Free-Breathing Dynamic Contrast-Enhanced Imaging of the Upper Abdomen Using a Cartesian Compressed-Sensing Sensing Sequence With Hard-Gated and Motion-State-Resolved Reconstruction

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Objectives: The aim of this study was to compare a compressed-sensing free-breathing VIBE (fbVIBE) with a conventional breath-hold VIBE (bhVIBE) for dynamic contrast-enhanced imaging of the upper abdomen.

Materials and Methods: In total, 70 datasets (bhVIBE, n = 30; fbVIBE n = 40; hard-gated [hg] reconstruction, n = 30; motion-state-resolved [mr] reconstruction, n = 10) were assessed by 2 experienced readers. Both sequences were performed on 1.5-T magnetic resonance imaging scanners. The prototypical fbVIBE sequence acquired a navigation signal along with the imaging data and supported 2 different reconstructions: an hg reconstruction that either accepted or rejected an echo train based on the navigation signal and an mr reconstruction that assigned echo trains to their determined motion states. The hg reconstruction to reduce respiratory motion artifacts was carried out inline on the scanner (duration: approximately 8 minutes on the scanner-integrated CPU). The mr reconstruction delivered better results, but the reconstruction time is multiplied by the number of selected motion states (6 in the current study). Comparable reconstruction times to hg reconstruction can only be achieved on GPU-supported scanners. Therefore, the acquired raw data were selectively reconstructed at a later timepoint (duration: approximately 45 minutes). Welch analysis of variance tests were applied to compare image quality (IQ), delineation of structures, artifacts, and diagnostic confidence, which were rated on Likert-type scales (IQ/delineation of structures/diagnostic confidence: 1 [nondiagnostic] to 5 [perfect]; artifacts: 1 [no artifacts] to 5 [severe artifacts]).

Results: Mean ratings for IQ/delineation of structures/diagnostic confidence of fb(hg)VIBE (4.2 ± 0.7/4.3 ± 0.3/4.8 ± 0.7) were significantly higher compared with that of bhVIBE (3.7 ± 0.8/3.8 ± 0.8/3.9 ± 0.9; p < 0.001). In the fb(hg)VIBE cohort, an insignificant trend toward lower artifacts in the younger age group (4.9 ± 0.3/4.9 ± 0.3/4.9 ± 0.3; p = 0.8/0.7/0.6) and fb(mr)VIBE (4.2 ± 0.7/4.3 ± 0.8/4.3 ± 0.7; κ = 0.8/0.7/0.6) was observed compared with those of bhVIBE (3.7 ± 0.8/3.8 ± 0.9/3 ± 0.9; κ = 0.9/0.9/0.9), whereas artifacts of fb(hg)VIBE/bfb(mr)VIBE were rated lower (fb(hg)VIBE/bfb(mr)VIBE/bhVIBE = 2.2 ± 0.9/1.3 ± 0.5/2.4 ± 0.9; κ = 0.6/0.6/0.9). The IQ of fb(hg)VIBE was rated significantly higher compared with that of bhVIBE (P = 0.03). All parameters were significantly improved by mr reconstruction compared with fb(hg)VIBE and bhVIBE (P < 0.001). In the fb(hg)VIBE cohort, an insignificant trend toward lower artifacts in the younger age group (270 years: 2.5 ± 0.9 vs <70 years: 1.9 ± 0.8) was found, whereas significant differences emerged in the bhVIBE cohort (≥70 years: 3 ± 0.9 vs <70 years: 2.1 ± 0.9; p = 0.02).

Conclusions: Fast fbVIBE using hg and mr reconstructions is technically feasible with improved IQ compared with that of bhVIBE. Free-breathing VIBE may be useful for dynamic contrast-enhanced imaging of the upper abdomen, particularly in older and/or severely ill patients with impaired breath-hold capabilities.

