

Respiratory-triggered SSFSE versus PROPELLER for contiguous thin-slice upper abdominal MRI: image quality and acquisition efficiency

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Research Article

Keywords: Magnetic resonance imaging, T2-weighted imaging, Single-shot fast spin-echo, Deep learning reconstruction, Respiratory triggering, Image quality

Posted Date: October 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11188439/v1>

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Additional Declarations: No competing interests reported.

Abstract

Purpose

To compare image quality and acquisition efficiency of respiratory-triggered single-shot fast spin-echo (RT-SSFSE) and periodically rotated overlapping parallel lines with enhanced reconstruction (RT-PROPELLER) for contiguous thin-slice upper abdominal T2-weighted MRI with deep learning reconstruction (DLR).

Methods

Forty-one participants underwent both sequences during the same 3.0-T examination. Each protocol acquired 50 contiguous 4-mm slices with high-strength DLR. Two radiologists independently scored five image-quality domains. Duct-to-parenchyma relative contrast (RC), left renal edge sharpness (ES), and actual acquisition time were measured. Paired tests were used; ten subjective comparisons underwent Holm correction.

Results

RT-SSFSE was faster than RT-PROPELLER (133.27 ± 22.57 vs 231.17 ± 27.51 s), with a mean paired reduction of 97.90 s (95% confidence interval [CI], 87.77–108.03; $P < 0.001$). Both readers scored overall quality, motion-artifact control, fat-suppression uniformity, and pancreaticobiliary duct depiction higher with RT-SSFSE, but intrahepatic detail lower (all adjusted $P < 0.05$). Pancreatic duct-to-pancreas RC, common hepatic duct-to-liver RC, and renal ES were higher with RT-SSFSE (all $P < 0.001$). Overall-quality acceptability was 100.0% versus 95.1% for both readers ($P = 0.500$).

Conclusion

Under these acquisition conditions, RT-SSFSE provided faster contiguous upper abdominal coverage and better pancreaticobiliary depiction, while RT-PROPELLER better preserved intrahepatic detail.

Introduction

Magnetic resonance cholangiopancreatography depicts fluid-filled pancreaticobiliary ducts, whereas axial fat-suppressed T2-weighted imaging (FS-T2WI) also shows adjacent parenchyma and surrounding tissues [1, 2]. Thin, contiguous slices aid assessment of small, tortuous ducts, but require more acquisitions to maintain upper abdominal coverage. Respiratory and gastrointestinal motion further complicate the balance between scan time and image quality [3].

RT-PROPELLER repeatedly samples the center of k-space with rotating blades and can correct motion between blades [4]. Prior upper abdominal studies found it useful for motion control [5–7]. Single-shot fast spin-echo (SSFSE) acquires most of the k-space data for a slice in one echo train, although earlier abdominal comparisons generally used breath-hold rather than respiratory-triggered acquisitions [8]. DLR can improve rapidly acquired T2-weighted images [9–12], while recent abdominal studies have reported structure-dependent effects of accelerated respiratory-triggered imaging [13, 14]. The performance of the two complete protocols has not been established for matched contiguous thin-slice coverage.

We compared RT-SSFSE with RT-PROPELLER using 50 contiguous 4-mm slices, the same field of view and nominal in-plane resolution, and high-strength DLR. We assessed subjective image quality first, followed by objective image-quality measures and acquisition time.

Materials and methods

Participants

This prospective, single-center, intraindividual study consecutively screened adults referred for clinically indicated upper abdominal MRI between March and September 2026. Eligibility required age ≥ 18 years, an upper abdominal imaging indication, and completion of both respiratory-triggered research sequences during one examination. Exclusion criteria were an MRI contraindication or incomplete examination; severe irregular breathing or motion that precluded evaluation; postoperative change, a large mass, or marked ascites preventing reliable measurements; and incomplete clinical or imaging data. The institutional review board approved the study (2025-SRFA-1173), and all participants gave written informed consent.

