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MAGNETIC RESONANCE

Reduction in respiratory motion artefacts on gadoxetate-enhanced MRI after training technicians to apply a simple and more patient-adapted breathing command

Andreas Gutzeit[1,2] · Simon Matoori[1] · Johannes M. Froehlich[1,3] · Constantin von Weymarn[1] · Carolin Reischauer[1] · Orpheus Kolokythas[2] · Matthias Goyen[1] · Klaus Hergan[1] · Matthias Meissnitzer[1] · Rosemarie Forstner[1] · Jan D. Soyka[2] · Aleksis Doert[2] · Dow-Mu Koh[4]

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Abstract

Objective To investigate whether a trained group of technicians using a modified breathing command during gadoxetate-enhanced liver MRI reduces respiratory motion artefacts compared to non-trained technicians using a traditional breathing command.

Materials and methods The gadoxetate-enhanced liver MR images of 30 patients acquired using the traditional breathing command and the subsequent 30 patients after training the technicians to use a modified breathing command were analyzed. A subgroup of patients (n=8) underwent scans both by trained and untrained technicians. Images obtained using the traditional and modified breathing command were compared for the presence of breathing artefacts [respiratory artefact-based image quality scores from 1 (best) to 5 (non-diagnostic)].

Results There was a highly significant improvement in the arterial phase image quality scores in patients using the modified breathing command compared to the traditional one (P<0.001). The percentage of patients with severe and extensive breathing artefacts in the arterial phase decreased from 33.3 % to 6.7 % after introducing the modified breathing command (P=0.021). In the subgroup that underwent MRI using both breathing commands, arterial phase image quality improved significantly (P=0.008) using the modified breathing command.

Conclusion Training technicians to use a modified breathing command significantly improved arterial phase image quality of gadoxetate-enhanced liver MRI.

Key Points

- *A modified breathing command reduced respiratory artefacts on arterial-phase gadoxetate-enhanced MRI (P< 0.001).*
- *The modified command decreased severe and extensive arterial-phase breathing artefacts (P= 0.021).*
- *Training technicians to use a modified breathing command improved arterial-phase images.*

Keywords Liver · MRI · Dyspnoea · Gadoxetate · Arterial phase

Introduction

Gadoxetate disodium (Gd-EOB-DTPA, Primovist® / Eovist®, Bayer HealthCare Pharmaceuticals, Berlin, Germany) is a liver-specific magnetic resonance imaging (MRI) contrast agent. Its diagnostic performance in the detection and assessment of focal liver lesions (e.g,. hepatocellular carcinoma) depends on the image quality of the dynamic phases, especially the arterial phase [1–8].

In recent years, several studies have described arterial phase image degradation for gadoxetate-enhanced liver MRI [9–13]. These motion-related artefacts were attributed to acute but transient episodes of dyspnoea in response to gadoxetate

✉ Andreas Gutzeit
agutzeit2000@gmail.com

[1] Department of Radiology, Paracelsus Medical University Salzburg, Salzburg, Austria

[2] Department of Radiology, Cantonal Hospital Winterthur, Brauerstrasse 15, 8401 Winterthur, Switzerland

[3] Department of Chemistry and Applied Biosciences, Institute of Pharmaceutical Sciences, ETH Zurich, Vladimir-Prelog-Weg 1-5 / 10, 8093 Zurich, Switzerland

[4] Department of Radiology, Royal Marsden Hospital, Downs Road, Sutton, Surrey SM2 5PT, Great Britain, UK

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administration and isolated to the arterial phase (Transient Severe Respiratory Motion Artefact, TSM). The incidence of TSM reportedly ranges from 5 to 17 % for gadoxetate compared to 1 to 2 % for gadobenate dimeglumine (MultiHance®; Bracco Diagnostics, Princeton, NJ). While the aetiology of TSM remains poorly understood, several risk factors such as an off-label fixed dose of 20 mL (recommended dose: 0.1 mL/kg body weight (BW) [0.025 mmol Gd/kg]), chronic obstructive pulmonary disease (COPD), and repeated gadoxetate administration, especially in patients with a previous history of TSM, were recognised [11, 13]. However, as there is incomplete data about the severity of such reactions, a lack of a clear physiological definition and the practical difficulty of distinguishing between contrast reaction versus poor patient breath-hold, gadoxetate contrast-induced dyspnoea remains a subject of controversy [14, 15]. Indeed, a recent study demonstrated that heart rate and peripheral capillary oxygen saturation were similar in TSM and non-TSM patients, casting doubt on the role of dyspnoea in arterial-phase degrading motion artefacts [16]. Moreover, another recent study found low and similar incidences of severe respiratory motion artefacts for gadoxetate and gadobutrol in dynamic phase imaging, calling into question that high-grade respiratory motion artefacts are a mainly gadoxetate-related phenomenon [17].

