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MAGNETIC RESONANCE

Modified CAIPIRINHA-VIBE without view-sharing on gadoxetic acid–enhanced multi-arterial phase MR imaging for diagnosing hepatocellular carcinoma: comparison with the CAIPIRINHA-Dixon-TWIST-VIBE

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Abstract

Purpose We evaluated the detection rate and degree of motion artifact of the modified CAIPIRINHA-VIBE (mC-VIBE) without view-sharing and compare them with the CAIPIRINHA-Dixon-TWIST-VIBE (CDT-VIBE) with view-sharing on multi-arterial gadoxetic acid–enhanced liver MRI in the assessment of hepatocellular carcinoma (HCC).

Material and methods We retrospectively identified 114 pathological-proven hepatic tumors in 114 patients with risk of HCC who underwent multi-arterial gadoxetic acid–enhanced MRI between June 2016 and June 2018. All patients underwent triple arterial phase imaging using the mC-VIBE without view-sharing (54 patients; 49 HCCs and 5 non-HCCs) or the CDT-VIBE with view-sharing (60 patients; 55 HCCs and 5 non-HCCs). We compared the detection rate of two sequences for HCC, with reference to LI-RADS.V.2017. We also compared the mean motion scores and proportions of transient severe motion (TSM) in two sequences.

Result For the examination using the mC-VIBE, the HCC-detection rate was significantly higher, compared with that using CDT-VIBE (93.9% [46/49] vs 80.0% [44/55], respectively; $p = 0.047$). For the examination with the mC-VIBE, mean motion scores were significantly lower compared with those of CDT-VIBE for all multi-arterial phases (1.21, 1.19, and 1.15 vs. 1.82, 1.85, and 1.84, respectively; $p < 0.001$ for all three comparisons). The proportion of TSM in the CDT-VIBE was significantly higher than that in the mC-VIBE (15.0% [9/60] vs 0.0% [0/54], respectively; $p = 0.003$).

Conclusion In multi-arterial phase gadoxetic acid–enhanced MRI, the mC-VIBE sequence without view-sharing has slightly higher HCC-detection rate and fewer motion artifacts compared with CDT-VIBE with view-sharing.

Key Points

- *Multi-arterial phase using the mC-VIBE without view-sharing can overcome motion artifacts, resulting in providing optimal arterial phase imaging.*
- *The HCC-detection rate is slightly higher with the mC-VIBE* vs. *CAIPIRINHA-Dixon-TWIST-VIBE with view-sharing (CDT-VIBE).*
- *View-sharing of CDT-VIBE in the multi-arterial phase is associated with increased frequency of TSM.*

Keywords Magnetic resonance imaging · Hepatocellular carcinoma · Gadoxetic acid · Detection · Artifact

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Abbreviations

APHE	Arterial phase hyperenhancement
CAIPIRINHA	Controlled aliasing in parallel imaging results in higher acceleration factor
CDT-VIBE	CAIPIRINHA-Dixon-TWIST-VIBE
mC-VIBE	Modified CAIPIRINA VIBE
TSM	Transient severe motion
TWIST	Time-resolved angiography with interleaved stochastic trajectories
VIBE	Volumetric interpolated breath-hold examination

Introduction

Detection of arterial phase hyperenhancement (APHE) is crucial for diagnosis of hepatocellular carcinoma (HCC), as is obtaining an optimal arterial phase image [1–4]. Gadoxetic acid is a widely used contrast media in magnetic resonance imaging (MRI) for diagnosing HCC, as the hepatobiliary phase image can be obtained by using this media. Therefore, gadoxetic acid shows excellent diagnostic performance in the diagnosis of HCC [5].

However, arterial phase images of gadoxetic acid–enhanced MRI can be suboptimal. The standard dosage of gadoxetic acid (0.1 ml/kg) is one fourth of the extracellular contrast media in terms of gadolinium concentration and half in volume, owing to its higher relaxivity [6]. Suboptimal arterial phase images may be obtained because of a shorter late arterial phase window in comparison with that of an extracellular contrast media. Additionally, intravenous administration of gadoxetic acid causes transient severe motion (TSM) in the arterial phase.

Many studies have been conducted for overcoming TSM and for acquisition of optimal arterial images in gadoxetic acid–enhanced liver MRI. Several studies showed that a slower injection rate (1 ml/s) is effective for overcoming suboptimal arterial enhancement [7, 8]. Further, subtraction between the unenhanced image and arterial phase image is known to be useful to detect APHE [9, 10]. Multi-arterial phase imaging is also helpful to overcome suboptimal enhancement [11, 12].

