

Non-contrast-enhanced hepatic MR arteriography with balanced steady-state free-precession and time spatial labeling inversion pulse: optimization of the inversion time at 3 Tesla

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Abstract

Background: A 3 Tesla (3 T) magnetic resonance (MR) scanner is a promising tool for upper abdominal angiography. However, no report has focused on the contrast behavior of non-contrast-enhanced hepatic MR arteriography at 3 T.

Purpose: To establish the optimal inversion time (TI) for favorable selective visualization of the hepatic arteries on non-contrast-enhanced MR arteriography with time spatial labeling inversion pulse (Time-SLIP) at 3 T.

Material and Methods: Twenty-five healthy volunteers were examined using respiratory-triggered three-dimensional balanced steady-state free-precession combined with Time-SLIP. According to the difference in the TI, five image groups (A, B, C, D, and E, from 1200 to 2000 ms, increasing at 200-ms intervals) were performed and compared to detect the optimal TI for hepatic artery visualization. The relative Cv-I (vessel-to-liver contrast) was quantified. For qualitative evaluation, the vessel visualization quality and order of the depicted hepatic artery branches were evaluated.

Results: In group C (TI of 1600 ms), the Cv-I showed the highest probably due to a favorable balance between the hepatic vessel signal and signal recovery of the surrounding tissue. Regarding qualitative assessment, in group C, the mean image quality score of all hepatic arteries and mean maximal visible order of the hepatic artery branches were the highest. However, there was no significant difference between these results.

Conclusion: Non-contrast-enhanced hepatic MR arteriography with Time-SLIP at 3 T enabled the selective visualization of hepatic arteries at a TI of 1600 ms with an optimal balance between Cv-I and peripheral hepatic artery visualization.

Keywords

Non-contrast-enhanced hepatic magnetic resonance (MR) angiography, balanced steady-state free-precession, time spatial labeling inversion pulse, 3 Tesla magnetic resonance imaging (MRI)

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Introduction

Non-contrast-enhanced magnetic resonance (MR) angiography is a non-invasive imaging modality for the visualization of various arteries and has marked clinical significance in patients with a decreased renal function or allergies to contrast agents. Recently, the capability of non-contrast-enhanced MR angiography for depicting the hepatic artery was demonstrated by the combined usage of a respiratory-triggered three-dimensional (3D) balanced steady-state free-precession

(bSSFP) sequence and a time spatial labeling inversion pulse (Time-SLIP) (1). Among the non-contrast-enhanced MR angiography methods, the Time-SLIP method is

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a type of spin labeling that can provide selective inflow information to place the inversion pulse before data acquisition and suppress the background signal (2,3). On non-contrast-enhanced MR angiography, the inversion time (TI) is an important factor in the image contrast. By changing the TI, this method can control the extent of inflow blood signal visualization instead of using an exogenous contrast agent.

A TI of 1200 ms was thought to be optimal regarding the balance between the vessel-to-liver contrast and peripheral hepatic artery visualization on non-contrast-enhanced MR arteriography at 1.5 Tesla (1.5 T) (1). However, on employing 3 Tesla (3 T) MR angiography, the hepatic artery was poorly depicted at the same TI (1200 ms) (Fig. 1). It is well known that the T1 relaxation time changes at different magnetic field strengths (4–7). A difference in the contrast of non-contrast-enhanced MR arteriography imaging between 3 and 1.5 T may be observed.

The purpose of our study was to establish the optimal TI for favorable selective visualization of the hepatic arteries on non-contrast-enhanced MR arteriography at 3 T.

Material and Methods

Participants

This study was conducted in accordance with the ethical standards of the World Medical Association (Declaration of Helsinki). From September 2012 to March 2013, 25 healthy adult participants (19 men, 6 women; age range, 22–48 years; average age, 30.2 years) were included in this prospective study. Institutional review board approval and informed consent from all participants were obtained before magnetic resonance imaging (examinations). All participants were instructed not to eat 3 h before the scan.

MRI protocol

All examinations were performed with the participant in the standard supine position using a 3 T MR unit (Toshiba Medical Systems Co., Otawara, Japan) equipped with a pair of phased array coil units placed at both the front and back, resulting in 16 channel outputs.