MRI acquisition

Imaging used a 3.0-T system (SIGNA Hero XT; GE HealthCare) with a 16-channel anterior body coil and 32-channel posterior spine coil. Participants fasted for 4 h and were positioned supine with arms raised. Quiet breathing was rehearsed and a respiratory belt placed at the site of greatest excursion. Sequence order was randomized. Both protocols used 50 contiguous 4-mm axial slices (200-mm coverage), a 36×36 -cm field of view, nominal 1.1×1.1 -mm in-plane pixels, and high-strength AIR Recon DL. RT-SSFSE acquired one to three sequential slices during each effective trigger window according to breathing rate. Protocol parameters are summarized in Table 1. Because the pulse sequences differ, parallel acceleration, signal averages, and fat-suppression methods could not be made identical; the comparison therefore evaluates the complete protocols rather than an isolated acquisition component.

Table 1
Acquisition parameters for the two respiratory-triggered FS-T2WI protocols

Parameter	RT-SSFSE	RT-PROPELLER
Slice thickness / gap (mm)	4 / 0	4 / 0
Field of view (cm × cm)	36 × 36	36 × 36
In-plane pixel size (mm × mm)	1.1 × 1.1	1.1 × 1.1
Number of slices	50	50
TE (ms)	92.90 ± 0.73	89.60 ± 1.29
TR (ms)	1500.0 (1407.0, 1826.0)	4000.0 (3529.4, 4615.3)
Parallel acceleration factor	2	3
Receiver bandwidth (kHz)	83.33	83.33
Number of excitations	1	1.5
Fat-suppression method	SPECIAL	Fat
Slices per effective trigger window	1–3	—
DLR method / strength	AIR Recon DL / high	AIR Recon DL / high

TE, echo time; TR, repetition time; DLR, deep learning reconstruction. TE is mean ± standard deviation; TR is median (25th, 75th percentiles). SPECIAL and Fat are the scanner's respective frequency-selective fat-suppression settings.

Sample size

In ten pilot examinations excluded from the final analysis, the paired difference in overall image-quality score averaged 0.30 points (standard deviation, 0.587), giving a standardized paired effect size of 0.51. With a two-sided α of 0.05 and 80% power, G*Power 3.1.9.7 indicated a minimum of 34 participants for a paired mean-difference test. Allowing approximately 10% for acquisition failure or missing measurements, the target enrollment was at least 38 participants.

Subjective image-quality assessment

Deidentified images were randomly numbered and reviewed on the same workstation with sequence names, parameters, and acquisition times concealed. Two radiologists with 10 and 3 years of abdominal MRI experience independently reviewed the images in randomized order; the two examinations from one participant were not displayed consecutively or side by side. Window settings and magnification could be adjusted. Overall image quality was the primary subjective outcome. Secondary scores covered

respiratory or gastrointestinal motion-artifact control, fat-suppression uniformity, pancreaticobiliary duct depiction, and intrahepatic anatomical detail. Each used a five-point scale, with higher scores indicating better quality (Table 2). Scores ≥ 3 for overall quality, artifact control, and fat suppression were considered acceptable. Readers did not reconcile or average their scores.

Table 2
Five-point criteria for subjective image-quality assessment

Domain	1	2	3	4	5
Overall quality	Nondiagnostic	Poor; markedly limited confidence	Diagnostic quality	Good; high confidence	Excellent; clear structures
Motion-artifact control	Severe displacement or ghosting; nondiagnostic	Key structures partly obscured	Moderate blurring; main structures assessable	Minor artifact without material effect	No or negligible artifact
Fat-suppression uniformity	Widespread failure (> 50%)	Multiple nonuniform regions impair assessment	Mild or moderate nonuniformity; assessable	Largely uniform; minor focal residual signal	Uniform and adequate
Pancreaticobiliary duct depiction	Most visible duct unrecognizable	Only segments recognizable	Main ducts recognizable; focal blur	Main ducts clear and largely continuous	Ducts clear, continuous, sharply defined
Intrahepatic detail	Main structures indistinct	Main structures visible; fine branches mostly lost	Main boundaries visible; some fine detail	Most fine branches visible with clear interfaces	Fine branches and interfaces sharply depicted

Higher scores indicate better image quality. Scores ≥ 3 for overall quality, motion-artifact control, and fat-suppression uniformity were deemed acceptable.