MR sequences have also been developed to obtain appropriate arterial phase images. Among them, controlled aliasing in parallel imaging results in higher acceleration factor (CAIPIRINHA) is known to maintain adequate spatial resolution despite reducing image acquisition time [13–15]. Breath-hold T1-weighted volumetric GRE sequence (volumetric interpolated breath-hold examination, VIBE) is also effective with a motion-insensitive technique within a single breath-hold period (up to 20 s) [16, 17]. Pietryga et al reported that multi-arterial phase imaging using single breath-hold CAIPIRINHA-VIBE technique minimized the effect of TSM during gadoxetic acid–enhanced liver MRI [12].

Recently, CAIPIRINHA-Dixon time-resolved angiography with interleaved stochastic trajectories (TWIST) VIBE (CDT-VIBE) has been developed and applied to abdominal imaging [18]. This sequence is known as the combination of the CAIPIPINHA technique and a view-sharing technique which fills incomplete interpolated k-space using a parallel imaging technique [19]. Therefore, CDT-VIBE sequence is an advanced sequence affording high temporal and spatial resolution for fast contrast-enhanced dynamic liver imaging, which enables to acquire multi-arterial phase images in one breath-hold [20]. Kazmierczak et al showed the greater diagnostic performance for detecting the hypervascular hepatic focal lesion in multi-arterial phase imaging using CDT-VIBE with view-sharing, compared with a standard hepatic arterial image [20]. However, they also described that application of key-hole technique may be limited in uncooperative patients, when respiration-induced motion occurs during first acquisition of the TWIST sequence [20].

Multi-arterial phase imaging using CAIPIRINHA-VIBE is to have sequential acquisitions in which all k-space in each arterial phase is fully acquired separate from other adjacent phases, whereas multi-arterial phase imaging using CDT-VIBE is a key-hole technique, having characteristic to perform the complete k-space readout in only the first acquisition of the TWIST sequence and sharing the k-space in subsequent images [21]. To the best of our knowledge, only Leonhard et al have compared the CAIPIRINHA-VIBE and CDT-VIBE sequences in the multi-arterial phase acquisition [22]. They found that the CDT-VIBE reduced motion-related image deterioration rates, compared to CAIPIRINHA-VIBE technique.

Recently, at our institution, we have performed the multi-arterial phase scanning in the gadoxetic acid–enhanced liver MRI by modifying the conventional CAIPIRINHA-VIBE technique. This new technique can further reduce the acquisition time and breath-hold time during multi-arterial phase sequential scans compared to the CAIPIRINHA-VIBE technique evaluated by Leonhard et al [22].

Therefore, in this retrospective cohort study, we evaluated the detection rate of the new modified CAIPIRINHA-VIBE (mC-VIBE) without view-sharing in comparison with the CDT-VIBE with view-sharing using multi-arterial gadoxetic acid–enhanced MRI for the evaluation of HCC. Additionally, we compared the degree of motion artifact and TSM between the two sequences.

Materials and methods

This retrospective study was approved by our institutional review board and requirement for informed consent was waived.

Study patients

We searched the institutional electronic database of our institution to identify patients with pathologically proven focal hepatic lesions between June 2016 and June 2018. The following patients were included in the study: (a) patients with chronic hepatitis or liver cirrhosis and (b) patients who underwent multi-arterial phase gadoxetic acid–enhanced liver MRI with the mC-VIBE imaging without view-sharing or the CDT-VIBE imaging with view-sharing within 120 days before the pathologic exam. Among 201 eligible patients, we excluded the 87 patients according to the following exclusion criteria: (a) previously treated for liver cancer, (b) recent history of other malignancy, and (c) locally advanced or disseminated lesion. Finally, we identified 114 patients (90 men; 24 women; mean age, 63.4 years) with pathologically proven 114 nodules (104 HCCs, 10 non-HCCs). Among them, 60 patients (45 men; 15 women; mean age, 64.7 years) with 60 nodules (55 HCCs, 4 cholangiocarcinomas, and 1 hepatic adenoma) underwent multi-arterial phase gadoxetic acid–enhanced MRI with the CDT-VIBE imaging with view-sharing. The other 54 patients (45 men; 9 women; mean age, 62.1 years) with 54 nodules (49 HCCs, 3 cholangiocarcinomas, 1 combined HCC and cholangiocarcinoma, 1 focal nodular hyperplasia) underwent multi-arterial phase gadoxetic acid–enhanced MRI with the mC-VIBE imaging without view-sharing. The flow diagram of this study is presented in Fig. 1.

Imaging techniques

All patients underwent MR examination with a 3.0 T (Skyra; Siemens Healthineers) scanner using a 30-element body coil and a 32-element spine coil. Non-enhanced MRI protocol included a breath-hold T1-weighted dual gradient echo in-phase sequence and out-of-phase sequence, breath-hold half-Fourier acquisition single-shot TSE T2-weighted imaging, a respiration-triggered single-shot T2-weighted sequence, and a respiratory-triggered single-shot echo-planar imaging sequence (b values of 0, 500, and 1000 s/mm^2).