Respiratory triggering was conducted at the beginning of expiration using a bellows wrapped around the participant's abdomen. To optimize the imaging quality, all participants were instructed by a recorded voice when to inhale and exhale during an image acquisition sequence. The aim was to restrict the participant's respiratory rate to 12 per min, creating an expiration plateau of approximately 2500 ms. With a higher respiratory rate, the T1 relaxation of background tissues becomes insufficient at the next selective inversion recovery (IR) pulse, so background suppression may become insufficient at the beginning of the next bSSFP sequence.

Initially, coronal fast advanced spin-echo (FASE) scout images without application of an inversion pulse were acquired (echo time [TE], 80 ms; flip angle [FA]/flop angle, 70°/120°; field of view [FOV], 350 × 350 mm²; matrix, 288 × 320; slice thickness, 5 mm; scanning time, 18 s; total number of slices, 22) to localize the abdominal aorta, celiac trunk, and liver.

Respiratory-triggered 3D bSSFP imaging was performed in the coronal plane using the following parameters: TR (repetition time)/TE/FA, 4.8 ms/2.4 ms/120°; slice thickness, 1.5 mm; slice number, 60; no gap; FOV, 330 × 200 mm; matrix size, 256 × 128; number of acquisitions, 1; acceleration factor, 2. The final images were reconstructed into an apparent spatial resolution of 0.6 × 0.6 × 0.75 mm. Using a time spatial labeling selective IR pulse with previously set up TIs of 1200, 1400, 1600, 1800, and 2000 ms, the signals of the liver parenchyma and venous blood were suppressed, while

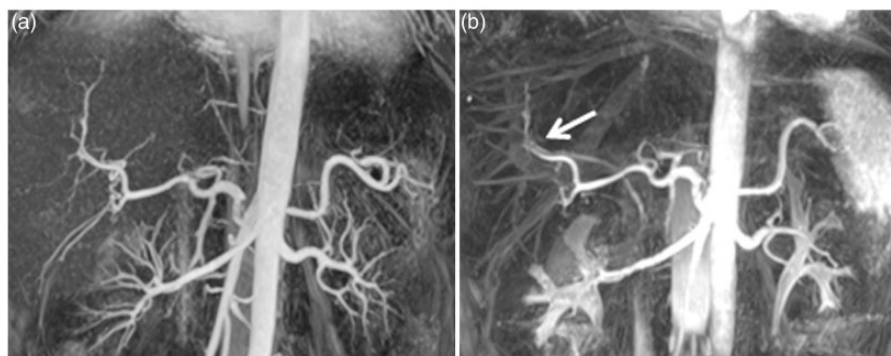


Fig. 1. Coronal MIP images of 3D non-contrast-enhanced hepatic MR arteriography in a 26-year-old participant at 1.5 T (a) and 3 T (b). TI of each image is 1200 ms. On image at 3 T (b), right hepatic artery (arrow) is unclear, and the portal veins and biliary tracts overlapped.

arterial blood inflow into the imaging area during TI delay maintained a high signal intensity. The short tau inversion-recovery method (TI, 220 ms) was used for fat suppression. The acquisition time was approximately 8 min in each participant.

Because 3 T MRI offers a longer T1 relaxation time than 1.5-T MRI, the optimal TI for background signal suppression may be longer than 1200 ms. Therefore, according to the difference in the TIs, the following five image groups – group A (TI of 1200 ms), group B (TI of 1400 ms), group C (TI of 1600 ms), group D (TI of 1800 ms), and group E (TI of 2000 ms) – were produced and compared to detect the optimal TI for hepatic artery visualization.

A selective inversion-recovery pulse with a 25-cm width was placed on the abdomen (Fig. 2) to invert the spines of blood and background tissues prior to the data sampling sequence. To shorten the inversion time, improve background signal suppression, and minimize the undesirable inflow blood effect (including the splenic vein, superior mesenteric vein, and inferior vena cava), the superior border of the selective IR pulse was set to approximately 8 cm cranial to the celiac trunk. Scout images were then reviewed to avoid overlooking the hepatic artery that diverges directly from the aorta.

