2$ -value = 68 ms) [19]. A bottle phantom was fixed around the liver phantom (bottle phantom;  $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$ , NaCl, length of 200 mm) (Fig. 1). Only the liver phantom was designed to move. Gadoxetate disodium (Primovist, Bayer Pharma, Osaka, Japan) was used as contrast agent.

**Table 1** Magnetic resonance imaging parameters

	GRAPPA	CAIPI-routine	CAIPI-short
TR/TE (ms)	3.98/1.51	3.91/1.51	3.44/1.32
FA (degrees)	12	121	12
Slice thickness (mm)	2.5	2.5	3.5
Number of slice	80	80	56
Pixel size (mm)	1.8 × 1.1	1.8 × 1.1	2.0 × 1.1
FOV (mm)	262 × 350	262 × 350	262 × 350
Scan time (s)	21	15	10
PAT factor	2	3	3
Time to center (s)	10.3	9.9	7.6
Reference line	40/0	32/48	32/48
phase encode/slice encode			
Reference mode	Integrated	Separate	Separate

*TR* repetition time, *TE* echo time, *FA* flip angle, *FOV* field of view, *PAT* parallel acquisition technique, *PE* phase encode

To investigate the influence of a breath-hold, the phantom was moved in the head–foot direction (20 mm) for each of the imaging methods (Fig. 1). The timing of each move was as follows: A, 5 s after the start of the routine method (CAIPI-routine); B, 5 s before the end of the CAIPI-routine; C, 5 s after the start of the short-scanning method (CAIPI-short); D, 5 s before the end of the CAIPI-short; E, 5 s after the start of GRAPPA; and F, original image (i.e., the image in which the phantom was not moved was defined as the original image). Scans were performed using the GRAPPA, CAIPI-routine, and CAIPI-short methods. Axial-section imaging was performed, and the phase-encoding direction was anterior–posterior. To see the uniformity of the signal, the center of the phantom was measured with a region of interest (ROI) of 12 cm in diameters and standard deviation (SD) was also obtained. Average values were calculated from the respective timings of 10 imaging scans. Movement was made in one reciprocation for 2 s to measure the influence of movement on the phantom image in the head–foot direction (20 mm). The amount of movement of the phantom speed was determined in a previous study [20].

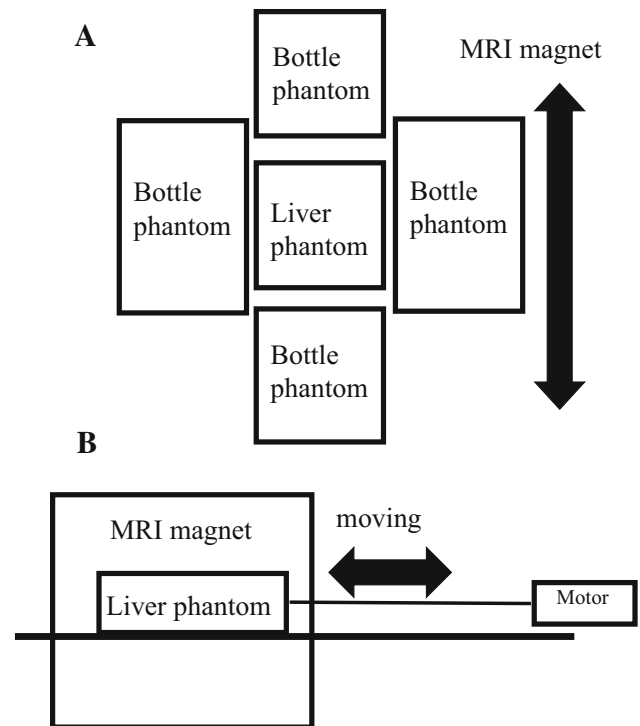
The phantom image at each time point (A–F) was evaluated, and the rates of change of SDs were compared. The ROI of the phantom center was used to measure SD. The rate of change of SD was evaluated using the average value. The rate of change of SD was defined as follows:

Rate of change of SD

$$= \left[ \frac{(\text{motion image SD} - \text{original image SD})}{(\text{original image SD})} \right] \times 100 \quad (1)$$