Key Words: MRI, compressed sensing, free-breathing acquisition, dynamic contrast-enhanced imaging, motion artifacts, hard-gated reconstruction, motion-state-resolved reconstruction

Received for publication June 1, 2019; and accepted for publication, after revision, June 28, 2019.

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ISSN: 0020-9966/19/5411–0728 $728–736

A bdominal magnetic resonance imaging (MRI) has gained significant importance in recent decades for the evaluation of upper abdominal organs. In particular, dynamic contrast-enhanced (DCE) MRI supports the characterization of lesions and the assessment of organ function.1–6 Observing the contrast agent’s wash-in and wash-out can often be useful in refining diagnosis. In recent years, therefore, highly accelerated sequences have been developed to morphologically display the dynamics of contrast agents.7

Older techniques such as “keyhole” and view-sharing accelerated acquisitions by sampling the center of the k-space more frequently and substituting data in the periphery with data points from earlier or later acquisitions. These techniques are mostly used in vascular examinations because of the lack of available morphologic information.8,7 Parallel imaging techniques such as GRAPPA and CAIPIRINHA have also contributed to increasing the temporal resolution of dynamic upper abdominal imaging.7,10 However, all of these techniques are sensitive to motion artifacts, a well-known challenge for DCE MRI,1,11 causing significant problems in individual cases. Especially older and severely ill patients are often unable to adequately perform breath-hold maneuvers, with a risk of critically reduced image quality (IQ) due to motion artifacts and consequently impaired interpretability of the imaging material.12 In the clinical setting, prevention is commonly attempted to avoid motion artifacts. In infants and babies, for instance, postfeeding imaging can be planned to take advantage of sleep. Moderate sedation, or in some cases general anesthesia, is commonly used in the examination of infants.13,14

The introduction of compressed-sensing (CS)15 accelerated sequences, which allow more flexible k-space sampling, has paved the way for new strategies of reducing motion artifacts.6–10 Golden-angle radial sparse parallel MRI (GRASP) combines the CS reconstruction with a motion-insensitive radial k-space sampling using an efficient golden-angle trajectory.16 As a result, DCE of the upper abdominal organs in free breathing is possible with good IQ in various organs.20–22 The disadvantages of GRASP include its limited availability on older MR systems and the possibility of long reconstruction times. Nowadays, MRI reports are often expected within a few minutes to hours after the examination by referring physicians. Hence, a long waiting period is hardly clinically feasible.

In the present study, we use a Cartesian free-breathing VIBE (fbVIBE) during free breathing with reduction of motion artifacts using either hard-gated (hg) or motion-state-resolved (mr) reconstruction.
The purpose of this study was to compare the IQ of this prototypical Cartesian fbVIBE with clinically acceptable reconstruction time with that of a conventional breath-hold VIBE (bhVIBE) for DCE MRI of the upper abdomen.

**MATERIALS AND METHODS**

**Ethics Statement**

This study was approved by the Local Ethics Committee (2018–01586). The need for written informed consent was waived.

**Patients’ Selection**

From August 2018 to April 2019, 30 datasets of fb(hg)VIBE datasets (patients’ age: 63 ± 17 years) and 10 fb(mr)VIBE datasets (patients’ age: 60 ± 17 years) from consecutive patients referred for MRI examinations of either liver, pancreas, or kidneys for various reasons were included in this study.

Another 30 datasets from patients examined using bhVIBE for DCE (age: 61 ± 17 years) were collected randomly from our MRI archive and served as a reference standard. All patients were examined using a clinically established standard MRI protocol, with the exception of the contrast-enhanced sequence (bhVIBE vs fbVIBE). There were no specific selection criteria. Young patients (aged <18 years) and patients with contraindications to gadolinium-based contrast agents were excluded.