Imaging analysis

In addition to the source images, maximum intensity projection (MIP) reconstructions were produced. All quantitative and qualitative assessments of the image quality were performed on a commercially available workstation (Ziostation, Ziosoft, Tokyo, Japan).

Quantitative analysis: Quantitative evaluation was conducted by a radiologist (with 14 years of experience).

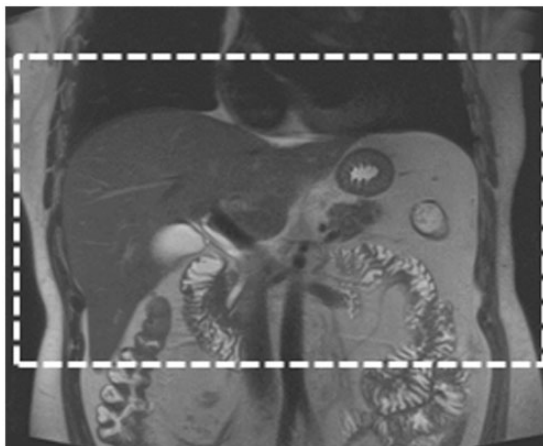


Fig. 2. The scout imaging in a 40-year-old participant. The superior border of the inversion pulse is placed about 8 cm cranial to the celiac trunk (dotted line).

Because the standard deviation (SD) of the background noise could not be used to calculate the image signal-to-noise ratio (SNR) due to the coronal orientation of data acquisition (the background lay in the non-phase-encoding direction of the FOV), the “relative signal intensity (SI)” of the right hepatic artery (RHA) was used to refer to tissue inside the FOV. Liver parenchyma was used as the reference tissue. Accordingly, in the coronal source images, the region-of-interest (ROI) was placed manually in the RHA (5–10 mm²) and the liver. The ROI of the liver was at least 50 mm² and was chosen in homogeneous, artifact-free areas adjacent to the RHA. These values were used to calculate the relative SI – that is, the vessel-to-liver contrast (Cv-l) – according to the following equation: $Cv-l = (SI_v - SI_{ro}) / SI_v$ (ro = reference organ, i.e. liver; v = RHA). The relative SI values between groups were compared and analyzed statistically.

Qualitative analysis: Data analysis was performed based on the consensus between two experienced MR radiologists (with 26 and 11 years of experience) who were blinded to the names and personal data of the participants. Visualization of the hepatic artery was scored on a four-point scale (1, non-diagnostic; 2, fair; 3, good; 4, excellent) regarding the assessment of the right hepatic, left hepatic, and segment IV hepatic artery. In addition, the readers were asked to note the maximal visible order of the hepatic artery branches. The codes were: 1 for the common hepatic artery; 2 for the proper hepatic artery; 3 for the left/right branch of the hepatic artery; and 4 for branches of the left or right hepatic artery.

Statistical analysis

The results are presented as the means and standard deviations. Statistical analyses of the differences between groups were performed using one-way analysis of variance (ANOVA) followed by a post-hoc test using computerized statistical software (version 12.4.0.0; MedCalc Software, Ostend, Belgium). Differences between the groups in terms of the relative SI and qualitative data were analyzed.

Results

Quantitative analysis

Imaging was successfully performed in all volunteers. The means and SDs of Cv-ls were 0.590 ± 0.16 for group A, 0.662 ± 0.17 for group B, 0.697 ± 0.12 for group C, 0.646 ± 0.13 for group D, and 0.635 ± 0.11 for group E, respectively (Fig. 3). In group A (TI of 1200 ms), background suppression was excellent; however, the signal intensity of the hepatic artery was lowest owing to a short inversion time delay. In

group E (TI of 2000 ms), the background signal recovery deteriorated the vessel-to-liver contrast. In group C (TI of 1600 ms), the relative SI was highest, probably due to the favorable balance between the hepatic vessel signal and signal recovery of surrounding tissue. However, there was no significant difference between the groups ($P > 0.05$, ANOVA).