## 2.2 Clinical study

All patients were administrated gadoxetate disodium (Primovist; Bayer Pharma, Osaka, Japan) intravenously at a weight-based dose of 0.025 mmol/kg of body weight (0.1 mL/kg; maximum volume, 10 mL), followed by 30 mL of saline. All the injection rates were 1 mL/s. Arterial phase images were acquired using a real-time bolus display method (CARE Bolus, Siemens Healthcare) after visual detection of the contrast material at the celiac artery [4]. Routine gadoxetate disodium-enhanced liver MR examination, including transverse multi-phase contrast-enhanced T1-weighted breath-hold sequences, was conducted using a fat-suppressed 3D-volume interpolated breath-hold examination (VIBE). Scans were performed using a fat-suppressed 3D-VIBE sequence with different parallel imaging techniques: GRAPPA with acceleration factor (AF) = 2 and CAIPIRINHA with AF = 3 (three-fold acceleration in the partition-encoding direction). The scan time of the CAIPI-routine was set to 15 s. CAIPI-

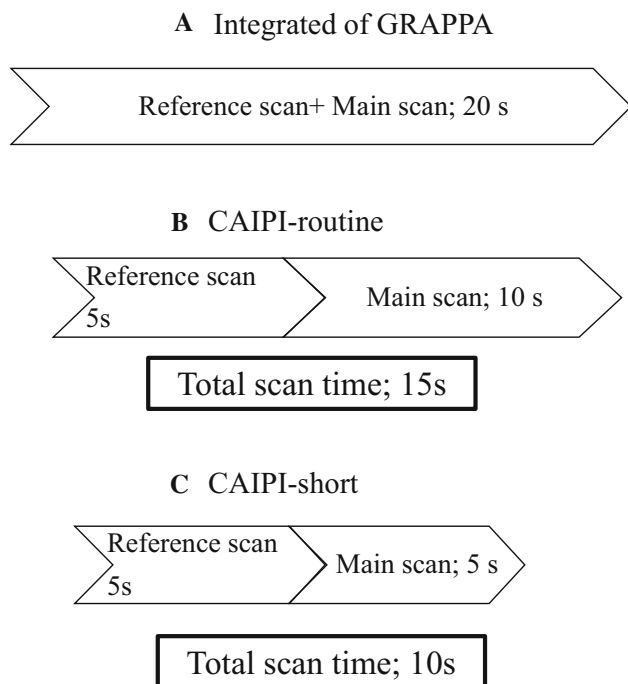


**Fig. 1** Placement of phantom and schematic of the movement. **a** A bottle phantom was fixed around the phantom. **b** Movement was made in one reciprocation in head–foot direction for 2 s to measure the influence of movement on the phantom image (20 mm). The phantom was moved by a motor. **a** Placement of phantom (**b**) schematic of motion

short had a scan time of 10 s. Both the CAIPI-routine and CAIPI-short began with a reference scan that comprised the first 5 s. The timing flow chart for each sequence is shown in Fig. 2.

The integrated of the GRAPPA method could not separate the reference scan from the remaining scan; however, the CAIPIRINHA technique allowed such separation. The slice thickness of CAIPI-routine scans was preset at 2.5 mm, and that of CAIPI-short scans at 3.5 mm. Scan times for the GRAPPA, CAIPI-routine, and CAIPI-short were 20, 15, and 10 s, respectively. Other parameters are shown in Table 1.

Between October 2013 and April 2016, a total of 554 patients with suspected focal liver lesions underwent gadoxetate disodium-enhanced liver MRI. The numbers of patients who underwent GRAPPA, CAIPI-routine, and CAIPI-short were 207, 206, and 141, respectively. The numbers of cirrhosis patients who underwent GRAPPA, CAIPI-routine, and CAIPI-short were 110, 101, and 90, respectively. The numbers of first experience of examination who underwent GRAPPA, CAIPI-routine, and CAIPI-short were 71, 49, and 39, respectively. The experience of examination was first or not, and the change in image quality was compared. Other study populations are shown



**Fig. 2** Flow chart showing timing. The scan time of the GRAPPA was set to 20 s. This setting simultaneously collected the reference scan and main scan. The scan time of the CAIPI-routine was set to 15 s. CAIPI-short had a scan time of 10 s. Both the CAIPI-routine and CAIPI-short methods began with a reference scan during the first 5 s. **a** Integrated of GRAPPA **(b)** CAIPI-routine **(c)** CAIPI-short. GRAPPA generalized autocalibrating partially parallel acquisition; CAIPI-routine, CAIPIRINHA routine method; CAIPI-short, CAIPIR-INHA short-scanning method

in Table 2. This investigation was performed retrospectively. Patient images were assigned either to non-transient severe motion (TSM) or the TSM group, according to the criteria listed below.

