Objective: The aim of this study was to assess whether a short breath-hold technique can improve hepatic arterial phase (HAP) image quality in gadoxetic acid–enhanced magnetic resonance (MR) imaging compared with a conventional long breath-hold technique.

Materials and Methods: Institutional review board approval and patient consent were obtained for this prospective randomized control study. One hundred nineteen patients undergoing gadoxetic acid–enhanced MR imaging were randomly assigned to groups A or B. Group A patients underwent an 18-second long breath-hold MR technique (conventional VIBE [volumetric interpolated breath-hold examination] technique with GRAPPA [generalized autocalibrating partially parallel acquisition]), and group B patients underwent a 13-second short breath-hold MR technique (VIBE technique with CAIPIRINHA [controlled aliasing in parallel imaging results in higher acceleration]). Respiratory-related graphs of the precontrast and HAP were acquired. The breath-hold degree was graded based on the standard deviation (SD) value of respiratory waveforms. Gadoxetic acid–related dyspnea was defined as when the SD value of the HAP was greater than that of the precontrast phase without degraded image quality in the portal and transitional phases (SD value of the HAP–SD value of the precontrast phase). The overall image quality and motion artifacts of the precontrast and HAP images were evaluated. The groups were compared using the Student t or Fisher exact test, as appropriate.

Results: The incidence of breath-holding difficulty (breath-hold grades 3 and 4) during the HAP was 43.6% (27/62) and 36.8% (21/57) for group A and B, respectively. The SD value during the precontrast phase and the SD value difference between the precontrast and HAP were both significantly higher in group A than in group B (P = 0.047 and P = 0.023, respectively). Gadoxetic acid–related dyspnea was seen in 19.4% (12/62) of group A and 7.0% (4/57) of group B. Group B showed better precontrast and HAP image quality than group A (P < 0.001). Degraded HAP (overall image quality ≥4) was observed in 9.7% (6/62) and 3.5% (2/57) of group A and B, respectively.

Conclusions: The short breath-hold MR technique, CAIPIRINHA, showed better HAP image quality with less degraded HAP and a lower incidence of breath-hold difficulty and gadoxetic acid–related dyspnea than the conventional long breath-hold technique.

Key Words: gadoxetic acid, liver, magnetic resonance imaging, breath-hold, hepatic arterial phase, dyspnea

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MATERIALS AND METHODS

This prospective observational study was approved by the institutional review board. Before the investigation, the adequate sample size was estimated as 128 patients using the independent z-test. We verbally explained to the patients the purpose and method of this study and emphasized that there was no additional harm in participating in the study as they would receive the standard amount of...
contrast media. After thorough review, the patients signed the informed consent forms.

Subjects

One hundred twenty-eight eligible patients (89 men and 39 women; mean [SD] age, 56.1 [12.2] years) were prospectively enrolled from October 1, 2013 to June 30, 2015 at a single tertiary university hospital. Patients were scheduled to undergo liver MRI for hepatocellular carcinoma (n = 63), metastasis (n = 2), cholangiocarcinoma (n = 2), liver cirrhosis (n = 21), hemangioma (n = 8), focal nodular hyperplasia (n = 6), focal eosinophilic infiltration (n = 3), fatty liver (n = 12), arterioportal shunt (n = 5), and hepatic cyst (n = 6).

The 128 patients were randomly assigned to groups A and B. Group A patients underwent an 18-second long breath-hold MR technique, and group B patients underwent a 13-second short breath-hold MR technique. Among them, 9 patients (2 from group A and 7 from group B) were excluded because the respiratory-related graphs could not be evaluated (Fig. 1). As a result, a total of 119 patients (62 in group A and 57 in group B) were included in this study (Supplement E1, Supplemental Digital Content 1, http://links.lww.com/RLI/A248).

