European Journal of Radiology Open 12 (2024) 100564

Contents lists available at ScienceDirect

European Journal of Radiology Open

journal homepage: www.elsevier.com/locate/ejro

Modified respiratory-triggered SPACE sequences for magnetic resonance cholangiopancreatography

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ARTICLE INFO

Keywords:
Breath-hold
Respiratory-triggered
Magnetic resonance cholangiopancreatography
Magnetic resonance imaging

ABSTRACT

Background: Respiratory-triggered (RT) and breath-hold are the most common acquisition modalities for magnetic resonance cholangiopancreatography (MRCP). The present study compared the three different acquisition modalities for optimizing the use of MRCP in patients with diseases of the pancreatic and biliary systems.

Materials and methods: Three MRCP acquisition modalities were used in this study: conventional respiratory-triggered sampling perfection with application-optimized contrasts using different flip evolutions (RT-SPACE), modified RT-SPACE, and breath-hold (BH)-SPACE. Fifty-eight patients with clinically suspected pancreatic and biliary system disease were included. All image data were acquired on a 1.5 T MR. Scan time and image quality were compared between the three acquisition modalities. Friedman test, which was followed by post-hoc analysis, was performed among triple-scan protocol.

Results: There was a significant difference in the mean acquisition time among conventional RT-SPACE, modified RT-SPACE, and BH-SPACE (167.41±32.11 seconds vs 50.84±73.78 seconds vs 18.00 seconds, $P<0.001$). Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were also significantly different among the three groups ($P<0.001$). The SNR and CNR were higher in the RT-SPACE group than in the BH-SPACE group ($P<0.05$). However, there were no statistically significant differences ($P>0.05$) among the 3 groups regarding quality of overall image, image clarity, background inhibition, and visualization of the pancreatic and biliary system.

Conclusions: MRCP acquisition with the modified RT-SPACE sequence greatly shortens the acquisition time with comparable quality images. The MRCP acquisition modality could be designed based on the patient's situation to improve the examination pass rate and obtain excellent images for diagnosis.

1. Background

Magnetic resonance cholangiopancreatography (MRCP) is a baseline technology that has the capability to offer anatomical and pathological details of the pancreatic bile ducts [1,2]. This technique has many advantages, including reducing the need for invasion, ionizing radiation, and contrast administration in the pancreatic and biliary ducts [3]. Its general feasibility is also aided by the fact that it does not require anesthesia. MRCP can provide high sensitivity (92.31%) and specificity (95.74%) for diagnosis of choledocholithiasis [4,5]. Most initial studies of the technique have focused on breath-hold MRCP acquisition sequences, which decrease the space resolution and result in un-isotropic voxel data [6,7]. As a result, navigator-triggered sequences of MRCP have become the principal method for obtaining high-resolution isotropic images over the past decade [8]. Several studies have shown that combined sampling perfection with application-optimized contrasts using different flip angle evolutions (SPACE) sequences with generalized autocalibrating partially parallel acquisition (GRAPPA) can be used for

Abbreviations: MRCP, magnetic resonance cholangiopancreatography; RT, respiratory-triggered; BH, breath-hold; SPACE, sampling perfection with application-optimized contrasts using different flip evolutions; IOA, interobserver agreement; SNR, signal-to-noise ratio; CNR, contrast-to-noise ratio; MIP, maximum intensity projection; LHD, left hepatic bile duct; RHD, right hepatic bile duct; CHD, common hepatic bile duct; PCBD, proximal common bile duct; DCBD, distal common bile duct; MPD, main pancreatic duct; CD, cystic duct; SI, signal intensity; ROI, region of interest; SD, standard deviation; GRAPPA, generalized auto-calibrating partially parallel acquisition; SENSE, sensitivity encoding.

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https://doi.org/10.1016/j.ejro.2024.100564
Received 19 January 2024; Received in revised form 1 April 2024; Accepted 15 April 2024

improving the image qualities and contrast-to-noise ratio (CNR) [9,10]. However, acquisition times for respiratory-triggered (RT)- MRCP sequences have remained problematic, always exceeding 6 minutes, even though parallel acquisition techniques were used [9]. Sun B et al. demonstrated that the proposed rapid RT MRCP protocol provided significantly higher overall image quality and shorter imaging time than conventional RT MRCP [11]. As magnetic resonance imaging techniques improved, it became feasible to perform 3D MRCP in a single breath-hold (BH). By improving the gradient system and reconstruction algorithm, the acquisition time of MRCP scans can be shortened without sacrificing image quality and spatial resolution. Chen Z et al. found that BH MRCP using the SPACE sequence, which was modified from the RT-3D-SPACE-MRCP sequence, had an acquisition time of approximately 18 seconds and resulted in significantly better image quality of the pancreaticobiliary tree in a single BH [12]. The proposed modified RT-SPACE sequence, which was modified from the BH-SPACE sequence, was feasible to shorten the MRCP acquisition time without sacrificing image quality or spatial resolution, the present study aimed to analyze and contrast both acquisition times and quality of MRCP images from conventional RT-SPACE-MRCP, modified RT-SPACE-MRCP, and BH-SPACE-MRCP in each patient suffering from bile duct and pancreatic diseases.