The image quality of the GRAPPA, CAIPI-routine, and CAIPI-short methods obtained during the arterial phase

was compared. Motion artifacts from the evaluations were also compared. For all 554 patients, images obtained in the dynamic arterial phases were anonymized, randomized, and reviewed by two readers, each with more than 20 years of experience in interpretation of abdominal MR images.

Each arterial phase image was rated on a five-point scale as follows: 5 = no motion artifact, 4 = minimal motion artifact, 3 = moderate motion artifact, 2 = severe motion artifact, and 1 = extensive motion artifact (Fig. 3). TSM was defined by a mean motion score of at least 2. Motion artifact scores were averaged across the two readers to produce a mean motion score for each arterial phase.

### 2.3 Comparison of breath-hold and breath-hold shortening methods under clinical conditions

Next, clinical images of the first and follow-up examinations were compared. All examinations were performed using the CAIPI-routine. The breath-holding time from before the reference scan to the arterial phase of the DCE were defined as the all-breath-hold method (ABH) and the time in the middle of the reference scan was defined as the breath-hold shortening method (BHS). The first examination method used ABH, and the follow-up examinations used BHS (mean days  $\pm$  SD,  $206 \pm 118$  days; range 9–390 days). The timing of breath-hold of BHS and ABH is shown in Fig. 4. Motion artifact scores of these two conditions were also compared. The number of patients was 30, including 19 male and 15 cirrhosis patients. The median age, body weight, and body mass index (BMI) were  $69 \pm 11.3$  years,  $63 \pm 13.2$  kg, and  $22.7 \pm 3.6$ , respectively.