Objective image-quality assessment

A technologist with 11 years of experience measured main pancreatic duct-to-pancreas and common hepatic duct-to-liver RC, and ES at the lateral border of the left kidney. Single-image background-noise estimates of signal-to-noise or contrast-to-noise ratio were avoided because multichannel coils, parallel imaging, and reconstruction produce spatially varying noise [15, 16]. The pancreatic duct was preferentially measured in the body and the common hepatic duct near the hilum on anatomically matched slices. Ductal regions of interest (ROIs) were centered within the lumen, avoided the edge, and

included at least five pixels. Adjacent parenchymal ROIs covered approximately 30–50 mm² while avoiding vessels, lesions, and conspicuous artifacts. ROI positions and areas were matched between protocols as closely as possible. RC was calculated for each measurement as $(SI_{duct} - SI_{parenchyma}) / (SI_{duct} + SI_{parenchyma})$, where SI is mean signal intensity; three measurements per participant were averaged.

ES was measured with ImageJ 1.54g [17]. At matched slices near the maximum transverse renal diameter or hilum, a line perpendicular to a relatively straight lateral renal margin crossed renal tissue and perirenal fat, avoiding vessels, lesions, fluid, and marked artifact. Distance was calibrated using the DICOM pixel spacing. From the line-intensity profile, $I_{20} = I_{min} + 0.2(I_{max} - I_{min})$ and $I_{80} = I_{min} + 0.8(I_{max} - I_{min})$; $ES = 1/|x_{80} - x_{20}|$, in mm⁻¹. Three measurements were averaged. A higher RC indicates greater relative duct-to-parenchyma signal difference; a higher ES indicates a steeper local edge transition.

Acquisition efficiency and statistical analysis

Actual acquisition time was measured from sequence start to completion of data acquisition, including waiting for respiratory triggers. Relative time reduction was $(RT_{\text{PROPELLER}} - RT_{\text{SSFSE}}) / RT_{\text{PROPELLER}} \times 100\%$. SPSS 25.0 and Python 3.12 with SciPy were used. Continuous outcomes are reported as mean $\pm$ standard deviation or median (25th, 75th percentiles). Normality of paired differences was assessed with the Shapiro–Wilk test; paired t tests or Wilcoxon signed-rank tests were used accordingly. Mean paired differences received t-based 95% CIs; median paired differences and weighted κ received participant-level percentile bootstrap CIs from 10,000 resamples. Ordinal scores were compared with two-sided asymptotic Wilcoxon tests, excluding zero differences and correcting ties; $r = |Z|/\sqrt{41}$. Ten reader-specific subjective comparisons underwent Holm adjustment [18]. Paired acceptability proportions were compared by exact McNemar tests. Quadratic-weighted Cohen κ assessed interreader agreement for each protocol [19]. All tests were two-sided, with $P < 0.05$ considered significant; other endpoints were not multiplicity-adjusted.

Results

Participants and acquisition time

Of 51 screened participants, ten were excluded: five for severely irregular breathing, three for postoperative change, one for marked ascites, and one for incomplete imaging data. The final cohort comprised 41 participants (21 men, 20 women; age range, 19–84 years; mean age, 58.37 ± 13.73 years). All had complete subjective scores, acquisition times, and triplicate objective measurements. RT-SSFSE was faster in every participant (133.27 ± 22.57 vs 231.17 ± 27.51 s; $t = -19.531$; $P < 0.001$). The mean paired reduction was 97.90 s (95% CI, 87.77–108.03), and the median relative reduction was 43.42% (25th–75th percentiles, 35.47%–51.25%; Fig. 1).

Subjective image quality

Both readers scored RT-SSFSE higher for overall quality, motion-artifact control, fat-suppression uniformity, and pancreaticobiliary duct depiction, but lower for intrahepatic detail (Table 3; Fig. 2). The effect sizes for overall quality were $r = 0.446$ and 0.485 for readers 1 and 2, respectively. All ten score comparisons remained significant after Holm adjustment (adjusted $P < 0.05$).