2. Methods

2.1. Participants

This was a prospective study that enrolled 58 patients (32 males and 26 females) from October 2019 to November 2020 in our hospital. Their mean age was 48.3 ± 19.5 years (age range: 18–83 years). All patients met the following criteria: inclusion criteria (1) clinical data of suspected pancreaticobiliary diseases requiring MRCP examination; (2) no contraindications on MRI examination; (3) breath-holding can be completed with regular respiratory rhythm after training before MRI examination. Exclusion criteria (1) previous surgical history of pancreaticobiliary disease; (2) the presence of a large amount of peritoneal fluid, intestinal gas interference, abdominal metal implant artifacts, etc., which affects the observation and analysis of MRCP images; (3) other reasons for failure to complete the examination. Based on clinical manifestations, medical history, physical examination, or abdominal ultrasound, examination of MRCP was accomplished in suspected patients with bile duct and pancreatic diseases, such as cholelithiasis, anatomical variation of the biliary system, obstructive diseases of the biliary system, pancreatitis and postoperative reexamination of the gallbladder or biliary tract. The research was ethical committee-approved. All patients have given their informed consent.

3. Magnetic resonance imaging acquisition

Each patient received conventional RT-SPACE, modified RT-SPACE, and BH-SPACE at the same 1.5 T MR scanner (MAGNETOM Aera, Siemens Healthcare, Erlangen, Germany). The 6-channel coil for the body and the 24-channel coil for the spine were used for scanning. Have an empty stomach for at least 4 hours before the examination, no need to take contrast agents. The scanning range was from the upper border of the liver to the lower border of the pancreas, encompassing the entire biliary system. The settings of the three types of SPACE sequences can be seen in Table 1. The time of acquisition for the MRCP images was recorded. The other sequences included: T1W in-phase using FLASH sequence with breath-hold acquisition, TR 197 ms, TE1/2.2 ms, TE2/4.4 ms, FOV 306×380, matrix 232×288; T2W using HASTE (Half Fourier Express Spin Echo sequence) with breath-hold acquisition, TR 1400 ms, TE 93 ms, FOV 320×380, matrix 216×320; T2W fat suppression imaging using TSE fast spin echo sequence with SPAIR fat technology suppression, TR 3000 ms, TE 94 ms, FOV 380×380, matrix 320×320.

Table 1
Sequence parameters for conventional, modified RT-SPACE-MRCP and BH-SPACE-MRCP.

Parameter	Conventional RT-SPACE-MRCP	Modified RT-SPACE-MRCP	BH-SPACE-MRCP
TR (ms)	Variable	Variable	2000
TE (ms)	727	597	597
FOV (mm)	350×350	350×350	350×350
Flip angle (°)	140	140	140
Matrix	272×320	256×256	256×256
Slice thickness (mm)	1.2	1.2	1.2
No. of slices	64	64	64
Echo space (ms)	3.6	3.34	3.34
PAT mode	GRAPPA 2	GRAPPA 3	GRAPPA 3
Bandwidth (Hz/Px)	651	849	849
No. of signal averages	1.8	1.4	1.4
Slice partial Fourier	7/8	6/8	6/8
Base resolution	320	256	256
Phase resolution	85	100	100
Slice resolution	58	50	59
Reconstruction voxel size(mm^3)	0.5×0.5×1.2	0.7×0.7×1.2	0.7×0.7×1.2
Acquisition voxel size (mm^3)	1.29×1.09×2.06	1.37×1.37×2.02	1.37×1.37×2.02

Abbreviations: RT: respiratory triggered; SPACE: sampling perfection with application-optimized contrasts using different flip evolutions; BH: breath-hold; GRAPPA: generalized auto-calibrating partially parallel acquisition.

4. Image analysis

Two radiologists with 5 years of abdominal radiology experience performed a retrospective review of all MRCP images independently. The images were read independently using a double-blind approach (blind to patient data and scan technique). The images were shown as coronal maximum intensity projection (MIP) images with the use of three sequences. Thin-section data had been reviewed to evaluate the image quality of the different MRCP techniques. All images were mixed in order of randomization and assessed on PACS workshops, yet no information was provided on the parameters of imaging used.