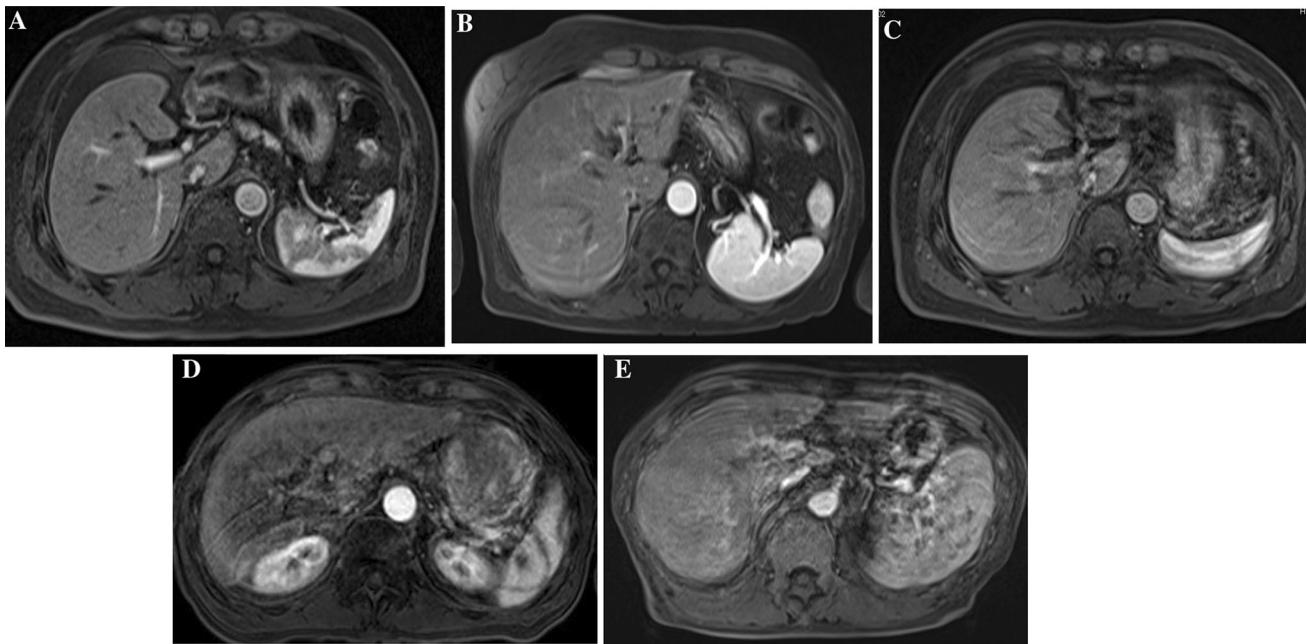
**Table 2** Patient characteristics

	GRAPPA	CAIPI-routine	CAIPI-short	<i>P</i> value
No. of patients	207	206	141	
Mean age <sup>a</sup>	65 (26–87)	66 (31–90)	78 (45–93)	0.01
Gender (male, %)	126 (60.9)	126 (61.1)	70 (49.6)	0.06
Mean patient weight (kg) <sup>a</sup>	61.8 (33.1–140)	60.6 (33–96)	54.5 (30.1–104)	0.01
Mean body mass index (kg/m <sup>2</sup> ) <sup>a</sup>	23.0 (14.8–46.3)	23.4 (15.1–36.9)	22.4 (13.4–36.1)	0.11
Cirrhosis	110 (53.1)	101 (49.0)	90 (63.8)	0.02
Child–pugh score of 5–6	163 (78.7)	163 (79.1)	99 (70.2)	0.08
Child–pugh score of 7–9	44 (21.2)	38 (18.4)	41 (29.1)	0.06
Child–pugh score of 10	1 (0.5)	5 (2.4)	1 (0.7)	0.21

Unless otherwise indicated, data represent numbers of patients, with percentages in parentheses

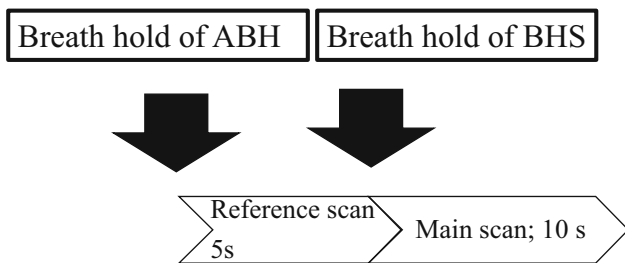
<sup>a</sup>Data are presented as median (range)

*P* values were calculated using the  $\chi^2$  test, with the exceptions of mean age, weight, and body mass index. Differences in mean age, weight, and body mass index were compared using a Kruskal–Wallis test



**Fig. 3** Image analysis according to motion artifacts. Each arterial phase image was rated on a five-point scale as follows: **a** no motion artifact; **b** minimal motion artifact; **c** moderate motion artifact;

**d** severe motion artifact; and **e** extensive motion artifact. Scores are  $A = 5, B = 4, C = 3, D = 2,$  and  $E = 1$



**Fig. 4** Comparison of the all-breath-hold method (ABH) and the breath-hold shortening method (BHS). Timing of the ABH and BHS breath-hold. In the ABH, breath hold occurs before the reference scan. In the BHS, breath-hold occurs before the main scan