**MR Acquisition**

Patients were examined on clinical 1.5-T MR machines (MAGNETOM Aera/Avanto®, Siemens Healthcare, Erlangen, Germany) equipped with 18-channel body and 32-channel spine matrix coils. Patients were placed in head-first supine position on the table. fbVIBE and bhVIBE were acquired after administration of body weight–adapted (0.1 mmol/kg) intravenous contrast agent at a rate of 2 mL/s. The prototypical fat-suppressed, CS T1-weighted gradient echo examination with injection of either gadopentetate dimeglumine (Dotarem; Guerbet, Paris, France) or gadodiacetate disodium (Primovist; Bayer Schering Pharma AG, Berlin, Germany) was performed during free breathing. For that purpose, the sequence used an incoherent k-space sampling with segmentation in acquisition order to support spectral fat suppression. In addition to the fat-suppression pulses, a gradient echo readout in the head-feet direction was acquired as a navigation signal. The insertion of this projection into the selected projections of the previous time point. Only the imaging projections for each time point. For each time point, the set of imaging projections with the lowest variation was chosen, taking into account the selected projections of the previous time point. Only the imaging data of the echo trains following a selected approach were used for image reconstruction. The main advantage of the hg approach was its numerical performance. Image reconstruction could be performed inline during patient examination on the scanner-integrated CPU with a duration of approximately 8 minutes.

For the motion-resolved reconstruction, the navigation projections were further processed to a 1-dimensional navigation curve. The projections were binned into a chosen number of motion states (6 in this work) based on the amplitude of the navigation signal. This assignment was transferred to the imaging data following the respective navigation projection and the motion index interpreted as an additional dimension. Consequently, the number of reconstructed image volumes was multiplied by the number of selected motion states as was the reconstruction duration. In routine clinical practice, this could only be performed on GPU-equipped scanners within 10 minutes. Data were therefore selectively exported and processed offline. This approach utilized all acquired imaging data, which resulted in better IQ at the cost of numerical performance.

Both reconstruction approaches after processing of the navigation data utilized iterative CS optimization. The cost function involved a data fidelity term that matched the reconstructed images to their assigned data as well as a sparsity-enforcing regularization. For the data fidelity term, coil sensitivity maps derived from a separate calibration scan were used. The regularization was the L1-norm of a multidimensional Haar transformation with different regularization weights for different levels. Figure 1 was adapted from Yoon et al and details how image reconstruction was performed.

**Imaging Quality Evaluation**

Two radiologists (observers 1 and 2, with 9 and 12 years of experience in abdominal MRI, respectively) independently assessed all images (including fb(hg)VIBE, fb(mr)VIBE, and bhVIBE) in a blinded, randomized fashion. Overall IQ, delineation of structures (DoS), artifacts (A), and diagnostic confidence (DC) were rated on Likert-type scales (IQ/DoS/A/DC: 1 [nondiagnostic] to 5 [perfect]; A: 1 [no artifacts] to 5 [severe artifacts]). Images were interpreted using a Centricity PACS workstation (Radiology RA 1000; GE Healthcare).

**Statistical Analyses**

SPSS (Version 22; IBM Corp, Armonk, NY) was used for statistical analysis. IQ, DoS, diagnostic confidence, and artifacts were assessed using Likert-type scales. Welch analysis of variance tests were applied and adjusted for multiple comparisons using the Games-Howell method to compare IQ/DoS/DC and A of fbVIBE and bhVIBE. Mann-Whitney U tests and Kruskal-Wallis H tests were used to compare the extent of artifacts in older (>70 years) and younger (<70 years) patients. In addition, the observers’ agreement in the assessment of subjective IQ was investigated.