Table 3
Reader-specific subjective image-quality scores for RT-SSFSE and RT-PROPELLER

Domain	Reader	RT-SSFSE	RT-PROPELLER	Z	P	Adjusted P	r
Overall quality	1	5 (4, 5)	4 (4, 5)	-2.856	0.004	0.013	0.446
Overall quality	2	5 (4, 5)	4 (4, 4)	-3.105	0.002	0.010	0.485
Motion-artifact control	1	5 (4, 5)	4 (4, 5)	-3.022	0.003	0.010	0.472
Motion-artifact control	2	5 (4, 5)	4 (4, 5)	-2.289	0.022	0.041	0.357
Fat-suppression uniformity	1	5 (4, 5)	4 (4, 4)	-4.596	< 0.001	< 0.001	0.718
Fat-suppression uniformity	2	5 (4, 5)	4 (4, 5)	-3.692	< 0.001	0.002	0.577
Pancreaticobiliary ducts	1	5 (4, 5)	4 (3, 4)	-4.437	< 0.001	< 0.001	0.693
Pancreaticobiliary ducts	2	5 (4, 5)	4 (3, 4)	-3.835	< 0.001	0.001	0.599
Intrahepatic detail	1	4 (4, 4)	5 (4, 5)	-3.206	0.001	0.008	0.501
Intrahepatic detail	2	4 (4, 4)	5 (4, 5)	-2.313	0.021	0.041	0.361

$n = 41$ paired examinations. Scores are median (25th, 75th percentiles). Readers 1 and 2 had 10 and 3 years of abdominal MRI experience. P values derive from Wilcoxon signed-rank tests; adjusted P values use Holm correction across ten comparisons. The sign of Z does not indicate which protocol scored higher.

Objective image quality

RT-SSFSE yielded higher pancreatic duct-to-pancreas RC, common hepatic duct-to-liver RC, and left renal lateral ES (all $P < 0.001$; Table 4; Fig. 3). The paired mean differences were 0.113 (95% CI, $0.088-0.137$) for pancreatic RC and 0.121 mm^{-1} (95% CI, $0.093-0.150$) for ES. The median paired difference in common hepatic duct RC was 0.046 (bootstrap 95% CI, $0.031-0.054$).

Table 4
Objective image-quality measures for the two protocols

Measure	RT-SSFSE	RT-PROPELLER	Paired difference (95% CI)	Statistic	P
Pancreatic duct-to-pancreas RC	0.435 ± 0.112	0.322 ± 0.099	0.113 (0.088–0.137)	t = 9.277	< 0.001
Common hepatic duct-to-liver RC	0.808 (0.762–0.846)	0.752 (0.690–0.802)	0.046 (0.031–0.054)	W = 22	< 0.001
Left renal lateral ES (mm ⁻¹)	0.772 ± 0.269	0.650 ± 0.233	0.121 (0.093–0.150)	t = 8.668	< 0.001

n = 41; triplicate measurements were averaged per participant. Values are mean ± standard deviation or median (25th, 75th percentiles). Difference is RT-SSFSE minus RT-PROPELLER. Mean-difference CIs are t based; the median-difference CI is bootstrap based. W is the smaller signed-rank sum. RC, relative contrast; ES, edge sharpness.

Acceptability and interreader agreement

For both readers, overall quality was acceptable in 41/41 RT-SSFSE and 39/41 RT-PROPELLER examinations (100.0% vs 95.1%; exact McNemar P = 0.500). Motion-artifact scores were acceptable in 41/41 versus 39/41 examinations for reader 1 (P = 0.500) and 41/41 versus 38/41 for reader 2 (P = 0.250). Fat-suppression scores were acceptable in all examinations for reader 1; reader 2 recorded 41/41 versus 40/41 (P = 1.000). Interreader weighted κ ranged from 0.650 to 0.811 for RT-SSFSE and 0.622 to 0.888 for RT-PROPELLER (Table 5).

Table 5
Quadratic-weighted interreader agreement by image-quality domain

Domain	RT-SSFSE κ (95% CI)	RT-PROPELLER κ (95% CI)
Overall quality	0.738 (0.517–0.895)	0.771 (0.536–0.892)
Motion-artifact control	0.650 (0.477–0.784)	0.858 (0.711–0.933)
Fat-suppression uniformity	0.767 (0.590–0.926)	0.622 (0.393–0.774)
Pancreaticobiliary ducts	0.746 (0.482–0.874)	0.851 (0.712–0.933)
Intrahepatic detail	0.811 (0.648–0.923)	0.888 (0.704–0.973)

CIs are participant-level percentile bootstrap intervals.

Discussion

With matched contiguous thin-slice coverage and the same DLR strength, RT-SSFSE shortened acquisition by a mean of 97.90 s and improved subjective overall quality, motion control, and pancreaticobiliary duct depiction. Duct-to-parenchyma RC and local renal ES also favored RT-SSFSE. Intrahepatic fine detail favored RT-PROPELLER, showing that the two protocols are not interchangeable for every anatomical target.