Magnetic Resonance Imaging

Liver MRI was performed on a 3 T MR scanner (MAGNETOM Skyra; Siemens, Erlangen, Germany) with a standard 18-channel body matrix coil and a table-mounted 32-channel spine matrix coil. Specific MR sequence parameters for both groups are summarized in Table 1.

For dynamic imaging, a fat-suppressed T1-weighted 3D GRE volumetric interpolated breath-hold examination (VIBE) sequence was obtained using generalized autocalibrating partially parallel acquisition (GRAPPA) in group A and controlled aliasing in parallel imaging results in higher acceleration (CAIPIRINHA) in group B. After the precontrast scan, intravenous bolus of 0.1 mL/kg gadoxetic acid (Primovist; Bayer Pharma AG, Berlin, Germany) was administered at a rate of 1 mL/s, followed by 25-mL saline flushing. Under real-time fluoroscopic monitoring, the arterial phase was obtained immediately after detection of the contrast media in the descending aorta for group A and in the aortic arch for group B.1 The portal venous, transitional, and hepatobiliary phase images were performed at 70 seconds, 2 minutes, and 20 minutes, respectively, after injection of contrast media. The patients were instructed to hold their breath at the end of inspiration, and then arterial phase acquisition was initiated.

Image Analysis

For qualitative analysis, 2 abdominal radiologists (J.L.Y and Y.S.P., with 3 and 7 years of abdominal imaging experience, respectively) blinded to the MR protocol and breath-hold pattern independently reviewed the precontrast and HAP images of both groups. The overall image quality and motion artifacts were assessed. The overall image quality was scored as follows with the highest grade indicating worst image quality: (1) excellent, (2) good, (3) acceptable, (4) poor, and (5) unreadable.14 Motion artifacts were graded

![Flowchart of the study population](https://www.investigativeradiology.com/)

**TABLE 1. MR Protocol and Sequence Parameters of Group A and B**

<table>
<thead>
<tr>
<th></th>
<th>Group A (n = 64)</th>
<th>Group B (n = 64)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR protocol</td>
<td>VIBE sequence with GRAPPA</td>
<td>VIBE sequence with CAIPIRINHA</td>
</tr>
<tr>
<td>TR, ms</td>
<td>4.12</td>
<td>4.12</td>
</tr>
<tr>
<td>TE, ms</td>
<td>1.20</td>
<td>1.89</td>
</tr>
<tr>
<td>Flip angle, degrees</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Slice thickness, mm</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Matrix</td>
<td>416 × 324</td>
<td>384 × 191</td>
</tr>
<tr>
<td>Field of view</td>
<td>316 × 319</td>
<td>360 × 363</td>
</tr>
<tr>
<td>Voxel size, mm³</td>
<td>0.76 × 0.98 × 3</td>
<td>0.94 × 1.90 × 3</td>
</tr>
<tr>
<td>Acceleration factor</td>
<td>2</td>
<td>4 (2 × 2)</td>
</tr>
<tr>
<td>Delta shift</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>Acquisition time, s</td>
<td>18</td>
<td>13 (3 s calibration time + 10 s acceleration time)</td>
</tr>
<tr>
<td>K-space</td>
<td>Linear</td>
<td>Segmented linear</td>
</tr>
</tbody>
</table>

MR indicates magnetic resonance; TR, repetition time; TE, echo time; VIBE, volumetric interpolated breath-hold examination; GRAPPA, generalized autocalibrating partially parallel acquisition; CAIPIRINHA, controlled aliasing in parallel imaging results in higher accelerations; NA, not applicable.