For gadoxetic acid–enhanced MRI, a 1-ml test bolus injection was performed, and 0.025 mmol/kg body weight of gadoxetic acid (Primovist; Bayer Schering Pharma) at 1 ml/s was administered. The triple arterial phase images were acquired with two different methods (mC-VIBE imaging without view-sharing or the CDT-VIBE imaging with view-sharing) within a single breath-hold period (15–20 s after contrast injection). Portal venous (60–90 s after contrast injection), transitional (120–240 s after contrast injection), and hepatobiliary phase images (15 or 20-min after contrast injection) were acquired in the same manner with breath-hold technique for all patients. Sequence parameters of the two different examinations are summarized in Table 1.

Imaging analysis

One of the authors (S.K.; board-certified abdominal diagnostic radiologist with 23 years of clinical experience), who did not participate in the subsequent image review, compiled the MR images and a list with the sizes and locations of the pathologically proven target lesions to be reviewed.

MR images were reviewed independently and randomly by two board-certified abdominal diagnostic radiologists (N.K.L. and S.B.H.; 15 and 6 years of clinical experience, respectively), who were blinded to the methods of multi-arterial phase images. During review, the reviewers analyzed APHE with reference to the categorization by LI-RADS V. 2017. We

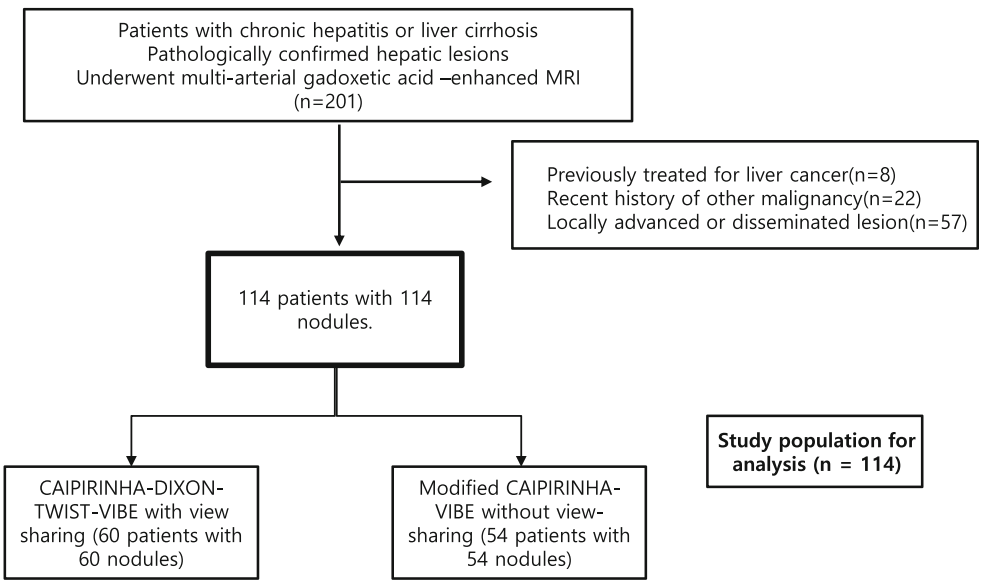

Fig. 1 Flow diagram of the study population

Table 1 Sequence parameters for two examination using CDT-VIBE and modified CAIPIRHINA VIBE (mC-VIBE)

Parameter	CDT-VIBE		mC-VIBE	
	Pre, portal venous, and delayed	Triple arterial phase	Pre, portal, venous and delayed	Triple arterial phase
Repetition time (msec)	4.01	3.77	4.01	3.91
Echo time (msec)	1.85	1.24–2.46	1.85	1.81
Flip angle	13	10	13	13
No. of phase acquired	1	3	1	3
Partition thickness (mm)	3.5	3.5	3.5	3.5
Reconstruction interval (mm)	3.5	3.5	3.5	3.5
Acquisition matrix	202 × 384	146 × 256	202 × 384	144 × 320
Parallel acceleration factor*	2 × 2	2 × 2	2 × 2	2 × 2
Receiver bandwidth (Hz/pixel)	500	1090	500	500
Acquisition time (sec)	13	8.3	13	14
Delay (sec)	NA, 60–90, and 120–240†	15–20	NA, 60–90, and 120–240†	15–20
Fat suppression	Spectral	Dixon	Spectral	Spectral
TWIST size of central k-space region	NA	20	NA	NA
TWIST sampling density k-space periphery	NA	20	NA	NA

*Data are shown as phase direction acceleration factor × partition direction acceleration factor

† Data are for pre-contrast, portal venous, and late dynamic phase, respectively

NA not applicable

regarded APHE as entire observation hyperenhances or part of observation hyperenhances. In particular, rim enhancement of the target observation in arterial phase was not regarded as APHE. The reviewers determined if the target lesion was consistent with HCC with reference to the categorization by LI-RADS V. 2017 [23]. During review, disagreement regarding arterial hyperenhancement and categorization by LI-RADS was resolved by consensus.