In accordance with previous studies [9–13], we have noticed that certain patients have difficulties to comply with traditional breathing commands for breath-hold T_1-weighted imaging, especially during the arterial phase. However, this phenomenon was not limited to patients receiving gadoxetate as contrast agent but also occurred with other contrast agents or on pre-contrast imaging. Recognizing the findings of Davenport et al. [9], we decided to develop a modified and more patient-oriented breathing command (Fig. 1) and trained our technicians to apply it. To the best of our knowledge, a role of breathing guidance of patients by technicians has not been reported as part of the problem or potential solution of respiratory motion artefact-associated arterial image degradation.

Hence, the aim was to investigate whether a trained group of technicians using a modified breathing command during gadoxetate-enhanced liver MRI reduces respiratory motion artefacts compared with a non-trained group of technicians using the traditional breathing command.

Materials and methods

A general institutional review board approval was given for this retrospective clinical study, and all patients provided

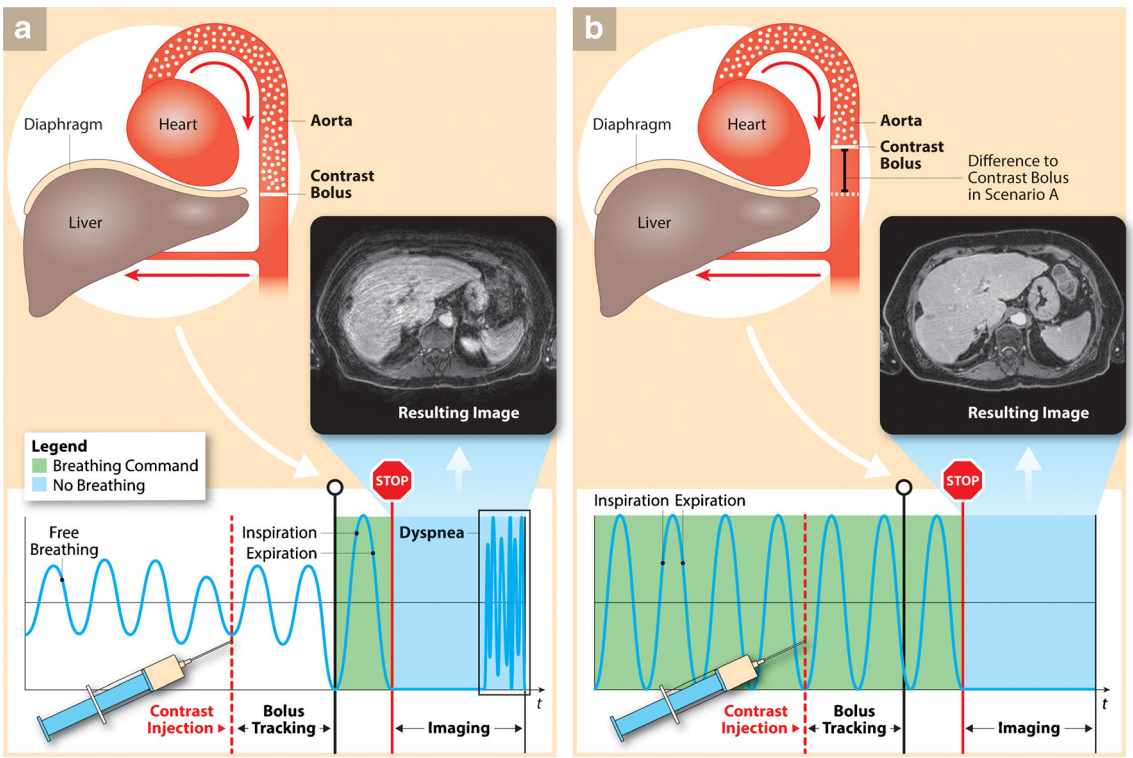

Fig. 1 Traditional (A) and modified breathing command (B). In the traditional breathing command, the patient breathes freely before and after contrast injection until he is instructed to breathe in and breathe out, and to hold the breath during the acquisition period. In the modified breathing method, the patient is guided to continuously breathe in and out four times in a row before contrast media injection and to continue in this rhythm during bolus tracking until he is instructed to hold his breath for the image acquisition. This example shows the same patient in an intraindividual comparison who had been investigated with untrained technicians (left hand side) and after training of technicians (right hand side) several weeks later

written informed consent. The two patient groups described below underwent gadoxetate-enhanced MRI between March 1, 2013 and June 3, 2013.