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FIGURE 1. Flowchart of the study population. Among the 128 patients enrolled in this study, 9 patients (2 from group A and 7 from group B) were excluded because the respiratory-related graphs could not be evaluated for the following reasons: (1) absence of SD value (n = 1), (2) linear waveform (n = 3), (3) bizarre waveform (n = 3), and (4) minimum SD value of zero (n = 2). Reasons 1 and 2 were caused by technical failure (disconnected electrical cord or bluetooth device); reason 3 was induced by coughing or sneezing; and reason 4 was due to physical movement of the patient. As a result, a total of 119 patients (62 in group A and 57 in group B) were included in this study. Figure 1 can be viewed online in color at www.investigativeradiology.com.
as follows: (1) no artifacts, (2) mild artifacts without diagnostic impairment, (3) moderate artifacts without diagnostic impairment, (4) severe artifacts with diagnostic impairment, and (5) nondiagnostic.5 The scores for each image quality parameter between the 2 readers were averaged to obtain the mean score, which was used in further analysis. Mean overall image quality scores of 4 or higher indicated degraded HAP.

Respiratory-Related Graphs

Before the MR examination, a pneumatic cushion usually used for patient monitoring was placed on the epigastric area of each patient and fastened with a body coil. The cyclic expansion or contraction of the thorax was transmitted to the pneumatic cushion, and a respiratory curve based on the pressure change was acquired. The respiratory signals were recorded during the precontrast and HAP and plotted on a graph. The y axis of the graph represented pressure change caused by respiratory movement, measured in arbitrary units, while the x axis represented time.14

Respiratory Pattern Analysis

For quantitative analysis, an experienced abdominal radiologist (C.H.L., with 17 years of abdominal imaging experience) blinded to the MR protocol and image quality scores analyzed the respiratory patterns during the breath-holding period by assessing the respiratory-related graph acquired during the precontrast and HAP.

According to the method of a previous study,14 the breath-hold degree was graded based on SD value with the highest grade indicating the worst breath-hold: grade 1, excellent breath-hold (SD <100); grade 2, mild difficulty in breath-holding (SD 100–200); grade 3, moderate difficulty in breath-holding (SD 200–300); and grade 4, severe difficulty in breath-holding (SD >300). Patients with breath-hold grades 3 and 4 (SD >200) were considered to have respiratory difficulty. When the SD value during the HAP was 200 greater than that of the precontrast phase without degraded image quality in the portal and transitional phases, it was defined as gadoxetic acid–related dyspnea (GARD; SD value of the HAP – SD value of the precontrast phase; Fig 3).14

Survey Questionnaire

Immediately after MR examination, patients blinded to the MR protocol underwent a survey questionnaire to investigate the subjective feeling of dyspnea. They were asked if they felt they had held their breath well after contrast media administration; if they did not hold their breath well, they were asked if they ordinarily have difficulty holding their breath.

Statistical Analyses

The SD values of the precontrast and HAP and the SD value differences between both phases were compared between groups A and B using the Student t test. Differences in the incidence of each breath-hold grade, breath-holding difficulty, GARD, and degraded HAP between the 2 groups were assessed using the Fisher exact test.

Interobserver agreement of the image quality scores for the precontrast and HAP was assessed by calculating intraclass correlation coefficients. The mean image quality scores of patients in groups A and B, and patients with and without GARD were compared using the Student t test.

P value less than 0.05 was considered statistically significant. Statistical analyses were performed with statistical software (SPSS version 20.0; IBM, Armonk, NY).

RESULTS

The patient demographics and characteristics are presented in Supplement E2, Supplemental Digital Content 2, http://links.lww.com/RLI/A249.

Image Analysis

Reader agreement was good to excellent for all image quality scores in both the precontrast and HAP, with intraclass correlation coefficients of 0.707 to 0.881. The mean image quality scores of the precontrast and HAP in both groups are summarized in Table 2 and Supplement E3, Supplemental Digital Content 3, http://links.lww.com/RLI/A250. The mean overall image quality and motion artifact scores of group A were significantly higher than group B in both phases (all P < 0.001). In other words, group B demonstrated better image quality. None of the patients in either group showed an overall image quality score of 5 (worst image quality) in either the precontrast or HAP. Degraded HAP (overall image quality 2–4) were seen in 8 patients in the total group (8/119, 6.7%)—6 in group A (6/62, 9.7%) and 2 in group B (2/57, 3.5%). Thus, degraded HAP was more commonly seen in group A than in group B.