<table>
<thead>
<tr>
<th>Imaging Protocol</th>
<th>Slice Thickness, mm</th>
<th>FOV, mm</th>
<th>TR, ms</th>
<th>TE, ms</th>
<th>Flip Angle, degrees</th>
<th>Temporal Resolution, s</th>
<th>Base Resolution</th>
<th>Slice Resolution, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>FbVIBE</td>
<td>3</td>
<td>380</td>
<td>3.71</td>
<td>1.76</td>
<td>10</td>
<td>8.85</td>
<td>320</td>
<td>65</td>
</tr>
<tr>
<td>BhVIBE</td>
<td>3</td>
<td>380</td>
<td>6.69</td>
<td>2.39</td>
<td>10</td>
<td>30</td>
<td>18</td>
<td>320</td>
</tr>
</tbody>
</table>

Imaging parameters for conventional breath-hold (BhVIBE) and free-breathing (FbVIBE) examinations. The sequences differ primarily in terms of temporal resolution and flip angle. The flip angle was set to 10 degrees in FbVIBE because of specific absorption rate constraints.

BhVIBE indicates breath-hold; FbVIBE, free-breathing; FOV, field of view; TR, repetition time; TE, echo time.
TABLE 2. Observer Ratings of Subjective Image Quality Parameters

<table>
<thead>
<tr>
<th>bhVIBE vs fb(hg)VIBE</th>
<th>Fb(hg)VIBE (n = 30)</th>
<th>Fb(mr)VIBE (n = 10)</th>
<th>bhVIBE (n = 30)</th>
<th>κ (hg)</th>
<th>κ (mr)</th>
<th>κ (bh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ</td>
<td>4.2 ± 0.7</td>
<td>4.9 ± 0.3</td>
<td>3.7 ± 0.8</td>
<td>0.8</td>
<td>0.3</td>
<td>0.9</td>
</tr>
<tr>
<td>DoS</td>
<td>4.3 ± 0.8</td>
<td>4.9 ± 0.3</td>
<td>3.8 ± 0.8</td>
<td>0.7</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td>DC</td>
<td>4.3 ± 0.7</td>
<td>4.9 ± 0.3</td>
<td>3.9 ± 0.9</td>
<td>0.6</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>A</td>
<td>2.2 ± 0.9</td>
<td>1.3 ± 0.5</td>
<td>2.4 ± 0.9</td>
<td>0.6</td>
<td>0.6</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Subjective image perception using hg and especially mr reconstruction were rated good-excellent, while artifacts (A) were rated low. All image quality parameters were rated higher compared with those obtained with conventional bhVIBE. Interobserver agreement was good except about image quality in the small mr collective.

BhVIBE indicates breath-hold; FbVIBE, free-breathing; IQ, image quality; DoS, delineation of structures; DC, diagnostic confidence; A, artifacts.

FIGURE 1. For the hard-gated (hg) reconstruction, an echo train was either accepted or rejected for reconstruction ("gating acceptance"), and for motion-state-resolved (mr) reconstruction, an echo train was assigned to its determined motion state (chosen to be the sixth movement state in this study) (A). In principle, the examination should be carried out with shallow and rhythmic breathing. In some patients, this was not possible, and relatively strong motion artifacts of the hg reconstruction were observed (B). These artifacts could be mitigating using mr reconstruction (C).
criteria was analyzed using Cohen $\kappa$. Boxplots were drawn for all comparisons of subjective IQ.

**RESULTS**

**BhVIBE vs fb(hg)VIBE**

The average IQ/DoS/DC/A ratings of the fb(hg)VIBE images were good to very good. The subjective assessments of all of these IQ parameters of the fb(hg)VIBE obtained better ratings compared with those of bhVIBE. However, only in the case of IQ were significant differences were found (Tables 2, 4; Figs. 2, 4, and 5). The agreement of the radiologists was good with regard to all parameters of fb(hg)VIBE and bhVIBE ($\kappa \geq 0.6$; Table 2).

**fb(mr)VIBE vs bhVIBE and fb(hg)VIBE**

The evaluation of IQ/DoS/DC/A values of the mr reconstruction displayed almost perfect results (Table 2, Fig. 2). Especially in patients with a very irregular navigation signal curve profile and moderate hg reconstruction quality, the IQ could be further improved (Fig. 1). Significantly improved results were achieved for all IQ parameters compared with those of both bhVIBE and fb(hg)VIBE (Table 4). The agreement of both observers regarding IQ/DoS/DC/A scores was mostly good ($\kappa \geq 0.6$), except for the assessment of IQ in the relatively small mr cohort ($n = 10$, $\kappa = 0.3$; Table 2).