Image acquisition

All imaging was performed on a 1.5 T MRI system (Achieva, Philips Healthcare, Best, The Netherlands). A 16 channel XL-torso coil (Philips Healthcare, Best, The Netherlands) was employed. Supporting information in Table 1 summarizes the technical details of our T_1-weighted pre-contrast and dynamic acquisition sequences. As described above, in order to track the bolus arrival time for the arterial phase, a two-dimensional triggering sequence was also utilized (bolus track sequence).

MRI performed using the traditional breathing command

The last 30 patients, who were evaluated using gadoxetate-enhanced liver MRI as clinically indicated, were selected for analysis. All patients received a standard intravenous dose of gadoxetate disodium (0.025 mmol Gd/kg BW). The injection scheme and MR sequences were standardized, but different technicians performed the examinations according to our routine study protocol. This protocol has not changed over the past four years.

Our traditional breathing command consisted of asking patients to suspend breathing in expiration during the dynamic contrast enhanced T_1-weighted acquisitions (approximately 18.5 seconds). Following planning of the acquisition stack, the technicians instructed the patients to "breathe in, breathe out, and stop breathing" (Fig. 1) to acquire the pre-contrast T_1-weighted images. During intravenous injection of gadoxetate disodium using a power injector (Accutron® Medtronic, Germany), the bolus track sequence was started. Once the technicians recognized the arrival of contrast bolus in the distal thoracic aorta, they started to issue the same breathing commands: "Breathe in, breathe out and stop breathing." After this short command, the arterial dynamic scan was performed. The venous phase and the late dynamic phase images were acquired in a similar way at 70 and 180 seconds after contrast injection. Across the dynamic acquisition, the breathing command was the same. The relevant MRI sequence and technical data are summarized in Table 1.

Table 1 Main MRI parameters of the native and dynamic three-dimensional sequences after application of contrast medium (equal for all phases)

Repetition time	4 ms
Echo time	1.95 ms
Field of view	Adapted in order to cover the entire liver
Matrix in frequency direction	188-375
Matrix in phase direction	147-295
Frequency direction	right to left
Section thickness	4 mm
Sense factor	2.4
Acquisition time	18.5 s
Delay arterial phase	Variable, bolus track
Venous phase	70 s
Late venous	180 s

MRI performed using the modified breathing command by trained technicians

This group included 30 patients who underwent gadoxetate-enhanced MRI using modified breathing command by trained technicians. Contrast dosage and MR sequence parameters were kept the same as for patients who underwent MRI using traditional breathing command. The selection of this cohort was neither influenced nor controlled by us or by the referring physicians and comprised of consecutive patients who were referred for gadoxetate-enhanced liver MRI. The patient data are summarized in Table 2.

To improve the patients' breathing compliance, our technicians reviewed their work practice in an in-house training, where difficulties in sustaining breath-hold during the entire T_1-weighted measurement and in hearing breathing instructions due to loud MR gradients during arterial phase bolus tracking were observed. Consequently, the modified breathing command was deployed as follows: before starting the pre-contrast acquisition, we issued the patient four consecutive breath-hold commands: "1) breathe in-breathe out, 2) breathe in-breathe out, 3) breathe in-breathe out, 4) breathe in-breathe out-stop breathing" followed by the start of the MR sequence and measurement. Thereafter, the arterial phase acquisition was started. Similar to the pre-contrast imaging, a series of four cycles of breathing in and out were instructed. After these four cycles, we initiated the contrast medium injection (same injection mode as before) together with the bolus track sequence. However, the patient was instructed to continue to breath-in and breath-out with the same regularity as before. Once contrast was seen to arrive in the mid-aorta the technicians gave the final breathing command (breathe in-breathe out and stop breathing) and the arterial phase imaging was acquired (Fig. 1). The venous and delayed phases were performed using identical four breathing cycles as described above at the appropriate time points.