For the objective image evaluation, one radiologist (S.B.H.) recorded the signal intensities (SI) of the hypervascular HCC, the surrounding liver parenchyma, and background noise in each multi-arterial phase of two cohorts. For measuring the SI of HCC, the circular regions of interest (ROIs) were placed as large as possible within the tumor. For SI measurement of liver parenchyma, ROI was drawn at the liver parenchyma around the tumor, avoiding major vessel and bile duct. Background noise was defined as the standard deviation (SD) of the SI that was measured in the air outside the body, just ventral to anterior abdomen. The size of the ROI for liver parenchyma and SD noise were kept nearly identical (1.5–2 cm^2). All measurement was twice and averaged. And then, the lesion-liver CNR for hypervascular HCC was calculated with the formula: $(SI_{lesion} - SI_{liver})/SD_{noise}$.

The two reviewers (N.K.L. and S.B.H.) also evaluated the degree of respiratory motion with a scoring system for pre-contrast, multi-arterial, portal venous, and transitional phase [24]: (1) no motion artifact; (2) minimal motion artifact, no effect on diagnostic quality; (3) moderate motion artifact with some, but not severe, effect on diagnostic quality; (4) severe motion artifact, images degraded but interpretable; and (5) extensive motion artifact, images nondiagnostic. Mean motion score for each imaging sequence was obtained by averaging the motion scores of two reviewers. Additionally, we evaluated the proportion of TSM between the two cohorts. TSM was considered to be present in an examination with (a) at least one arterial phase with a mean motion score equal to or greater than 4 and (b) mean motion score of pre-contrast and either portal venous or late dynamic images equal to or less than 2.

Patient risk factors

One radiologist (S.B.H.) reviewed the patient characteristics and risk factors for respiratory motion and HCC including the following: age, sex, body mass index (BMI), asthma, chronic obstructive pulmonary disease (COPD), any obstructive lung disease, ascites, pleural effusion, portal hypertension, portal vein thrombosis, obstructive sleep apnea, and Child-Pugh score.

Statistical analysis

The detection rate of APHE and of HCC were determined and compared between the two study cohorts (mC-VIBE imaging without view-sharing cohort and CDT-VIBE imaging with view-sharing cohort) using Fisher's exact test. LR-4 or LR-5

observation was classified as true-positive (in case of an HCC in the reference standard) or false-positive (in case of other liver tumor in the reference standard).

For the objective image evaluation of hypervascular HCC, the mean of the lesion-liver CNR in each arterial phase (the first, second, and third arterial phase) and the maximum among the lesion-liver CNRs of triple arterial phases were compared between two study cohorts with Wilcoxon rank sum test.

The mean and standard deviation of motion scores for two readers was calculated for each dynamic phase. We also compared mean motion scores between the two cohorts using Wilcoxon rank sum test. For each cohort, we compared the mean motion score of each dynamic phase with that of the pre-contrast phase using Wilcoxon rank sum test. The number of examinations presenting TSM was compared between the two cohorts using Fisher's exact test. Furthermore, to analyze the correlation between respiratory motion artifacts and the detection of APHE, we compared the proportion of TSM between the HCC with APHE and HCC without APHE, in each cohort, using Fisher's exact test.

For patient characteristics and risk factors for HCC, continuous variables are presented as mean ± standard deviation and categorical variables are presented as counts (percentage). Patient characteristics and risk factors for HCC were compared between the cohorts using Fisher's exact test or Student *t* test.

We evaluated inter-observer agreement for the motion scores on each dynamic phase, pattern of arterial phase enhancement, and categorization of the target lesion with LI-RADS score using intraclass correlation coefficients (ICCs). Agreement was defined as poor (ICC, 0–0.4), fair to good (ICC, 0.40–0.75), or excellent (ICC, 0.75).

For all tests but the inter-observer agreement test, we considered $p < 0.05$ statistically significant. All statistical analyses were performed using SPSS v.21 (IBM).

Results

Characteristics and risk factors for respiratory motion of the study population

The characteristics and risk factors of the two study cohorts are summarized in Table 2. There were no significant differences in patient characteristics and risk factors between the two cohorts ($p > 0.05$, for all).

Detection rate of APHE and of HCC

The detection rate of APHE in HCC was significantly higher in the examination using multi-arterial phase gadoxetic acid–enhanced MRI with the mC-VIBE imaging without view-sharing than in the examination with the CDT-VIBE imaging with view-sharing (93.9% [46/49] vs 78.2% [43/55], respectively; $p < 0.001$) (Figs. 2, 3). In the mC-VIBE imaging, the HCC-detection rate was significantly higher compared with the CDT-VIBE imaging (93.9% [46/49] vs 80.0% [44/55], respectively; $p = 0.047$) (Table 3).