Respiratory Waveform Analysis

The breath-hold grades during the precontrast and HAP were listed in Table 2. Breath-holding difficulty was seen in 27.7% (33/119) of the total group, 33.9% (21/62) of group A, and 21.1% (12/57) of group B during the precontrast phase; and in 40.3% (48/119) of the total group, 43.6% (27/62) of group A, and 36.8% (21/57) of group B during the HAP (Table 2). Group A generally showed a higher incidence of breath-holding difficulty compared with group B, although the difference was not statistically significant (P > 0.05).

Respiratory waveform analysis revealed that the SD values during the precontrast phase and the SD value differences between the precontrast and HAP were significantly higher in group A (P = 0.047, P = 0.023, respectively; Table 3). In addition, during the HAP, the SD values of group A tended to be higher than group B, although the difference was not statistically significant (P = 0.056; Table 3).

Patients With GARD

Gadoxetic acid–related dyspnea, defined as when the SD value of the HAP was 200 greater than that of the precontrast phase without degraded image quality in the portal and transitional phases, it was defined as gadoxetic acid–related dyspnea (GARD; SD value of the HAP – SD value of the precontrast phase; Fig 3).14

Among the 16 patients who experienced GARD, 5 (31.3%) demonstrated degraded HAP (4 of 12 patients in group A and 1 of 4 patients in group B). Among the 6 group A patients who manifested degraded HAP, 4 experienced GARD; of the 2 group B patients who showed degraded HAP, one manifested GARD. Thus, not all patients who experienced degraded HAP showed degraded HAP and, vice versa, not all patients who showed degraded HAP demonstrated GARD.

Survey Questionnaire Analysis

Among the 116 patients who reported that they held their breath well, 71 demonstrated good breath-hold graphs (breath-hold grades 1
FIGURE 2. Representative cases of respiratory-related graphs and gadobetate dimeglumine–enhanced MRIs for each breath-hold grade. A, Respiratory-related graph showing excellent breath-hold (grade 1, SD <100) of a 68-year-old woman in group B. Precontrast (B) and HAP (C) MRIs both demonstrate excellent overall image quality (mean overall image quality scores of 1). D, Respiratory-related graph showing mild difficulty in breath-holding (grade 2, SD = 100–200) of a 76-year-old man in group B. Precontrast (E) and HAP (F) MRIs both manifest good overall image quality (mean overall image quality scores of 2). G, Respiratory-related graph demonstrating moderate difficulty in breath-holding (grade 3, SD = 200–300) of a 69-year-old woman in group A. Precontrast (H) and HAP (I) MRIs show mean overall image quality scores of 2 and 3, respectively. J, Respiratory-related graph showing severe difficulty in breath-holding (grade 4, SD >300) of a 75-year-old woman in group A. Precontrast (K) and HAP (L) MRIs manifest mean overall image quality scores of 2.5 and 4, respectively. Figure 2 can be viewed online in color at www.investigativeradiology.com.
and 2; SD ≤ 200) while 45 showed breath-holding difficulty (breath hold grades 3 and 4; SD > 200). Among the 45 patients who thought they held their breath well but actually did not, 25 were in group A and 20 were in group B. Thus, 38.8% (45/116) of the survey questionnaire replies proved to be false and thus unreliable. Furthermore, among the 116 patients who answered that they held their breath well, 108 patients (93.1%) showed mean overall image quality scores lower than 4, and 8 patients (6.9%) demonstrated scores of 4 (degraded image quality). Among these 8 patients, 6 and 2 were from group A and B, respectively (Supplement E4, Supplemental Digital Content 4, Figure 3 can be viewed online in color at www.investigativeradiology.com).