Hence, the main differences in the modified versus traditional breath-hold approaches include: (1) four instead of one cycle of breathing instruction was issued prior to image acquisition; (2) arterial phase measurement was initiated when the contrast agent bolus reached the mid-aorta instead of the distal thoracic aorta (Fig. 1) and (3) the audio system was set louder so that it is easy for the patients to understand the breathing command. No oxygen was administered to the patients nor was hyperventilation performed.

Table 2 Summary of patient characteristics (*P<0.05)

Parameter	Traditional breathing command	Modified breathing command	P-value
Total number of patients	30	30	
No. of women/no. of men	16/14	12/18	P=0.438
Mean age (min, max), years	63.7 (37, 90)	61.8 (32, 84)	P=0.572
Mean body weight (min, max), kg	75.1 (48, 96)	76.6 (47, 125)	P=0.724
Mean BMI (min, max), kg/m^2	25.2 (17.0, 32.4)	25.5 (17.7, 43.3)	P=0.811
Mean gadoxetate dose[1] (min, max), mL	7.51 (4.8, 9.6)	7.66 (4.7, 12.5)	P=0.724
Anxiety	0/30 (0 %)	1/30 (3.3 %)	P=1.000
Cardiac insufficiency	0/30 (0 %)	1/30 (3.3 %)	P=1.000
Lung disease	0/30 (0 %)	1/30 (3.3 %)	P=1.000
Cirrhosis	7/30 (23.3 %)	3/30 (10.0 %)	P=0.299
Ascites	6/30 (20.0 %)	4/30 (13.3 %)	P=0.731
TSM	4/30 (13.3 %)	0/30 (0 %)	P=0.112

[1] Dose of 0.025 mmol/kg bodyweight (0.1 ml/kg) as indicated by Summary of Product Characteristics (European Medicine's Agency)

Patient risk factors

In accordance with recently published findings [11], we recorded any known possible risk factors (Table 2) that may be associated with TSM. The presence of ascites and pleural effusion on the MRI were also recorded.

Contrast medium

Gadoxetate disodium has been routinely used in our practice for liver MRI for the past 4 years and is administered (Primovist®, Bayer HealthCare Pharmaceuticals, Berlin, Germany) according to the recommendations of the manufacturer (weight-adjusted: 0.1 mL/kg BW [0.025 mmol Gd/kg]). It was injected undiluted at a rate of 1 mL/s followed by a 30 mL saline chaser injected at the same rate (Accutron®, Medtronic, Germany). The injection protocol was standardized and not individualized for each patient, except for the weight-adjusted gadoxetate dosing.

Image analysis

The pre-contrast and dynamic phase (arterial, venous and late dynamic phase) images of both groups (i.e., acquired using traditional and modified breath-hold instructions) were blinded, randomized, and loaded separately onto our PACS system (Agfa Systems). Similarly to the study methodology described by Davenport et al.[9], we did not analyze the image quality in the hepatobiliary phase of contrast enhancement.

Three independent board certified abdominal body readers (AG, AD, and JS) with 14, 7 and 5 years' experience, respectively, in liver MRI, who could recognize and discriminate respiratory artefacts, were invited to analyze the images. The three readers analyzed the randomized images independently and individually, blinded to the results of the other two. They scored each image for the presence and severity of respiratory artefacts according to the grading system used in the previous study by Davenport et al.[9]: Grade 1=no visible breathing artefacts, Grade 2=minimal breathing artefacts with no effect on diagnostic quality, Grade 3=moderate breathing artefacts with some but not severe impairment of diagnostic quality, Grade 4=severe breathing artefacts but still interpretable, Grade 5=extensive breathing artefacts and images not interpretable.

The grading scores of the arterial, venous and late dynamic phase images for each patient from each of the three readers were recorded. Grading scores between readers were compared using intraclass correlation coefficients (ICC) for inter-reader agreement. An averaged breathing artefact score was also calculated between the readers for each phase in each patient. A mean score of 4 or 5 was defined as severe motion artefacts [13]. TSM was considered to be present in MR examinations with an average grade score of at least 4 on the arterial phase images; and with average grade scores of up to 2 on the pre-contrast images and on either the portal venous or late dynamic images as previously described [11].