Table 2 The characteristics and risk factors for respiratory motion of two cohorts

Characteristics	CDT-VIBE	mC-VIBE	*p* value
No of patient	60	54	NA
No. of MR examination	60	54	NA
Mean age*	64.7 ± 9.5	62.1 ± 8.7	0.14
Nodule size(cm)*	2.1 ± 0.6	1.9 ± 0.6	0.91
No of women	15 (25.0)	9 (16.7)	0.36
BMI*	24.6 ± 3.9	24.3 ± 3.1	0.59
Asthma	0 (0.0)	0 (0.0)	1
COPD	8 (13.3)	6 (11.1)	0.78
Any obstructive lung disease	15 (25.0)	11 (20.4)	0.66
Restrictive lung disease	0 (0.0)	0 (0.0)	1
Ascites	8 (13.3)	5 (9.3)	0.57
Pleural effusion	14 (23.3)	8 (14.8)	0.34
CPC	1.1 (0.3)	1.1 (0.2)	0.55
Portal hypertension	43 (71.7)	44 (81.5)	0.27
Obstructive sleep apnea	0 (0.0)	0 (0.0)	1
Portal vein thrombosis	0 (0.0)	0 (0.0)	1

Data are the number of patients with the percentages in parentheses

*Data are mean ± standard deviation

Comparison of the lesion-liver CNR for hypervascular HCC

The mean of the lesion-liver CNR in each arterial phase and maximum among the lesion-liver CNRs of triple arterial phases are summarized in Table 4. For the examination using mC-VIBE imaging, the mean of the lesion-liver CNR was significantly higher compared with the examination using CDT-VIBE imaging in each three arterial phase. In the mC-VIBE cohort, the maximum among CNRs of three arterial phases is also significantly higher compared to the CDT-VIBE cohort.

Respiratory motion artifacts

Motion scores are summarized in Table 5. In the CDT-VIBE with view-sharing cohort, mean motion scores of three arterial phases were significantly higher than those of pre-contrast phase ($p < 0.001$ for all), whereas motion scores of other dynamic phases were not significantly different compared to that of the pre-contrast phase. In the mC-VIBE without view-sharing cohort, motion scores were not significantly different

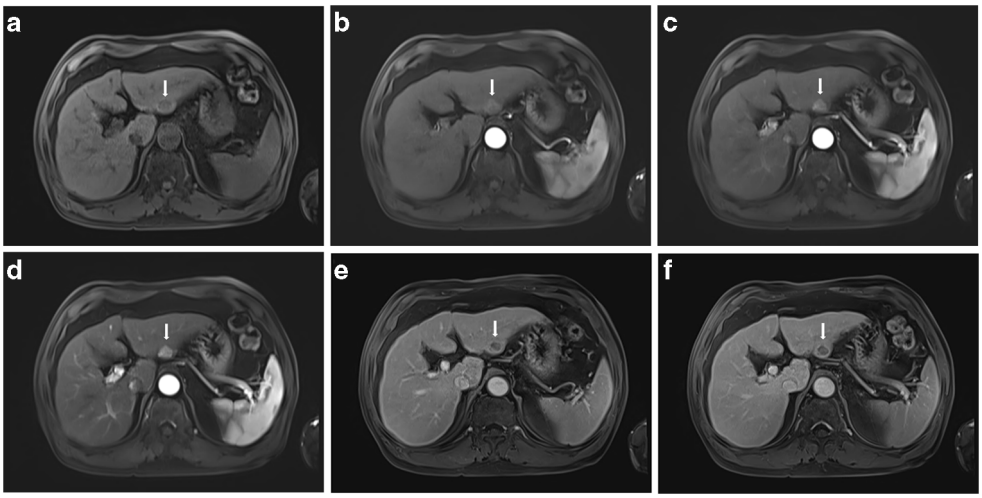

Fig. 2 Sixty-nine-year-old man with liver cirrhosis on gadoxetic acid–enhanced liver MR examination using mC-VIBE sequence without view-sharing. MR images in (**a**) pre-contrast, (**b**) first arterial, (**c**) second arterial, and (**d**) third arterial phases, (**e**) portal venous phase, and (**f**) transitional phase. Note no motion artifact for all arterial phases. MR images show a 1.5-cm mass (white arrows) in S3. This mass presents APHE and washout in portal venous phase. This mass was categorized as LR-4 observation. Left lateral segmentectomy was performed. Pathologic examination revealed hepatocellular carcinoma

in all dynamic phases compared with the pre-contrast phase. Mean motion scores of each three arterial phases were significantly lower in mC-VIBE imaging compared with those in CDT-VIBE imaging (1.21, 1.19, and 1.15 vs. 1.82, 1.85, and 1.84, respectively; $p < 0.001$ for all).