Shimada et al. found better pancreatic edge and duct depiction with thin-slice SSFSE and DLR than with thicker alternatives [11]. The present protocol extends this question to 50 contiguous slices under respiratory triggering. Acquiring up to three slices per effective trigger window may have reduced waiting time, although its independent contribution cannot be separated from the fast single-shot readout. RT-PROPELLER's rotating-blade sampling can correct motion [4–7], but long acquisitions and changing respiratory or gastrointestinal motion may still produce inconsistency between blades. Respiratory variability has been associated with image quality in gated abdominal T2WI [14], and it was not quantified here.

The higher ductal RC agrees with the readers' assessment of pancreaticobiliary depiction. However, fat suppression differed between protocols (SPECIAL versus Fat), potentially affecting both tissue contrast and edge transitions. The renal ES measures one tissue interface, not whole-image spatial resolution or liver detail. A long SSFSE echo train can broaden the point-spread function through T2 decay [20], which may help explain the lower intrahepatic-detail scores. The clearer intrahepatic branches on RT-PROPELLER in a representative case are shown in Fig. 4. Both protocols had high overall acceptability; the nonsignificant McNemar result, based on only two discordant pairs, does not establish equivalence.

This study is limited by its single-center, single-vendor setting, small sample, and exclusion of participants with severe respiratory irregularity or structures unsuitable for objective measurement. Disease-specific performance and respiratory waveform features were not assessed. The protocols differed in acceleration and fat suppression, so the independent effects of acquisition, triggering, and reconstruction cannot be inferred. One observer made the objective measurements, and their reproducibility was not assessed. Local ES cannot represent other organs or lesions, and no reference standard was used to determine diagnostic accuracy. Multicenter evaluation across scanner platforms and clinical indications is needed.

For contiguous thin-slice upper abdominal FS-T2WI, RT-SSFSE may be useful when acquisition speed and pancreaticobiliary depiction are priorities; RT-PROPELLER retains value when intrahepatic fine detail is important.

Declarations

Author Contribution

Da Cao: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft. Zhiyong Hu: Investigation, Data curation, Validation, Writing – review &

editing.Chuanbing Wang: Investigation, Image evaluation, Validation, Writing – review & editing.Binbin Wang: Investigation, Data curation, Validation, Writing – review & editing.Chunjuan Song: Conceptualization, Methodology, Supervision, Project administration, Writing – review & editing.Hongyuan Ding: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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Figures