Subgroup analysis

Eight patients in the cohort underwent initial MRI using the traditional breath-hold commands and subsequently underwent another MRI using the modified breath-hold command after technician training. The second MRI was requested as per clinical indications (e.g., follow up after systemic therapy) and the radiologists/ technicians had no influence over their selection. We performed pair-wise intra-individual comparison for this subgroup.

Statistical analysis

In establishing the trial design, assuming a 0.3 difference of the quality scoring with a *p*-value of 0.05 and with a power of 80 % revealed that 25 patients would be necessary to achieve statistical significance.

Statistical analysis was performed similar to the study by Davenport et al.[9]. For baseline characteristics, the patient cohorts instructed by the traditional and the modified breathing command were compared with a Fisher's exact test for categorical variables and with the Student's t-test for quantitative variables. Age was defined at the time of examination.

We compared the average mean image grading scores from all three readers between images derived using traditional versus modified breathing commands by the Mann-Whitney U test. For the patients who underwent MRI with both traditional and modified breathing commands, mean image grading scores were compared with the Wilcoxon signed-rank test.

Spearman's rho correlation statistics was performed to determine the relationship between the pre-contrast and arterial phase image grading scores. Correlation was classified as very weak (rho below 0.20), weak (rho between 0.20 and 0.39), moderate (rho between 0.40 and 0.59), strong (rho between 0.60 and 0.79), and very strong (rho above 0.79).

The intraclass correlation coefficient (ICC, two-way mixed model, absolute agreement) was calculated for each phase of contrast enhancement to determine the inter-reader reliability for the image quality grading scores. Agreement among raters was classified as poor (ICC of 0–0.4), fair to good (ICC of 0.40–0.75) or excellent (ICC of >0.75). For all statistical analysis, a P value of <0.05 was deemed to be statistically significant and a P value of <0.001 as highly statistically significant.

Results

Table 2 demonstrates that the baseline characteristics of the patients who underwent MRI using traditional versus modified breathing commands were comparable. Notably, no statistically significant differences were found between the two groups with regards to the number of patients with liver cirrhosis (P=0.299), ascites (P=0.731), pleural effusion (P=0.353), cardiac insufficiency (P=1.000), and anxiety rating (P=1.000). The mean weight-adjusted gadoxetate dose-volume (0.1 mL/kg BW [0.025 mmol Gd/kg]) was 7.51 mL and 7.66 mL for the cohorts using the traditional and the modified breathing command, respectively (P=0.724).

The inter-reader agreement on the averaged image quality grading scores of the T1-weighted images among the three blinded readers was excellent with ICC of 0.80 (precontrast phase), 0.92 (arterial), 0.88 (venous), and 0.89 (late dynamic). The averaged image quality grading scores for patients who underwent liver MRI using the traditional breathing command (Fig. 2A, Table 3) were 1.9 (precontrast), 3.2 (arterial), 2.0 (venous), and 1.7 (late dynamic). For patients who underwent liver MRI using the modified breathing guidance scheme (Fig. 2A),