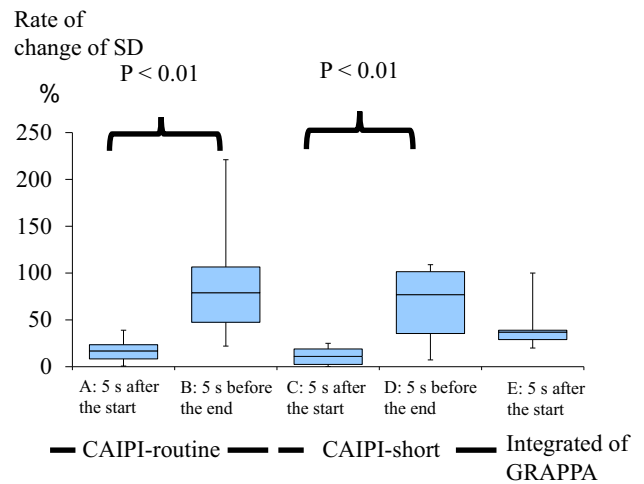
**2.4 Statistical analysis**

Statistical analysis was performed using SPSS Statistics for Windows, Version 17.0 (SPSS, Inc., Chicago, IL). The average values of the rate of change of SD were compared using the Wilcoxon signed-rank test. Patient characteristics and differences with respect to mean age, weight, and body mass index were compared using the Kruskal–Wallis test or Mann–Whitney *U* test. Differences in the first experience of examination and Child–Pugh score were compared using the  $\chi^2$  test. Motion artifact scores of ABH and BHS were compared using the Wilcoxon signed-rank test. The two readers were compared using kappa coefficients. *P* value of 0.05 or smaller was considered significant for all the hypothesis tests. [5].

**3 Results**

**3.1 Phantom study**

Figure 5 shows the rate of change of SD for the results of the phantom study. At 5 s after the start of the CAIPI-



**Fig. 5** Rate of change of standard deviation. Rate of change of standard deviation (SD) is shown for the results of the phantom study. A significant difference was found between results at 5 s after initiation and 5 s before termination of scanning (CAIPI-routine:  $P < 0.01$ ; CAIPI-short:  $P < 0.05$ ). CAIPI-routine CAIPIRINHA routine method, CAIPI-short CAIPIRINHA short-scanning method, GRAPPA generalized auto-calibrating partially parallel acquisition, SD standard deviation

routine and CAIPI-short scans (Fig. 5a, c), the rate of change of SD was within 30% of that of the original image. There were significant differences between the rate 5 s after the start and 5 s before the end of the CAIPI-routine (Fig. 5a, b) and CAIPI-short methods (Fig. 5c, d), respectively, (both,  $P < 0.01$ ).

Integrated of GRAPPA was approximately 40% (E).

### 3.2 Clinical study

Tables show the motion artifact scores (Tables 3, 4, and 5). TSMs for the various sequences were 5.8% (GRAPPA, 12/207), 1.9% (CAIPI-routine, 4/206), and 0.7% (CAIPI-short, 1/141). In addition, the kappa coefficients of the two readers for the motion scores were 0.791 (GRAPPA), 0.772 (CAIPI-routine), and 0.803 (CAIPI-short). The two readers' opinions were typically in agreement. Artifact scores improved with decreased scan time. There were no significant differences between patient characteristics of the non-TSM and TSM groups in CAIPI-routine or CAIPI-short. However, there were significant differences in weight ( $P = 0.04$ ) and first experience of examination ( $P = 0.03$ ) between the non-TSM and TSM groups in GRAPPA.

### 3.3 Comparison of breath-hold and breath-hold shortening methods under clinical conditions

Both the BHS and ABH rendered image evaluation difficult for one patient (1/30, 3.3%). The motion artifact score was 4.68 for the BHS and 4.72 for the ABH; the difference in these scores was not significant ( $P = 0.27$ ). This showed that image quality was the same for both the ABH and BHS methods (Fig. 6). Motion artifacts did not affect image capture with either method, and high-quality images were obtained.

## 4 Discussion

The present study demonstrated the effectiveness of shortening the scan time and the influence of the reference scan. The phantom study, the reference scan was not found to depend on the rate of change of SD of motion artifacts. As CAIPI-RINHA uses a separate reference scan and main scan, it is inferred that reference scan information is not reflected in the image. However, the main scan can be used to fill all k-space after the reference scan. Therefore, motion artifacts may be introduced during the main scan.