The proportion of TSM in the CDT-VIBE cohort was significantly higher than that in the mC-VIBE cohort (15.0% [9/60] vs 0.0% [0/54], respectively; $p = 0.003$) (Fig. 4). In the CDT-VIBE with view-sharing cohort, TSM was more often observed in patients with HCC presenting no APHE than that in patients with HCC presenting APHE (9.3% [4/43] vs 41.7% [5/12], respectively; $p = 0.017$).

Inter-observer agreement

Inter-observer agreement was excellent for the pattern of the arterial phase enhancement, categorization of the target lesion with LI-RADS, and motion scores on each dynamic phase. The ICCs for the pattern of the arterial phase enhancement and categorization of the target lesion with LI-RADS were 0.94

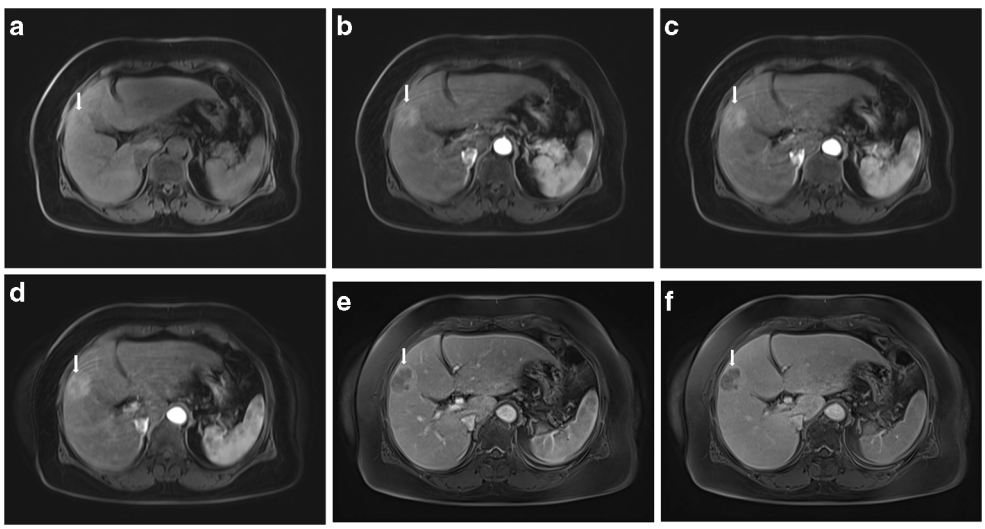

Fig. 3 Fifty-eight-year-old man with chronic hepatitis B on gadoxetic acid–enhanced liver MR examination using CDT-VIBE sequence with view-sharing. MR images in (**a**) pre-contrast, (**b**) first arterial, (**c**) second arterial, and (**d**) third arterial phases, (**e**) portal venous phase, and (**f**) transitional phase. Note moderate motion artifact with some, but not severe, effect on diagnostic quality for all arterial phases. MR images show a 2.9-cm mass (white arrows) in S5/8. This mass presents peripheral arterial enhancement and washout in portal venous phase. This mass was categorized as LR-M observation. Pathologic examination proved hepatocellular carcinoma by segmentectomy

Table 3 Comparison of the detection rate of APHE in HCC and the detection rate for HCC between two cohorts

	CDT-VIBE HCC(55)	mC-VIBE HCC(49)	*p* value
APHE[†]			
Present	43 (78.2)	46 (93.9)	< 0.001
Absent	12 (21.8)	3 (6.1)	
LI-RAD score			
LR 4 or 5	44 (80.0)	46 (93.9)	0.047
LR 3 or M	11 (20.0)	3 (6.1)	

Data are the number of patients with the percentages in parentheses

[†] APHE is regarded as entire observation hyperenhances or part of observation hyperenhances (not rim enhancement)

and 0.93, respectively. The ICC for the motion scores ranged from 0.86 (pre-contrast phase) to 0.96 (second arterial phase).

Discussion

The use of gadoxetic acid increased the diagnostic performance for HCC by enabling hepatobiliary phase imaging. However, weak arterial enhancement and respiratory motion artifact are still limitations in diagnosing HCC [1, 25–28]. Our study shows that detection rate for diagnosing HCC was increased (93.9% [46/49] vs. 80.0% [44/55], respectively; $p = 0.047$), and TSM was decreased (15.0% [9/60] vs 0.0% [0/54], respectively; $p = 0.003$) in multi-arterial gadoxetic acid–enhanced liver MRI using the mC-VIBE imaging without view-sharing, compared with examination using CDT-VIBE imaging with view-sharing.