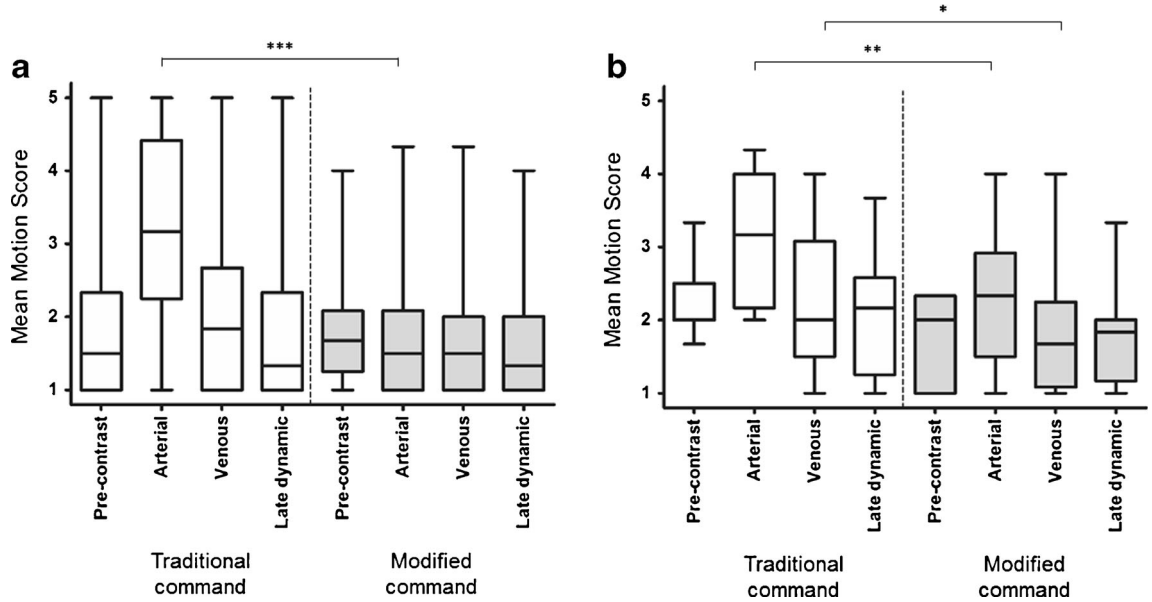

Fig. 2 Box plot showing the mean image quality scores for patients following the traditional or the modified breathing command in the early dynamic phases in the entire cohort (A, n=30 for each group) and a subpopulation of patients who underwent gadoxetate-enhanced MR scans with both commands (B, n=8). Using the modified breathing command, there is a highly significant improvement in arterial phase image quality in the entire population (A, P<0.001). In the patient subpopulation, which underwent a first scan following the traditional and a second one following the modified breathing command, a significant improvement in the arterial phase image quality is observed in the second scan (B, P=0.008). The error bars depict minimum and maximum scores. The boxes indicate interquartile ranges demarcated by median scores. *P<0.05, **P<0.01, ***P<0.001

Table 3 Mean quality scores of the entire patient population (n=30) and the subpopulation of eight patients which underwent an MR scan with the traditional, and subsequently with the modified breathing command (mean image quality score±standard deviation, *P<0.05, **P< 0.01, ***P<0.001).

	Traditional breathing command	Modified breathing command	p-value
n=30			
Precontrast	1.86±0.99	1.74±0.66	P=0.985
Arterial	3.19±1.31	1.78±0.92	P<0.001***
Venous	2.04±1.11	1.60±0.82	P=0.076
Late dynamic	1.74±1.01	1.63±0.85	P=0.834
n=8			
Precontrast	2.21±0.53	1.75±0.66	P=0.094
Arterial	3.17±0.91	2.33±0.94	P=0.008**
Venous	2.25±0.99	1.88±0.97	P=0.031*
Late dynamic	2.13±0.87	1.83±0.73	P=0.063

the averaged image quality scores were 1.7 (precontrast), 1.8 (arterial), 1.6 (venous), and 1.6 (late dynamic).

There was a significant difference in the arterial phase T_1-weighted image quality grading scores between the patients instructed to use the traditional versus the modified breathing command (P<0.001, Fig. 2A, Table 3). The percentage of patients with severe and extensive motion artefact (i.e., image quality score ≥4) in the arterial phase decreased from 33.3 % (10/30) to 6.7 % (2/30) using the modified breathing command (P=0.021). There was a decrease in the incidence of TSM from 13.3 % (4/30) to 0 % (0/30), with a trend towards statistical significance (P=0.112).

For patients who first underwent a gadoxetate-enhanced liver MRI scan using traditional breathing commands and a subsequent liver MRI study using the modified breathing command (n=8), significantly improved arterial phase image quality grading score (P=0.008) were observed for the MRI studies performed using the modified breathing command by trained technicians (Fig. 2B, Table 3).

There was a moderate positive correlation between the image quality of the precontrast and the arterial phase T_1-weighted images in patients instructed to use the traditional breathing command (Spearman's rho=0.406, P=0.026, Fig. 3A). Analysis of the patients who underwent MRI using the modified breathing command revealed a very strong positive correlation of the precontrast and the arterial phase T_1-weighted images (Spearman's rho=0.874, P<0.001, Fig. 3B).

Interestingly, the modified breathing command did not result in a significant difference in the image quality grading scores of the precontrast (P=0.985), venous (P=0.076), and late dynamic phases (P=0.834) images compared with the patients who underwent MRI using the traditional breathing command. However, in the subset of patients with two serial MRI scans performed using traditional and then the modified breathing commands, there was significant or near-significant improvement in the mean image quality grading scores using the modified breathing command compared with the traditional breathing command on the precontrast (P=0.094), venous (P=0.031), and late dynamic phase images (P=0.063).