**TABLE 2.** Qualitative and Quantitative Analyses of Group A and B During the Precontrast and HAP

<table>
<thead>
<tr>
<th></th>
<th>PRE</th>
<th>HAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group A (n = 62)</td>
<td>Group B (n = 57)</td>
</tr>
<tr>
<td>Overall image quality†</td>
<td>2.1 (0.5)</td>
<td>1.3 (0.4)</td>
</tr>
<tr>
<td>Motion artifact†</td>
<td>2.1 (0.5)</td>
<td>1.3 (0.4)</td>
</tr>
<tr>
<td>Degraded HAP§</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Grade 1 (SD &lt;100)§</td>
<td>16/62 (25.8%)</td>
<td>22/57 (38.6%)</td>
</tr>
<tr>
<td>Grade 2 (SD 100–200)§</td>
<td>25/62 (40.3%)</td>
<td>23/57 (40.4%)</td>
</tr>
<tr>
<td>Grade 3 (SD 200–300)§</td>
<td>15/62 (24.2%)</td>
<td>8/57 (14.0%)</td>
</tr>
<tr>
<td>Grade 4 (SD &gt;300)§</td>
<td>6/62 (9.7%)</td>
<td>4/57 (7.0%)</td>
</tr>
<tr>
<td>Breath-holding difficulty (SD &gt;200)§</td>
<td>21/62 (33.9%)</td>
<td>12/57 (21.1%)</td>
</tr>
<tr>
<td>GARD§</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

*P values were calculated by using the Student t test or Fisher exact test, as appropriate.
†Data are presented as mean (SD).
‡Significant value.
§Data are the number of patients, and the value in parentheses is the percentage.
PRE indicates precontrast phase; HAP, hepatic arterial phase; NA, not applicable.
TABLE 3. SD Values of Group A and B

<table>
<thead>
<tr>
<th></th>
<th>Total Group (n = 119)</th>
<th>Group A (n = 62)</th>
<th>Group B (n = 57)</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD value of the precontrast phase</td>
<td>156 (119)</td>
<td>176 (143)</td>
<td>133 (83)</td>
<td>0.047</td>
</tr>
<tr>
<td>SD value of the HAP</td>
<td>213 (156)</td>
<td>239 (181)</td>
<td>185 (119)</td>
<td>0.056</td>
</tr>
<tr>
<td>SD value difference</td>
<td>102 (127)</td>
<td>139 (156)</td>
<td>72 (88)</td>
<td>0.023</td>
</tr>
</tbody>
</table>

Data are presented as mean (SD).

*P values were calculated by using the Student t test.


DISCUSSION

There have been many efforts to overcome degraded HAP and achieve optimal HAP image quality in gadoxetic acid-enhanced MRI by shortening the scanning time, lowering the contrast injection rate, using weight-based dose of contrast media, and employing optimized protocols such as the bolus tracking technique, saline flushing, and contrast dilution. Among these efforts, shortening the scanning time while maintaining high resolution can be a promising solution. Through this prospective study, we validated if minimizing breath-hold time with short breath-hold MR techniques can be of help in improving HAP image quality. Based on respiratory waveform analysis, group B showed lower incidences of breath-holding difficulty (36.8% [21/57] vs 43.6% [27/62]) and GARD (7.0% [4/57] vs 19.4% [12/62]) compared with group A. This may be explained by the fact that the required breath-hold time for patients in group B was 5 seconds shorter than that of patients in group A (13 vs 18 seconds). For image-based analysis, patients in group B showed better HAP image quality and less degraded HAP (3.5% [2/57] vs 7.8% [6/62]) than patients in group A. As patients in group B showed lower incidences of breath-holding difficulty and GARD, this may have led to less motion artifacts and better HAP image quality.