**Table 3** Patient characteristics for motion artifacts of GRAPPA

	GRAPPA non-TSM	GRAPPA TSM	P Value
No. of patients	195	12	
Mean age	63.9 ± 12.5	64.4 ± 15.4	0.94
Mean patient weight (kg)	62 ± 14.6	68.1 ± 14.1	0.04
Mean body mass index (kg/m <sup>2</sup> )	23.3 ± 4.1	24.8 ± 3.6	0.08
First experience of examination <sup>a</sup>	63 (32.3)	8 (66.7)	0.03

Except where indicated, data are presented as mean ± standard deviation

$P$  values were calculated using the Mann–Whitney  $U$  test except for the first DCE MRI examination

Differences in the first DCE MRI examination were compared using a  $\chi^2$  test

TSM transient severe motion, NA not applicable

<sup>a</sup>Data represent numbers of patients; percentages are in parentheses

**Table 4** Patient characteristics for motion artifacts of CAIPI-routine

	CAIPI-routine non-TSM	CAIPI-routine TSM	$P$ value
No. of patients	202	4	
Mean age	65.5 ± 12.5	69.7 ± 6.7	0.18
Mean patient weight (kg)	61.8 ± 12.9	61.1 ± 17.1	0.32
Mean body mass index (kg/m <sup>2</sup> )	23.3 ± 3.5	25.7 ± 9.8	0.72
First experience of examination <sup>a</sup>	48 (23.7)	1 (25)	0.67

Except where indicated, data are presented as mean ± standard deviation

$P$  values were calculated using the Mann–Whitney  $U$  test except for the first DCE MRI examination

Differences in the first DCE MRI examination were compared using a  $\chi^2$  test

TSM transient severe motion, NA not applicable

<sup>a</sup>Data represent numbers of patients; percentages are in parentheses

**Table 5** Patient characteristics for motion artifacts of CAIPI-short

	CAIPI-short non-TSM	CAIPI-short TSM	<i>P</i> value
No. of patients	140	1	
Mean age	77.1 ± 8.8	85	NA
Mean patient weight (kg)	56.3 ± 13	45	NA
Mean body mass index (kg/m <sup>2</sup> )	22.8 ± 4	18.9	NA
First experience of examination <sup>a</sup>	39 (27.9)	0 (0)	NA

Except where indicated, data are presented as mean ± standard deviation

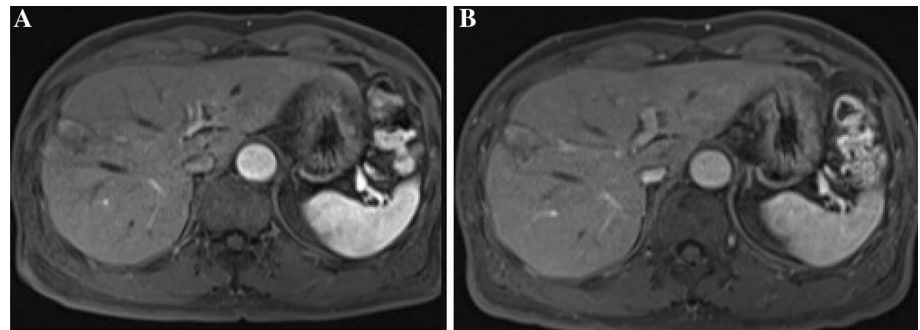
*P* values were calculated using the Mann–Whitney *U* test except for the first DCE MRI examination

Differences in the first DCE MRI examination were compared using a  $\chi^2$  test

TSM transient severe motion, NA not applicable

<sup>a</sup>Data represent numbers of patients; percentages are in parentheses

**Fig. 6** Clinical images.  
**a** Arterial phases of the all-breath-hold (ABH) and  
**b** breath-hold-shortening (BHS) of the dynamic contrast material-enhanced magnetic resonance (DCE MR) scan of a 64-year-old man



For this reason, the patient is not required to hold his or her breath during the reference scan. A decrease in scan time may significantly reduce motion artifacts. A long breath-hold is not essential during a CAIPIRINHA reference scan which implies that the scan can be performed with a short breath-hold. Our findings suggested that accurate measurement of the arterial phase is possible during a 5-s breath-hold.