The arterial phase image is important for categorizing the LI-RADS score for focal liver lesions in patients with a chronic liver disease or liver cirrhosis [23]. Recently, multi-arterial phase image has been used to optimize arterial phase image acquisition, while minimizing the effect of TSM due to gadoxetic acid. The CAIPIRINHA-VIBE technique is a form of parallel imaging technique that skips lines of k-space along the diagonal; the sequence is fast and affords generally good overall image quality. Indeed, the images are of excellent quality (exhibiting high spatial resolution) in multi-arterial gadoxetic acid–enhanced liver MRI [13, 14, 21]. TWIST is a time-resolved 3D MR angiography technique using a view-sharing, and can also allow the acquisition of multi-arterial phase image with high temporal resolution and high spatial resolution [29, 30]. The Dixon fat separation technique, which can be combined with VIBE technique, is known to be insensitive to B0 inhomogeneity [31]. Therefore, the CDT-VIBE technique has become increasingly popular in gadoxetic acid–enhanced liver imaging, by the combination of faster imaging, data under-sampling, and the motion-artifact minimization method. It is also known to be an excellent sequence for detecting hypervascular liver lesions in multi-arterial gadoxetic acid-enhanced liver MRI [20].

Table 4 Comparison of the lesion-liver CNR in the HCC with APHE between two cohorts

Phase	CDT-VIBE CNR*	mC-VIBE CNR*	*p* value
Arterial			
First	28.4 ± 17.7	50.9 ± 34.4	< 0.001
Second	32.5 ± 18.8	59.6 ± 42.9	< 0.001
Third	31.3 ± 17.4	53.8 ± 42.2	0.009
Maximum[†]	37.0 ± 19.5	69.7 ± 44.50	< 0.001

*Data are mean ± standard deviation

[†] Maximum is regarded as the highest CNR among the three lesion-liver CNRs of the triple arterial phases

During examination with CDT-VIBE, if images obtained during one of the three arterial phases are distorted, the images of other arterial phases may also be distorted, because of view-sharing. Therefore, examination using CDT-VIBE using view-sharing still has a limited ability to prevent respiratory artifact.

Recent advances in MRI allow acquisition of multi-arterial phase using CAIPIRINHA-VIBE (without view-sharing). This mC-VIBE technique reduced acquisition time, compared with the conventional CAIPIRINHA sequence; all k-space data associated with each arterial phase is fully acquired, but separately from those of adjacent phases during arterial phase, with preservation of the image quality. Due to the difference of k-space between two sequences, in our study, CDT-VIBE with view-sharing may have a limitation in detecting APHE, resulting in a lower detection rate and a lower lesion-liver CNR than the examination using mC-VIBE. With regard to aforementioned limitation, the higher mean motion artifact and higher frequency of TSM were also explained in the examination CDT-VIBE.

Additionally, comparing the two cohorts with regard to acquisition time of the triple arterial phase, a shorter time was observed by using CDT-VIBE. This short acquisition time is also attributed to the view-sharing technique. If the acquisition time is increased, the probability of image distortion due to motion artifact or TSM may be increased. Although this shorter time can be beneficial in terms of temporal resolution, lower spatial resolution was a limitation. This is thought to be one of the factors underlying the lower detection rate in the examination using CDT-VIBE.

The cause of TSM is yet to be studied. In the current study, the causes may be previous history of TSM, previous history of allergy to CT contrast media, low body weight, and COPD. The frequency of TSM is known to range from 10.7 to 18% in

Table 5 Mean motion scores in two cohorts

Phase	CDT-VIBE		mC-VIBE		
	Motion score*	*p* value (post-contrast vs. pre-contrast)	Motion score*	*p* value (post-contrast vs. pre-contrast)	*p* value (Sequence vs. Sequence)
Pre	1.19 ± 0.43	NA	1.13 ± 0.34	NA	0.322
Arterial					
First	1.82 ± 1.18	< 0.001	1.21 ± 0.49	0.244	< 0.001
Second	1.85 ± 1.21	< 0.001	1.19 ± 0.48	0.528	< 0.001
Third	1.84 ± 1.21	< 0.001	1.15 ± 0.36	0.695	< 0.001
Portal venous	1.15 ± 0.38	0.469	1.11 ± 0.37	0.419	0.272
Late dynamic	1.12 ± 0.37	0.098	1.10 ± 0.36	0.297	0.674

*Data are mean ± standard deviation

gadoxetic acid-liver MRI [12, 24, 32, 33]. The frequency of TSM in previous studies is similar to that in our examination using CDT-VIBE. In the cohort examined with mC-VIBE, although minimal to moderate motion artifacts were detected, there was no TSM in our study. We believe that the mC-VIBE sequence without view-sharing is a motion-insensitive sequence.