Discussion

The main result of this study is that a modified breathing command with a more patient-oriented and longer breathing guidance significantly improved the arterial phase image quality on gadoxetate-enhanced liver MRI (P<0.001, Fig. 2A, Table 3). We further showed a significant decrease in the occurrence of severely and extensively degraded arterial phase T_1-weighted images using our modified breathing command (P=0.021) and a trend towards a decrease in TSM incidence from 13 % in the group using traditional breathing command to 0 % in the group using modified breathing command (P= 0.112). Comparing a subpopulation who underwent an initial MRI scan using the traditional breathing command with untrained technicians and a subsequent MRI scan using the

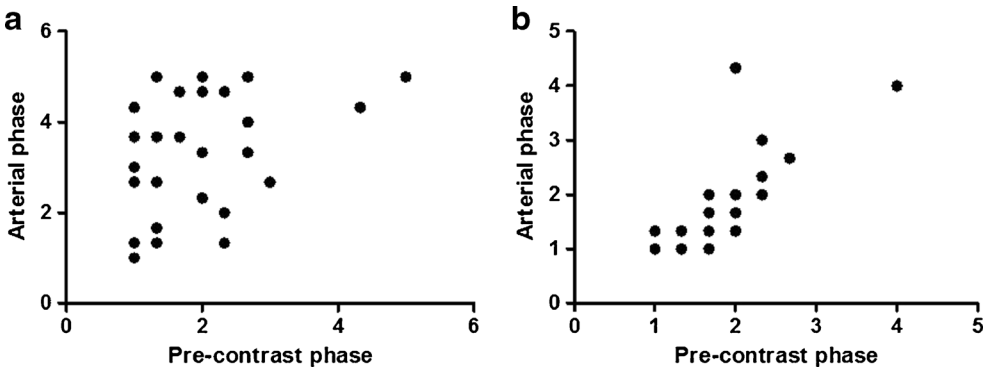

Fig. 3 Scatter plots representing the arterial phase and the pre-contrast phase quality scores for patients following the traditional breathing command (A, n=30) and for patients following the modified command (B, n=30). There is a moderate correlation between the average image quality scores of the precontrast and arterial phase images (Spearman's rho= 0.406, p=0.026), and a very strong association when the modified breathing command is used (Spearman's rho=0.874, p<0.001).

modified breathing command with trained technicians, we observed a significant improvement in the arterial phase image quality in the second scan (i.e., using the modified breathing command, $P=0.008$, Fig. 2B, Table 3).

In this study, we investigated the potential of introducing a modified breathing command at image acquisition to overcome respiratory motion artefact-associated arterial phase image degradation at gadoxetate-enhanced liver MRI. We trained our technicians to instruct patients with a more patient-adapted breathing command, instead of our traditional single breathe in – breathe out instruction, which was more difficult to adhere to and may be missed because of the background noise, patient nervousness or other interfering factors (Fig. 1). Using our modified breathing command, the breathing instructions are repeated four times to allow the patient to get accustomed to both the nature and pace of the breath-hold. The modified breathing scheme guides the patient more closely to breathe in and out four times consecutively before intravenous contrast media is injected, without resulting in hyperventilation, and continues to guide the patient to breathe in and out until the final breathe in - breathe out command is given when the bolus reaches the mid-aorta.

Davenport et al. showed that gadoxetate-enhanced liver MRI is related to significantly more cases of arterial phase image degradation than gadobenate-enhanced liver MRI [9]. The authors postulated that acute transient dyspnoea is the explanation for the increased frequency of respiratory motion related artefacts, particularly in the arterial phase of contrast enhancement. This hypothesis was challenged by a recent study, which demonstrated that patients experiencing TSM had a similar heart rate and peripheral capillary oxygen saturation as patients without TSM [16]. In our study cohort, who underwent MRI using the traditional breathing command, we found similar incidences of respiratory motion artefacts (Fig. 2A) and TSM (13.3 %) as in the reported literature [9, 12, 13]. By applying our modified breathing command, however, it was possible to minimize these artefacts, which significantly improved the arterial phase image quality grading scores ($P<0.001$) and reduced the incidence of severe and extensive respiratory motion degraded arterial phase T_1-weighted images ($P=0.021$).