Qualitative analysis

The scores of different artery segments and mean values for the order of the depicted hepatic artery branches in each group are shown in Table 1. Regarding the hepatic artery delineation, a change in image quality was observed in most of the participants according to the difference in TI (Fig. 4a–e).

In group A (TI of 1200 ms), the image quality score and mean value for the order of the hepatic artery branches were both the lowest because the inflow signal of intrahepatic arteries was not sufficient to be evaluated due to the short inversion time. In group B (TI of 1400 ms), the signal of peripheral vessels was still weak compared with that of group C. In group C (TI of 1600 ms), both the image quality score and mean value for the order of the hepatic artery branches were the highest.

Discussion

MRI at 3 T markedly increases the SNR compared with that at 1.5 T, and 3 T whole-body MR scanners have

become available for upper abdominal imaging (8,9). They can facilitate high-quality clinical imaging, reflecting the abundant SNR. However, a difference in the contrast of T1-weighted (T1W) imaging between 3.0 and 1.5 T is sometimes observed because T1 increases at different rates between various tissues at higher magnetic field strengths, requiring protocol adjustment. T1 increases with the magnetic field strength, although this prolongation is tissue dependent. The T1 relaxation times were 38% longer for the liver, 26% longer for the spleen, and 5% longer for the paravertebral muscle at 3 T than those at 1.5 T (6). This prolongation of T1 relaxation at 3 T may lead to the difference in the contrast of non-contrast-enhanced MR angiography.

Among the non-contrast-enhanced MR angiography methods, Time-SLIP is a vascular imaging technique based on spin labeling, and it provides excellent arterial bright blood imaging through the combined use of 3D bSSFP with fat suppression (2,3). By adjusting TI between the selective IR pulse and imaging sequence, this method can balance the blood signal against background suppression. With this technique, Shimada et al. (1) reported that the hepatic artery could be effectively demonstrated by non-contrast-enhanced MR angiography, and the highest contrast visualization was obtained at a TI of 1200 ms at 1.5 T; however, the hepatic artery was poorly depicted at the same TI of 1200 ms at 3 T (Fig. 1). The prolongation of T1 relaxation at 3 T may cause the difference in the contrast of non-contrast-enhanced hepatic MR arteriography,

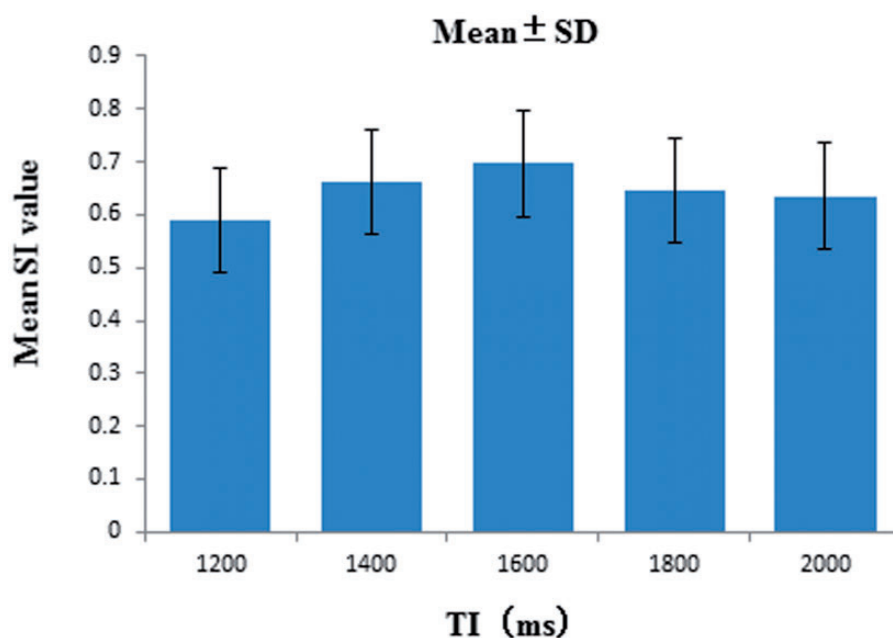


Fig. 3. The mean relative SI (vessel to liver contrast) values of each different TI. In group C (TI = 1600 ms), the relative SI was the highest, but there was no significant difference between groups.