**Comparison of Age Groups (>70 vs <70 Years)**

In the fb(hg)VIBE cohort (age distribution: $n = 15 \geq 70$ years; $n = 15 < 70$ years), a trend toward lower artifacts in the younger age group ($\geq 70$ years: $2.5 \pm 0.9$ vs <70 years: $1.9 \pm 0.8$) was found. However, the difference was not significant ($P = 0.11$).

There were also no significant differences in the fb(mr)VIBE group (age distribution: $n = 3 \geq 70$ years; $n = 7 < 70$ years). Again, the artifacts were less pronounced in young patients ($\geq 70$ years: $1.4 \pm 0.5$ vs <70 years: $1 \pm 0$; $P = 0.38$).

Similar results were observed in the bhVIBE cohort (age distribution: $n = 10 \geq 70$; $n = 20 < 70$ years). Here, however, significant differences have emerged ($\geq 70$ years: $3 \pm 0.9$ vs <70 years: $2.1 \pm 0.9$; $P = 0.02$).

The comparison of artifacts in the 70 years or older age group between fb(mr)VIBE and fb(hg)VIBE ($P = 0.08$) with those of the bhVIBE with the fb(hg)VIBE ($P = 0.05$) showed no significant differences. When comparing fb(mr)VIBE to bhVIBE, significant differences in favor of the mr reconstruction were detected ($P = 0.01$). However, the very small group size in the mr cohort ($n = 3$) has to be considered.
Assessment of Motion States

Among the 6 different motion states (ms), ms 1 was the most robust and was preferred by both readers in the majority of cases (Fig. 3, Table 3).

DISCUSSION

Motion artifacts have been a known problem since the earliest days of MRI.24–27 According to a publication by Lee et al,28 approximately 7% of all patients are unable to hold their breath for 15 seconds. Triggering and gating are established techniques for reducing physiological movement such as heartbeat and breathing. These movements occur periodically, allowing accurate timing of MR data acquisition to mitigate artifacts.29,30

Imaging techniques based on spiral or radial encoding strategies can also be used, because they are less prone to motion artifacts than Cartesian sequences, and the artifacts that do appear are of a more benign nature.31 The reason for this is that these techniques typically oversample the k-space center, which either extracts the artifacts by averaging or can be used for advanced motion correction during postprocessing.31–35 For the hepatobiliary phase in liver MRI, motion-insensitive radial sequences are established to improve IQ.36,37 However, the radial readout technique is generally more time-consuming than the Cartesian readout technique. Hence, the sequence is not suitable for fast dynamic imaging because of its low temporal resolution.

New sequences combine parallel imaging and radial encoding with highly accelerated image acquisition using a CS reconstruction, thus allowing multiphase contrast-enhanced imaging of the abdomen in free breathing with a sufficiently high temporal resolution for DCE and even perfusion quantification.19–22

Feng’s initial work demonstrated that GRASP provides dynamic imaging with high spatial and temporal resolution for a variety of clinical applications, including DCE abdominal imaging in both adult and pediatric patients.38

New scanner generations provide dedicated reconstruction hardware and a workflow with background reconstruction allowing for fast reconstruction within a few minutes. Unfortunately, in older MRI scanners with low computational power, the reconstruction time is 2 to 6 hours, which limits the use of GRASP in routine clinical practice. In addition, an external reconstruction server is necessary for older systems, the purchase of which is associated with additional costs.