5. Qualitative image analysis

The same two radiologists performed the quantitative analysis. A 4-point score was adopted to evaluate the quality of overall image (1= bad; 2= average; 3= well; 4= wonderful) [12], image clarity (1= no diagnosis; 2= severe blurring; 3= slight blurring; 4= no blurring) [13] and background inhibition (1= obvious background signal, affecting the diagnostic ability of the reader; 2= extensive background signal, significant reduction in image quality; 3= slight background signal, minor degradation of image quality; and 4= complete background inhibition, no degradation of image quality) [14]. The assessment was performed by dividing the intrahepatic bile ducts, extrahepatic bile ducts, cystic ducts, and pancreatic ducts into 7 sections: left hepatic bile duct (LHD), right hepatic bile duct (RHD), common hepatic bile duct (CHD), proximal common bile duct (PCBD), distal common bile duct (DCBD), main pancreatic duct (MPD) and cystic duct (CD). A 5-point score was used by them to assess image qualities of pre-defined sections of the pancreatic and biliary tree: 1, not shown; 2, not shown completely, not diagnosable; 3, not identified in all parts of sections but still diagnosable; 4, included all parts of sections, some of which could not be identified but still diagnosable; 5, identified entirely and dependably in all parts of the sections [15].

6. Quantitative image analysis

We selected the center of each patient's common bile duct (CBD) as a representative slice level. We measured signal intensity (SI) through the placement of a rounded region of interest (ROI) in CBD and surrounding tissue of the duct. Biliary SI had an ROI of a minimum of 5 square mm and was located in an area of uniform, with no artifacts in the middle third of the CBD. Periductal tissue SI had an ROI of a minimum of 20 square mm and was located in an area uniform, with no artifacts in the CBD (Fig. 1). The standard deviation (SD) for CBD of ROI same as SI was used to represent the image noises. Through 3D-MRCP, calculations of signal-to-noise ratio (SNR) for CBD and CNR with respect to CBD and peri-ductal tissue were performed using the following equations: $SNR = SI_{CBD} / SD_{CBD}$; $CNR = (SI_{CBD}\text{-}SI_{periductal\ tissue}) / SD_{CBD}$ [16].

7. Statistical analysis

IBM version 19.0 SPSS software was used for statistical analyses. Mean ± SD was used to express the measurement data. Using Kolmogorov Smirnov to test whether data followed normality of distribution. Friedman test was applied to the differences in the comparison of SNR, CNR, and acquisition time among conventional RT-SPACE, modified RT-SPACE, and BH-SPACE sequences. The quality of the overall image, image clarity, background inhibition, and visualization of the pancreatic and biliary system of three groups were compared, and the Friedman test was used. Interobserver agreement (IOA) between two radiologists was estimated via calculation of the kappa statistics of Cohen (poor: 0.00–0.20, fair: 0.21–0.40, moderate: 0.40–0.60, good: 0.61–0.80; excellent: 0.81–1.00) [17]. Statistical significance was indicated by $P < 0.05$. The Bonferroni method was used to correct the significance level of post hoc comparisons.

8. Results

We identified forty-two gallbladder stones, eight choledocholithiasis, one intrahepatic cholangiocarcinoma, three gallbladder carcinoma, two pancreatic cancer, and two pancreatitis, of which six cases were secondary to biliary obstruction. The differences in the mean acquisition time between conventional RT-SPACE, modified RT-SPACE, and BH-SPACE (167.41±32.11 seconds vs 50.84±73.78 seconds vs 18.00 seconds, $P < 0.001$, Table 2) were statistically significant. SNR and CNR also differed significantly among 3 groups ($P < 0.001$, Table 2). It was found that no significant difference was observed in SNR or CNR between conventional RT-SPACE and modified RT-SPACE images (adjusted $P = 0.233$), but statistical differences were found among conventional RT-SPACE and BH-SPACE, modified RT-SPACE and BH-SPACE images (adjusted $P < 0.001$). However, there was no statistical difference ($P > 0.05$, Table 3, Figs. 2–3) among the 3 groups regarding the quality of the overall image, image clarity, background inhibition, and visualization of the pancreatic and biliary system. The IOA between two radiologists was highly consistent in three groups (Table 3).

Table 2
Comparison of acquisition time, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) for the three MRCP imaging sequences.