The incidence of degraded HAP (3.5%) and GARD (7.0%) in group B was lower than previous studies using long breath-hold techniques (18–23 seconds), which reported incidences of 12%–18% and 10.7%–39%, respectively. This is probably because patients in group B underwent an advanced parallel imaging technique, CAIPRINHA, which allowed high resolution in a reduced acquisition time of 13 seconds. Although the CAIPRINHA technique demonstrated lower resolution than the conventional breath-hold technique in this study, it allowed a short breath-hold time without compromising resolution. In our study, the CAIPRINHA technique showed higher resolution compared with the MR techniques of previous studies assessing GARD. Actually, the breath-hold time can be minimized to only 5 to 8 seconds with the CAIPRINHA technique. However, as it is very difficult to sustain high resolution while minimizing the breath-hold time, a breath-hold time of 13 seconds was considered appropriate in maintaining a short breath-hold time while maintaining high resolution in our study. As MR techniques undergo further advances, new techniques allowing high resolution with a breath-hold of less than 10 seconds are anticipated.

In addition, the incidence of degraded HAP and GARD in group A was 9.7% and 19.4%, respectively, which was similar or lower than previous studies also using long breath-hold techniques. This is probably because a new 3 T MR machine using optimized protocols such as the bolus tracking technique, saline flushing, slower injection rate (1 mL/s), and on-label dosage (0.1 mL/kg) was used in our study, all leading to a positive effect on breath-holding capacity and image quality.

Based on survey questionnaire responses from 116 patients who answered that they held their breath well, 45 (38.8%) showed respiratory graphs of SD greater than 200 (breath-holding difficulty). This suggests that some patients may have experienced dyspnea without being aware of it, which could be explained as involuntary dyspnea. However, it is unlikely that all 45 patients experienced involuntary dyspnea. Thus, the survey questionnaire responses, which represent the subjective feeling of dyspnea, did not completely correspond to the objective assessment of patients’ respiratory conditions based on respiratory waveform. Therefore, indirectly evaluating dyspnea by surveying the subjective feeling of dyspnea may not be reliable. In addition, among the 116 patients who replied that they held their breath well, 8 (6.9%) showed image quality scores of 4 (degraded image quality). This finding implies that dyspnea may not be the only factor responsible for degraded image quality.

As 27.7% (33 patients; 21 in group A and 12 in group B) of the total group in our study showed breath-holding difficulty in the precontrast phase, it is not surprising that 40.3% (48 patients; 27 in group A and 21 in group B) showed breath-holding difficulty in the arterial phase after contrast injection. Therefore, many patients, especially those who are inpatients, heavy smokers, have chronic obstructive pulmonary disease, or congestive heart failure, experience difficulty holding their breath. As the breath-holding capacity of the majority of patients should be taken into consideration, the breath-hold time must be shortened to improve image quality leading to improved diagnosis regardless of the contrast agent.

TABLE 4. Mean Image Quality Scores of Patients With and Without GARD in Precontrast and HAP

<table>
<thead>
<tr>
<th>Group</th>
<th>Total (n = 16)</th>
<th>Group A (n = 12)</th>
<th>Group B (n = 4)</th>
<th>P*</th>
<th>Total (n = 103)</th>
<th>Group A (n = 50)</th>
<th>Group B (n = 53)</th>
<th>P*</th>
<th>P†</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE</td>
<td>2.2 (0.7)</td>
<td>2.4 (0.6)</td>
<td>1.5 (0.4)</td>
<td>&lt;0.05</td>
<td>1.7 (0.6)</td>
<td>2.0 (0.4)</td>
<td>1.3 (0.4)</td>
<td>&lt;0.001</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Motion artifact</td>
<td>2.2 (0.7)</td>
<td>2.4 (0.5)</td>
<td>1.5 (0.4)</td>
<td>&lt;0.05</td>
<td>1.7 (0.6)</td>
<td>2.0 (0.4)</td>
<td>1.3 (0.5)</td>
<td>&lt;0.001</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>HAP</td>
<td>2.8 (0.9)</td>
<td>2.9 (0.9)</td>
<td>2.4 (0.8)</td>
<td>0.288</td>
<td>1.9 (0.7)</td>
<td>2.3 (0.6)</td>
<td>1.6 (0.7)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Motion artifact</td>
<td>2.8 (0.9)</td>
<td>2.9 (0.9)</td>
<td>2.4 (0.8)</td>
<td>0.288</td>
<td>1.9 (0.8)</td>
<td>2.3 (0.6)</td>
<td>1.6 (0.7)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Data are presented as means (SD). The numbers are averaged values between the 2 readers.