In the presented sequence, the problem of respiratory motion artifacts and image acceleration is solved solely by reconstruction algorithms. The hg reconstruction step takes only 8 minutes and was performed on the scanner’s native hardware. Such a reconstruction time does not disturb clinical processes. The mr reconstruction is also feasible on the scanner’s hardware, but the process takes 45 minutes. During

TABLE 4. Statistical Comparison of Subjective Image Quality Parameters

<table>
<thead>
<tr>
<th></th>
<th>IQ</th>
<th>DoS</th>
<th>A</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>bh vs hg</td>
<td>0.034</td>
<td>0.117</td>
<td>0.593</td>
<td>0.065</td>
</tr>
<tr>
<td>bh vs mr</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>hg vs mr</td>
<td>&lt;0.001</td>
<td>0.002</td>
<td>0.002</td>
<td>0.004</td>
</tr>
</tbody>
</table>

When the fast hard-gated reconstruction was compared with VIBE in the breath-hold condition, a significantly improved IQ of the fb sequence was found. All image quality parameters were further significantly improved by mr reconstruction compared with bhVIBE and fb(hg)VIBE.

BhVIBE indicates breath-hold; FbVIBE, free-breathing; IQ, image quality; DoS, delineation of structures; DC, diagnostic confidence; A, artifacts; bh, breath-hold; hg, hard-gated; mr, motion-state-resolved.
this time, no other sequences can be reconstructed. For this reason, selected examinations were exported and reconstructed offline.

Based on the observer ratings, a significant improvement of IQ was achieved by fbVIBE compared with bhVIBE when using fast hg reconstruction, which only employed the dominant ms ($P < 0.05$). The IQ was significantly improved by the mr reconstruction compared with either fb(hg)VIBE or bhVIBE (Tables 2, 4; Figs. 1, 2). Especially, mr reconstructions led to improved visualization of the liver, pancreas, and kidney despite free breathing compared with bhVIBE, and mr was also associated with significantly increased DC by experienced radiologists ($P < 0.001$; Table 4).

CS is often criticized for the emergence of new types of artifacts (eg, a synthetic image impression), which in some cases could mask important anatomical characteristics. In our analysis, however, the extent of A of fb(hg)VIBE/fb(mr)VIBE was rated as less serious compared with that of bhVIBE (fb[hg]VIBE/fb[mr]VIBE/bhVIBE = 2.2 ± 0.9/1.3 ± 0.5/2.4 ± 0.9), which was significant in the case of mr reconstruction ($P < 0.001$).

Weiss et al$^{39}$ published a technical feasibility study on the use of the presented prototypical fbVIBE in comparison to conventional bhVIBE for rapid arterial liver imaging. The time with the subjectively best IQ was defined as the dominant arterial hepatic phase (HAD). The HAD could be seen reliably in the fbVIBE cohort, whereas in the bhVIBE collective, HAD was only recognizable in 65% of the cases. The IQ of fbVIBE was significantly higher compared with that of bhVIBE ($P < 0.001$).

Similar results were reported by Kaltenbach et al,$^{40}$ wherein dynamic free-breathing liver imaging was performed using the prototypical Cartesian T1 VIBE with CS and simultaneous acquisition of a navigation signal for hg and mr reconstruction. In total, 43 patients referred for evaluation of liver metastases in colorectal carcinoma were included in the study. Both reconstructions were compared with the most recent staging breath-hold MRI.

Compared with fb(hg)VIBE, fb(mr)VIBE had significantly higher IQ in both the arterial (4.2 ± 0.6 vs 3.8 ± 0.7, $P = 0.008$) and venous (4.7 ± 0.4 vs 4.3 ± 0.7, $P < 0.001$) phases. There was no significant difference in IQ between fb(hg)VIBE and bhVIBE in the venous phase (4.7 ± 0.4 vs 4.8 ± 0.4, $P = 0.834$), but there was a significant difference in the arterial phase (4.5 ± 0.6 vs 4.2 ± 0.6, $P = 0.024$).