Table 1. The mean score of vessels and mean values for the order of hepatic arterial branches.

	Group A	Group B	Group C	Group D	Group E	P
LHA	2.0 ± 1.2	2.8 ± 1.2	2.9 ± 1.1	2.6 ± 1.2	2.5 ± 1.1	Between group A and B, A and C* Between group A and D**
RHA	1.9 ± 1.1	2.7 ± 1.2	3.2 ± 1.0	3.0 ± 1.1	2.7 ± 1.2	Between group A and other groups*
IV	1.2 ± 0.5	1.5 ± 0.9	1.8 ± 1.0	1.7 ± 1.0	1.3 ± 0.5	Between group A and C, C and E* Between group A and D*
MAX	2.2 ± 0.9	2.9 ± 0.9	3.4 ± 0.9	3.3 ± 1.0	2.9 ± 1.0	Between group A and other groups* Between group A and other groups*

*P value < 0.01.

**P value < 0.05.

Group A (TI = 1200 ms), Group B (TI = 1400 ms), Group C (TI = 1600 ms), Group D (TI = 1800 ms), Group E (TI = 2000 ms).

IV, segment IV artery; MAX, maximally visible order of hepatic artery branches.

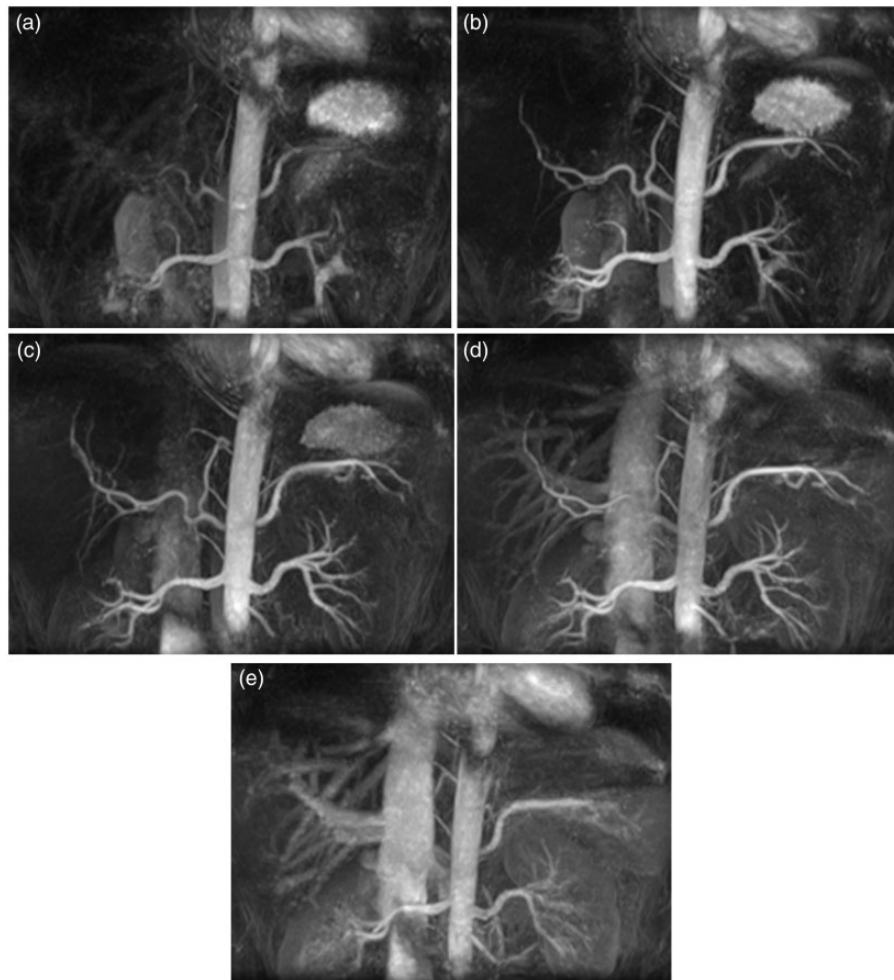


Fig. 4. The change of image quality according to the different TI from 1200 to 2000 ms. (a) Group A (TI = 1200 ms), (b) Group B (TI = 1400 ms), (c) Group C (TI = 1600 ms), (d) Group D (TI = 1800 ms), (e) Group E (TI = 2000 ms). Coronal MIP images of non-contrast-enhanced hepatic MR arteriography in a 30-year-old participant. The background hepatic signal recovery with time is observed. The signal of intrahepatic arteries tends to increase with time. In group A, the maximal visible order of the hepatic artery branches is lowest and the portal veins overlap with the hepatic artery (a). In groups D and E, background signal recovery deteriorates the vessel-to-liver contrast, and the peripheral hepatic vessel signal becomes unclear due to the signal recovery of the surrounding hepatic tissues (d, e). Also the portal and hepatic veins overlap with the hepatic artery in groups D and E (d, e). The highest contrast visualization is obtained at TI of 1600 ms at 3 T (c).

while no reports have focused on the contrast behavior of non-contrast-enhanced hepatic MR arteriography using 3D bSSFP with Time-SLIP at 3 T. This study was designed to determine the optimal TI on non-contrast-enhanced MR arteriography at 3 T, and we adopted a longer TI from 1200 to 2000 ms, increasing at 200-ms intervals in each.

In the current study, hepatic signal suppression was favorable in group A (TI of 1200 ms), but the maximal visible order of the hepatic artery branches was lowest due to an inadequate inversion time. A short TI such as 1200 or 1400 ms was favorable to suppress the hepatic signal, but the inflow signal of the hepatic arteries was weak and not suitable for peripheral vessel visualization. Additionally, the portal veins sometimes overlapped with the hepatic artery in group A (TI of 1200 ms). Conversely, in group E (TI of 2000 ms), the hepatic signal recovery deteriorated the relative SI, and the hepatic vessel signal sometimes became unclear due to the signal recovery of the surrounding tissue in MIP images. Additionally, conspicuous overlapping of the portal and hepatic veins was observed in groups D (TI of 1800 ms) and E (TI of 2000 ms). A long TI was suitable for peripheral vessel delineation, but an over-long TI such as 2000 ms deteriorated the vessel-to-liver contrast owing to background signal recovery.