Acquisition time

n = 41 pairs | Paired t test
P < 0.001

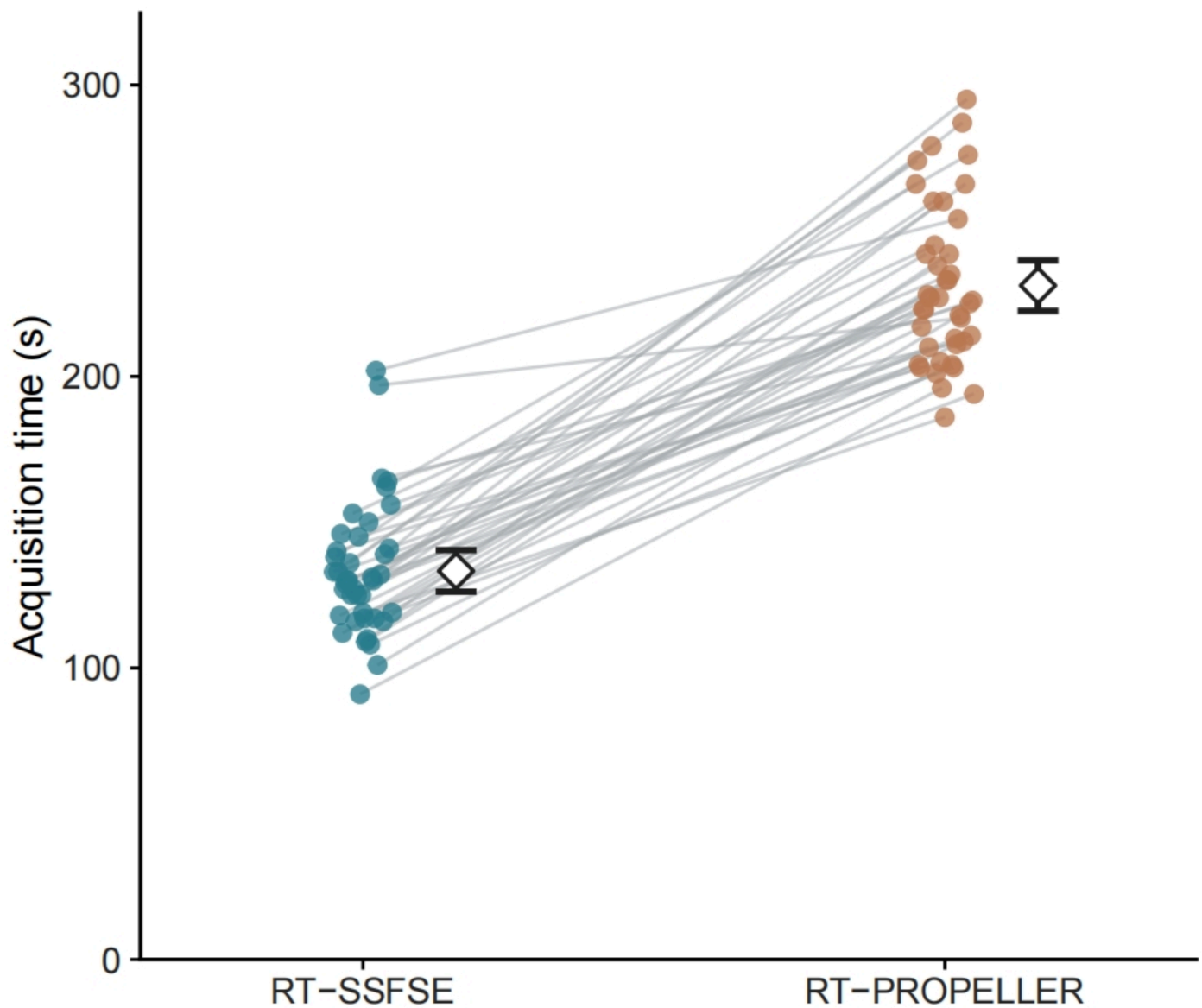
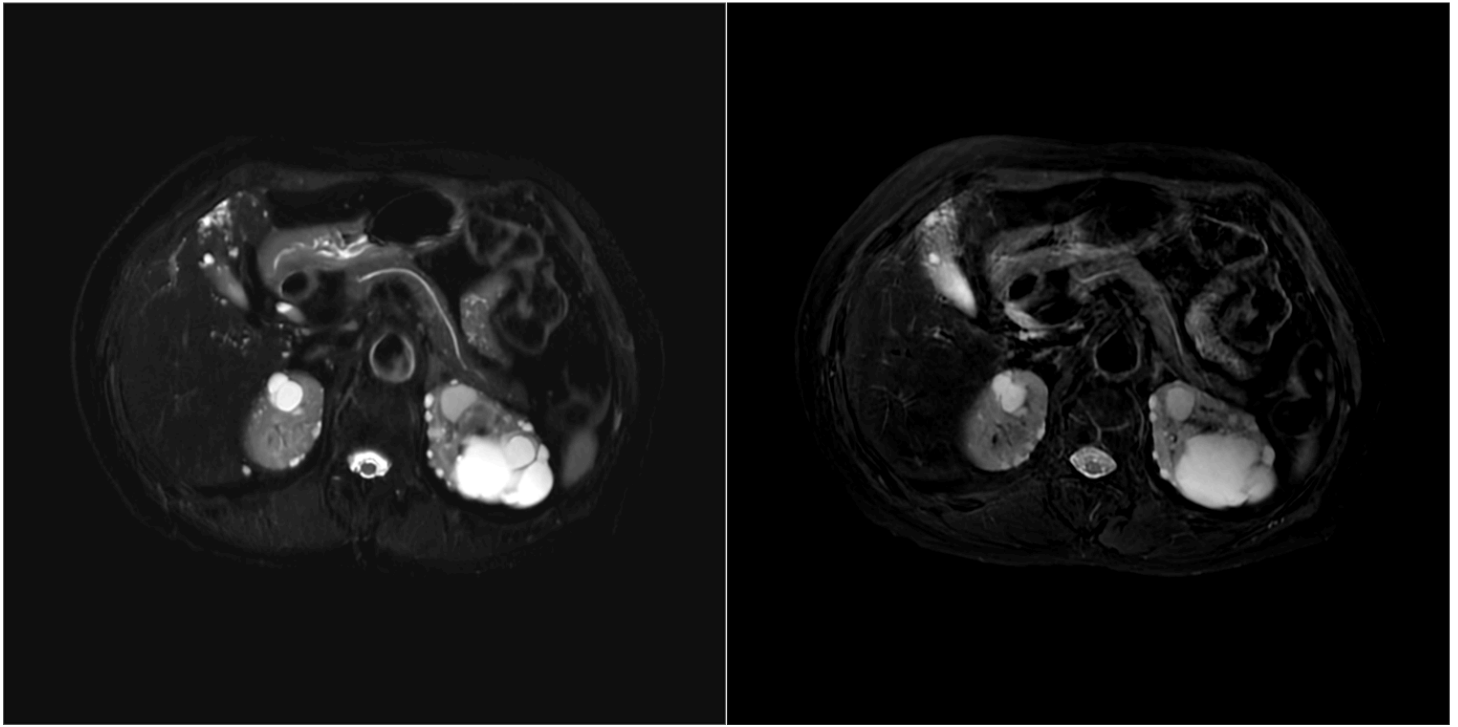