Comparing to previous study, Pietryga et al [12] reported TSM during 10.7% of examinations (37 of 345) employing multi-arterial phase gadoxetic acid–enhanced MRI (the CAIPIRINHA-VIBE without view-sharing). However, unlike our study, the acquisition time of multi-arterial phase was longer (23 s vs. 14 s), associated with higher TSM. They also reported multi-arterial phase images affected by TSM were recovered in 30 of 37 examinations, due to at least one well-timed arterial phase with a mean motion score of 3 or less, emphasizing the importance of eschewing view-sharing technique. And in our examination using multi-arterial phase gadoxetic acid–enhanced MRI acquired by the mC-VIBE without view-sharing, flip angle is higher (13° vs. 9–12°). And it may result in decreased chance of suboptimal arterial enhancement [12].

Our study has several limitations. First, a selection bias existed because we only analyzed MR images of patients with pathologically confirmed nodules. Thus, no diagnostic accuracy analysis was possible within the framework of the current study. Second, we did not investigate the cause of TSM. The risk factors for TSM were investigated in both cohorts, but this was not the focus of our study and thus these factors were not analyzed in detail. This aspect should be investigated in further research using only one MRI protocol. Third, we compared the APHEs of two completely different cohorts; we did not perform intra-individual comparison. In LI-RADS categorization, APHE is an important feature, however not constant

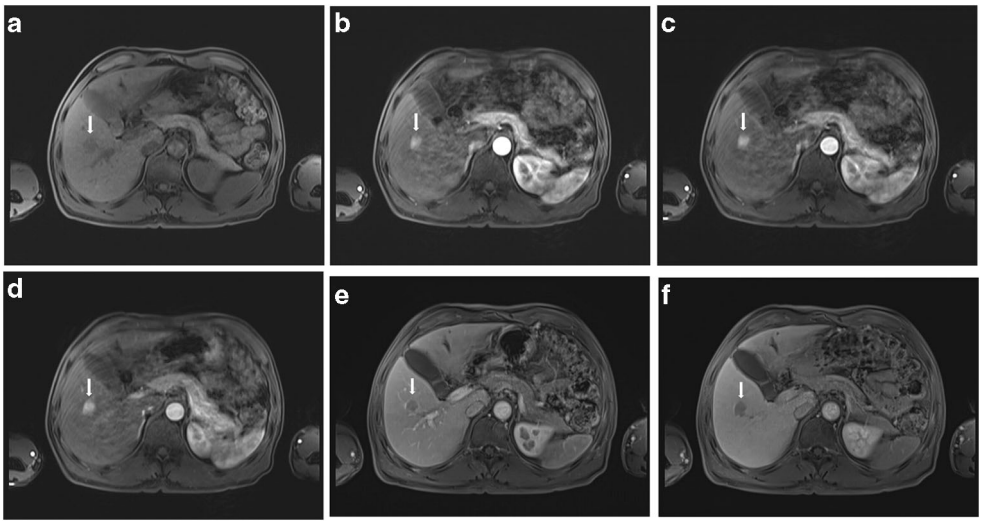

Fig. 4 Sixty-year-old man with chronic hepatitis B on gadoxetic acid–enhanced liver MR examination using CDT-VIBE sequence with view-sharing. MR images in **a** pre-contrast, **b** first arterial, **c** second arterial, and **d** third arterial phases, **e** portal venous phase, and **f** transitional phase. Note severe motion artifact but interpretable for all arterial phases. MR images show a 1.5-cm mass (white arrows) in S5/8. This mass presents APHE and washout in portal venous phase. This mass was categorized as LR-4 observation. Pathologic examination proved hepatocellular carcinoma by segmentectomy

and not mandatory for the diagnosis of HCC. Because tumors can behave differently, technical settings, like using different sequences, may not fully explain the differences in APHE between the two cohorts. Finally, detection rates for HCC between two cohorts were significantly different but its statistical significance is marginal ($p = 0.047$), but very strong p value is demonstrated in comparison of two cohorts for the presence of APHE in HCC ($p < 0.001$). This big difference in p value is depending on just single tumor (43 vs 44 of the total 55 HCCs), representing the relatively low statistical power. Further prospective study with one cohort and a large number of patients is needed, in order to have enough statistical power.

In conclusion, the mC-VIBE without view-sharing has slightly higher HCC-detection rate and fewer motion artifacts, compared with CDT-VIBE with view-sharing, in multi-arterial phase gadoxetic acid–enhanced liver MRI. Multi-arterial phase using mC-VIBE without view-sharing can overcome the limitation of motion artifacts in multi-arterial phase using CDT-VIBE with view-sharing, resulting in optimal arterial phase imaging.

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Compliance with ethical standards

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Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- diagnostic or prognostic study
- performed at one institution

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