The parallel imaging method allows for a shorter scan time and does not require additional expensive hardware. The use of a CAIPIRINHA sampling strategy was previously shown to reduce signal-to-noise ratio losses and residual aliasing artifacts; these improvements have been explored in a clinical setting. However, the influence of the reference scan of the CAIPIRINHA approach has not been investigated [21, 22]. Integrated of GRAPPA is the traditionally used technique; however, this method does not allow for segregation of the reference scan. Integrated of GRAPPA simultaneously collects a reference scan and a main scan. GRAPPA allows for the selection of separate mode and integrated mode. However, the reference mode of CAIPIRINHA is only compatible with the separate mode. Additionally, the reference scan can acquire only the first part of the scan. Motion artifacts are one of the primary causes of image degradation during DCE imaging of the abdomen. In previous studies, shorter scan times have been shown to ameliorate motion artifacts [16]. Our study

revealed similar results in that decreased scan time was associated with decreased frequency of motion artifacts with all the three methods (GRAPPA, CAIPI-routine, and CAIPI-short).

Five seconds after the start of CAIPIRINHA, phantom experiments showed a low rate of change of SD for motion artifacts. With CAIPIRINHA, this timing was equivalent to that observed for the reference scan. In addition, BHS artifacts were not included in the scan. It was, therefore, possible to obtain a high-quality image and time reference scan, even when the breath-hold time is short. Because, the timing of the reference scan is separate in CAIPIRINHA and is not required to fill the k-space, motion artifacts are not created.

In phantom experiments, at 5 s before the end of CAIPIRINHA, there were motion artifacts and the rate of change of SD was high. Therefore, in the clinical case, breath-hold must be done perfectly to the end. In comparison, GRAPPA produced artifacts even 5 s after the initiation of scanning. Reference scans for GRAPPA create a sensitivity map of the collected data, which stretches several lines from the k-space center [12]. GRAPPA incorporates a reference scan into the primary scan. In addition, the amount of k-space data from the integrated GRAPPA was larger, because it made the fit by producing motion artifacts throughout the entire scan. Instead of shortening the scan time, the resolution of CAIPI-short is

lower compared to CAIPI-routine. This should be taken into consideration. The DCE of the arterial phase is an important examination method for evaluation of tumor blood flow.

The current study has proven the importance of the reference scan. However, this study has several limitations. First, tumor detectability was not evaluated, due to the retrospective nature of the study. To study this, it would be necessary to perform an examination at the same time using both the approaches, but this was not possible in this retrospective study. Second, we allowed free breathing, rather than setting the phantom to a specific deep breath movement. However, it has been inferred from both phantom and clinical studies that there is no relationship between the amount of movement and the reference scan. Finally, due to the retrospective nature of the study, the results were gathered over a lengthy period of time.

Davenport et al. reported that intravenous gadoxetate disodium can result in acute self-limiting dyspnea, which can have a deleterious effect on arterial phase MR image quality. This occurs significantly more often with intravenous gadoxetate disodium than with intravenous gadobenate dimeglumine. Motion artifacts were often observed during the arterial phase with this approach with gadoxetate disodium as compared to other contrast agents [7]. This problem has been greatly improved by the shorter scan time. Our findings suggested that motion artifacts are influenced by breath time rather than by contrast agent. The most important factor with respect to imaging is likely to be the shorter scan time. GRAPPA results differed significantly according to the weight and age of the patient and between the non-TSM and TSM groups, with respect to the first DCE MRI examination. This result is the same as that of a previous study [4]. However, there was no significant difference between the CAIPI-routine and CAIPI-short methods with respect to patient characteristics of each group. This was because the scan time was extremely short, and the TSMs were decreased considerably. Even though breath-hold is difficult, elderly patients are often imaged using the CAIPI-short technique. The data collected in this study showed that the incidence of motion artifacts in this group was low. The technique described here, i.e., the shortening of scan time by CAIPI-RINHA(CAIPI-short), or another high-speed technique, such as a compressed sense and radial scan, may allow completely dynamic scans [23].

## 5 Conclusions

Use of a reference scan technique with the CAIPI-RINHA method facilitates a decrease in the time required for breath-hold, and reduces the scan time to 5 s. Failure of

arterial phase scanning was significantly reduced using this approach.

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## Compliance with ethical standards

**Conflicts of interest** The authors declare that they have no conflicts of interest.

**Ethical approval** The IRB approved this study and waived the requirement that patients provide informed consent. This article does not contain any animal studies.

**Informed consent** Informed consent was obtained from all participants for whom identifying information was included in this article.

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