In the present study, an improved liver visualization using fbVIBE with and without mr reconstruction compared with bhVIBE was observed through both sharper organ contours and multiphasic organ depiction, which allowed the evaluation of lesions’ contrast dynamics in detail over long periods (Fig. 6A). The low flip angle of the fbVIBE may be a disadvantage compared with high-flip angle sequences for detection of small liver lesions because of fbVIBE’s presumably inferior lesion-to-background contrast. However, another study by Weiss et al$^{41}$ found that fbVIBE provides similar IQ and lesion conspicuity to those of bhVIBE.

The use of fbVIBE is interesting not only for the liver but also for other upper abdominal organs. A study on the use of DCE MRI for the differentiation of common benign and malignant histological subtypes of cortical renal tumors showed that some such tumors can be characterized by their signal intensity patterns.$^{42}$ Significant differences in signal intensity percentage change between clear cell, papillary, and chromophobec carcinomas in all phases of enhancement ($P < 0.0001–0.0120$) were detected.
In the present study, we found that renal parenchyma and cysts were more sharply defined using fb(hg)VIBE compared with bhVIBE (Figs. 4, 5). This could contribute to improved renal lesion characterization and assessment of enhanced septa and cystic walls to facilitate early detection of malignant transformations of complicated renal cysts.

FIGURE 5. Images of an 85-year-old female patient with impaired breath-holding capability. Initial bh VIBE examination (B and D) was nondiagnostic because of severe breathing artifacts. Fb(hg)VIBE (A and C) was acquired with superior image quality. Clear demarcation of organ borders (eg, liver [arrowheads] and kidney [arrows]) due to artifact reduction is noticeable.

In the present study, we found that renal parenchyma and cysts were more sharply defined using fb(hg)VIBE compared with bhVIBE (Figs. 4, 5). This could contribute to improved renal lesion characterization and assessment of enhanced septa and cystic walls to facilitate early detection of malignant transformations of complicated renal cysts.

FIGURE 6. A 65-year-old male patient with metastatic lung and liver lesions of unknown primary origin. Pancreatic head appears normal on initial CT scan (left). Multiphase free-breathing MR images of the same patient using hg reconstruction depict a hypovascular adenocarcinoma of the pancreatic head.
Moreover, small structures such as the pancreatic duct were clearly visible and well-defined using fbVIBE (Fig. 5). Application in the field of intraintral papillary mucinous neoplasms diagnostics would be interesting, both to detect communication of lesions with the duct system and to improve detection of enhancing mural nodules, which are an indication for surgery.

Particularly impressive was the almost motion-artifact-free visualization of the pancreas in multiple contrast phases, which facilitated easy recognition of a hypovascularized adenocarcinoma of the pancreas (Fig. 6A).

The study has some limitations. First, the present work is a clinical feasibility study with a small and heterogeneous collective. Second, it would be interesting to use the sequence for the assessment of certain diseases in larger cohorts to test the sequence’s clinical value, but that was not done in this study. Finally, the ms-resolved reconstruction collective was particularly small. Randomly selected datasets had to be sent to the manufacturer to perform reconstruction, which is time-consuming (45 minutes) and can only be achieved on GPU-equipped scanners in an acceptable amount of time.

In summary, fbVIBE allows artifact-insensitive DCE of the upper abdomen with improved IQ compared with bhVIBE. The technique seems to be particularly useful for robust renal and pancreatic imaging, especially in the context of assessment of cystic lesions to evaluate enhancement of soft tissue components. However, the lower lesion-to-background contrast caused by the lower flip angle compared with bhVIBE might interfere with detection of small liver lesions. These hypotheses need to be confirmed in dedicated studies.

The fbVIBE sequence may be helpful to avoid invasive sedation in infants and repetition of examinations in severely ill and elderly patients, which could reduce healthcare costs and contribute to avoid repetitive contrast agent exposure in a collective that is prone to renal failure.

ACKNOWLEDGMENTS

The authors thank Richard Lipkin, PhD, from Edanz Group (www.edanzediting.com/ac) for editing a draft of this manuscript.

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Investigative Radiology • Volume 54, Number 11, November 2019

Free-Breathing DCE of the Upper Abdomen