Figure 1

Paired actual acquisition times for 41 examinations. Lines connect the two protocols acquired in each participant; markers at the side summarize the group estimates



a RT-SSFSE

b RT-PROPELLER

Figure 2

Representative matched upper abdominal images from a 68-year-old woman. The pancreatic duct is more conspicuous on RT-SSFSE (a) than on RT-PROPELLER (b)

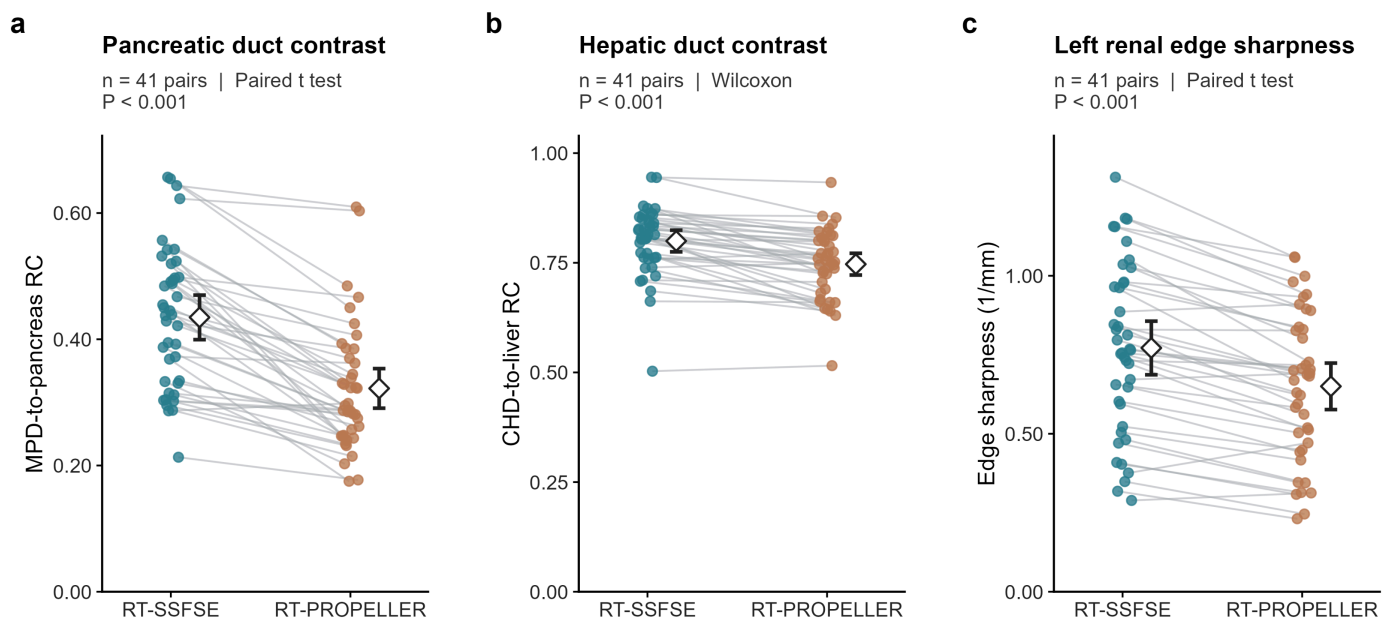
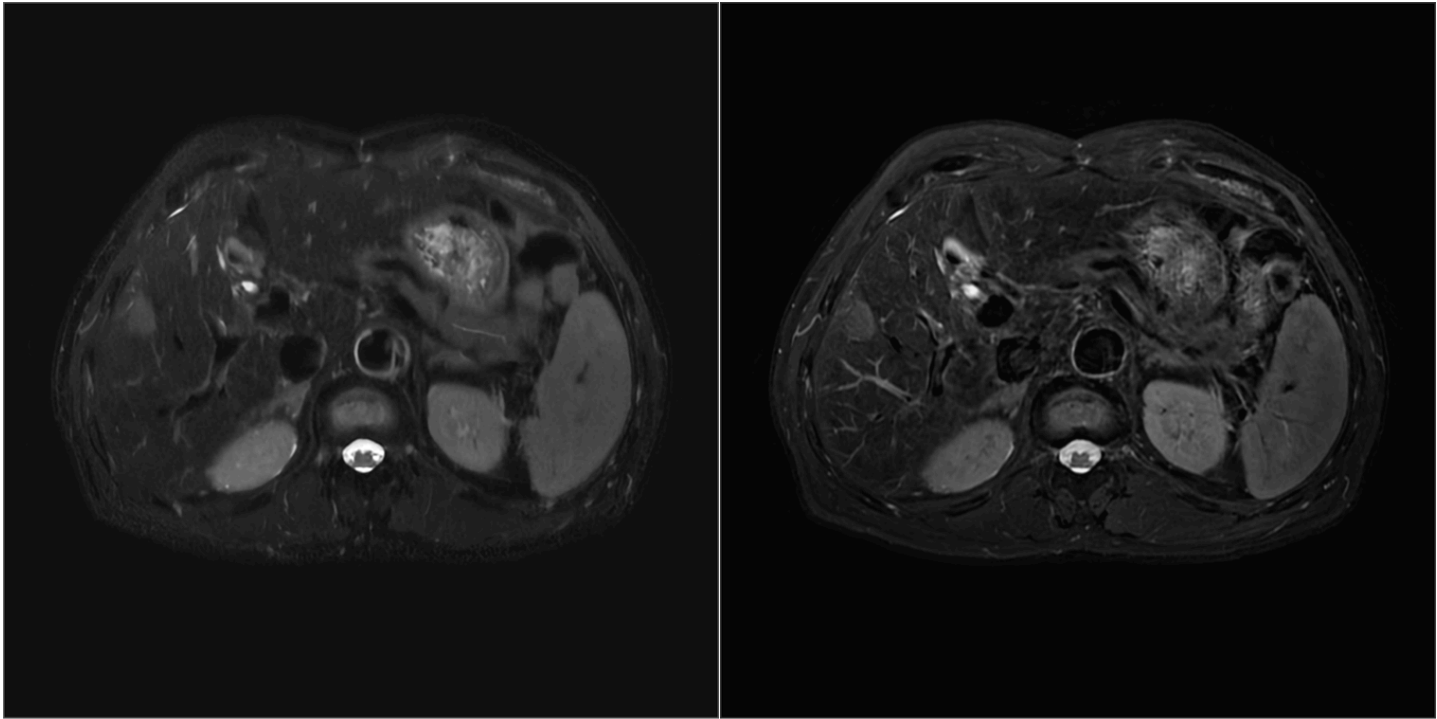


Figure 3

Paired comparison of pancreatic duct-to-pancreas RC, common hepatic duct-to-liver RC, and left renal lateral ES in 41 participants



a RT-SSFSE

b RT-PROPELLER

Figure 4

Representative matched images from a 72-year-old man. The pancreatic duct appears more conspicuous on RT-SSFSE (a), whereas intrahepatic vessel branches and the margin of a focal hepatic lesion appear clearer on RT-PROPELLER (b).