A modification of the traditional breathing command with longer and repetitive breathing might be essential for liver MRI as a breath-hold duration of typically 18 to 20 seconds in expiration is required for whole liver coverage using a T_1-weighted three-dimensional volume interpolated imaging technique. The observation reported by Davenport et al.[4] that certain patients had difficulties in holding their breath even during the precontrast phase of liver MRI, supports the hypothesis that poor patient compliance in following the breathing commands is probably a source of respiratory motion artefacts during liver MRI. Hence, we decided to optimize the way we issue respiratory commands during liver MRI as a means to further understand and improve the quality of images at dynamic gadoxetate-enhanced liver MRI.

Unfortunately, recent publications lacked detailed descriptions of the breathing commands employed in these studies [9–13]. According to the Materials and Methods sections, image acquisition was carried out at end inspiration without hyperventilation [9–13]. The respiratory motion artefacts in the gadoxetate-enhanced arterial phase may in part be explained, at least following our own observations, by the rather loud bolus track sequence. The background noise compromises the patients' acoustic capabilities to understand the breathing instructions by the technician, especially if these are short as in our traditional breathing command. As an optimal volume of the audio system is a prerequisite for any breathing command to be adequately followed, particularly when close patient guidance is needed to enable a sufficiently long breath hold, we optimized this parameter as well.

We found a moderate correlation between the image grading scores of the precontrast and the arterial phase images when using the traditional breathing command and a very strong association when using the modified breathing command (Fig. 3A, B). Patients with difficulties maintaining a breath-hold in the precontrast phase therefore seem to have similar difficulties during the contrast-enhanced phases, which also points to the challenging nature of the breath-hold suspension for certain patients and the influence of patient behaviour and technician support on the image quality of gadoxetate-enhanced MRI. In our study, subgroup analysis of the eight patients who underwent two gadoxetate-enhanced MRI scans, first using traditional breathing command and then using the modified breathing command, highlights how technician training and an optimized breath-hold command can help to improve image quality ($P=0.008$, Fig. 2B, Table 3). Our finding contrasts with the notion brought forward by Bashir et al. that in cases with significant degradation of the arterial phase images at initial MRI, the probability of having poor arterial phase image quality increases in subsequent gadoxetate-enhanced MRI studies [13].

Multiple risk factors were described to be associated with an increased likelihood of respiratory motion artefacts on dynamic-phase gadoxetate-enhanced liver MRI [11, 13]. A volume of 20 mL gadoxetate (off-label use) increased the risk of TSM two fold compared to a standard 10 mL dose [11]. In our study, we adhered to the official recommendations using a weight-adjusted gadoxetate dosing scheme (0.1 mL/kg BW [0.025 mmol Gd/kg]; mean dose-volume 7.51 mL and 7.66 mL for the traditional and modified breathing command, respectively). There was a similar incidence of TSM in the first cohort as reported in the literature [9, 12, 13]. The influence of pulmonary diseases such as COPD could not be investigated due to the low number of affected patients ($n=1$).

There are limitations to our study that have to be discussed. First, the study group was relatively small. However, the trial design was informed by our statistical consideration and power analysis. Second, we introduced the modified breathing command scheme to improve our clinical practice in the context of our quality management system. This clinically driven modification and an increased awareness amongst the technicians may incur a bias, but the technicians performing the scans had no knowledge of this study. In future studies, a prospective and double-blinded comparison with a well-defined control group including the various influencing factors could be performed to validate our findings. Thirdly, the increase of the volume of the audio system might incur a bias as this parameter differed between groups. Fourth, highly accelerated and free breathing image acquisition techniques, which reduce the breath-hold time in general and potentially decrease the incidence of respiratory breathing artefacts, were not investigated in this study as we retrospectively analysed data from routine clinical practice [12, 18–20].

In conclusion, we propose the use of a modified extended breathing command, which significantly improved the arterial phase T_1-weighted MR image quality scores and reduced severe and extensive respiratory motion artefacts at gadoxetate-enhanced liver MRI. Our findings support the role and importance of well-trained technicians in applying more patient-oriented breathing commands to guide their patients more closely during liver MRI. We believe that respiratory motion artefacts may be largely overcome by training technicians to apply an optimized patient-oriented breathing command.

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