Our results suggest that a TI of 1600 ms is optimal to strike a balance between vessel-to-liver contrast and peripheral hepatic artery visualization. The optimal TI on non-contrast-enhanced MR arteriography at 3 T differs from that at 1.5 T. The difference is attributed to T1 increases occurring at different rates between various tissues at higher magnetic field strengths. We also found conspicuous overlapping of the portal and hepatic veins on non-contrast-enhanced MR arteriography with short and long TIs at 3 T, preventing visualization of the hepatic artery. We speculate that the overlapping is attributed to a marked difference in T1 relaxation times between various tissues at 3 T. The non-contrast-enhanced MR arteriography at 3 T may require careful TI selection with regulated breathing to avoid the overlapping of the portal and hepatic veins and to achieve selective visualization of the hepatic arteries.

Our study had several limitations. First, the main limitation was the absence of a reference standard with which to compare the results of our qualitative analysis. Ideally, a hepatic arteriogram or surgical exploration would have provided a more definitive determination of the hepatic arterial anatomy in each participant. However, this study was performed with healthy volunteers, so further invasive testing or surgery was not justifiable or feasible. Second, only healthy adult participants were examined in this study. This study was designed to visualize the hepatic arteries using the non-contrast-enhanced MR arteriography technique and optimize the study protocol

at 3 T. Further studies with a larger sample size and including patients with a condition requiring depiction of the hepatic arterial anatomy are required. Third, the difference in the visualization of the hepatic artery between 1.5 and 3 T was not investigated. However, this study was aimed at optimization of the TI, and a comparative study is our next aim.

In conclusion, non-contrast-enhanced MR arteriography using respiratory-triggered 3D bSSFP with Time-SLIP at 3 T enabled the selective visualization of the hepatic arteries at TI of 1600 ms with an optimal balance between vessel-to-liver contrast and peripheral hepatic artery visualization.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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