*P values were calculated between groups A and B by using the Student t test.

†P values were calculated between patients with and without GARD by using the Student t test.
In previous studies, transient severe motion was used to describe GARD based on image analysis.\(^6,9,10\) In our study, degraded HAP, which was qualitatively evaluated based on image quality scoring, corresponded to transient severe motion. However, GARD was quantitatively defined based on respiratory pattern analysis by comparing respiratory waveforms before and after contrast injection to evaluate the effect of gadoxetic acid on respiration. In other words, we assessed the difference in SD values between the precontrast and HAP to evaluate GARD. However, GARD did not completely correlate with degraded HAP image quality in our study. Objective dyspnea evaluated by respiratory waveforms and subjective dyspnea assessed by survey questionnaires did not completely correspond. In addition, not all objective and subjective dyspnea led to motion-related artifacts. Therefore, it is uncertain if dyspnea can be fully evaluated by evaluating respiratory waveforms, querying subjective feelings of dyspnea, or assessing motion-related artifacts in MRIs. Further studies are anticipated to establish a tool for accurately assessing dyspnea.

This study had several limitations. First, the study population was limited to a single center. Second, respiration was analyzed objectively by recording thoracoabdominal movement via a pneumatic cushion, which may not correspond to the actual respiratory state. Although it would be ideal to record diaphragm movement, we believe that thoracoabdominal movement is sufficient to represent the respiratory condition to some degree. Third, the criteria or thresholds for the SD values were determined at the discretion of the radiologist after roughly reviewing the respiratory graphs.\(^6\) As the incidences of breath-holding difficulty and GARD rely greatly on this threshold value, a more objective criterion and further studies on this matter are required. Fourth, only the respiratory waveforms of the precontrast and HAP were evaluated in this study. As the respiratory waveforms of the portal and transitional phases were not evaluated, it was unclear if the dyspnea was transient or retained in later phases. Therefore, we evaluated the image quality of the portal and transitional phases to confirm that image quality degradation was transient and not retained in the phases following the HAP. Fifth, the impact of image quality on liver lesion detection and assessment of the 2 groups was not evaluated. Further within-patient studies comparing the diagnostic performance of the 2 groups are anticipated.

In summary, respiratory waveform analysis revealed incidences of breath-holding difficulty of 43.6% and 36.8% in group A and B, respectively. Gadoxetic acid–related dyspnea during the HAP was seen in 19.4% of group A and 7.0% of group B. Image-based analysis demonstrated degraded HAP in 9.7% of group A and 3.5% of group B. Therefore, the respiratory waveform and image quality analyses in this study indicated that the short breath-hold MR technique, CAIPIRINHA, showed better HAP image quality with less degraded HAP and a lower incidence of breath-holding difficulty and GARD than the conventional long breath-hold technique. The difference in breath-hold time between groups A and B was only 5 seconds (18 vs 13 seconds). Although 5 seconds may seem like a short time, it significantly affected HAP image quality during gadoxetic acid–enhanced MRI. This may be the “magic of 5 seconds.” Therefore, we believe the short breath-hold MR technique, CAIPIRINHA, can be the first step to overcoming degraded HAP in gadoxetic acid–enhanced liver MRI.

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REFERENCES

1. Park YS, Lee CH, Kim IS, et al. Usefulness of controlled aliasing in parallel imaging results in higher acceleration in gadoxetic acid-enhanced liver magnetic resonance imaging to clarify the hepatic arterial phase. Invest Radiol. 2014;49:183–188.