	Conventional RT-SPACE-MRCP	Modified RT-SPACE-MRCP	BH-SPACE-MRCP	χ^2	P
acquisition time (s)	167.41±32.11	50.84 ±73.78	18.00	114.034	<0.001
CNR	15.49±10.14	13.60 ±7.00	11.11 ±5.63	50.803	<0.001
SNR	17.68±11.39	16.13 ±8.32	13.20 ±6.66	90.502	<0.001

Abbreviations: RT: respiratory triggered; SPACE: sampling perfection with application-optimized contrasts using different flip evolutions; BH: breath-hold.

9. Discussion

In this study, we performed 3 different MRCP scanning sequences in comparison of the acquisition time and image quality of conventional RT-SPACE, modified RT-SPACE, and BH-SPACE in patients with bile duct and pancreatic diseases.

It is well known that RT-3D-MRCP sequences are widely used in clinical practice; however, the long acquisition time of conventional RT-3D-MCRP results in greater variation of respiratory depth, which in turn results in image blurring and motion artifacts. Parallel imaging reconstruction is available to reduce the time of total scanning and to improve patient adherence. Generalized auto-calibrating partially parallel acquisition (GRAPPA) is a steady and extensively performed technique in clinical applications that shortens acquisition time, sharpens spatial resolution, and/or reduces acoustic noise to improve patient comfort [18–21]. Compared with conventional RT-SPACE, the modified RT-SPACE sequence, which used GRAPPA 3, led to a shorter data acquisition time than conventional RT-SPACE. For this reason, our study results may be of clinical value as modified RT-SPACE protocols will save scanning times and maintain comparable image qualities if patients cannot hold their breath.

In addition, patients with variable or superficial breathing rhythms, or breath-gated collections may not be triggered successfully, which can extend the scanning time and result in a large number of motion artifacts within images [22]. In our study, we have demonstrated that modified

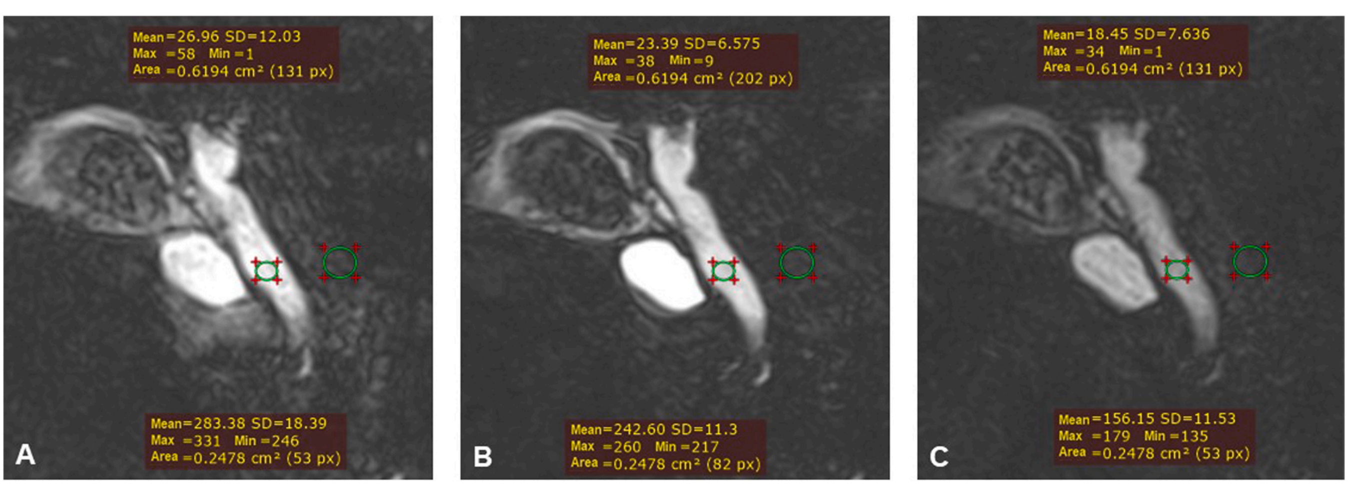

Fig. 1. 51-year-old man with gallbladder stones. A, B and C, Coronal source images show ROIs used to calculate common bile duct data and periductal tissue data (small circle, large circle) for modified respiratory-triggered (RT) sampling perfection with application-optimized contrasts using different flip-angle evolutions (SPACE) MRCP image (A), RT SPACE MRCP (B), and breath-hold (BH) SPACE MRCP image (C).

Table 3
Qualitative analysis of MRCP images.

	CR	*Kappa*	MR	*Kappa*	BH	*Kappa*	χ^2	*P*
LHD	4.57±0.68	0.75	4.48±0.68	0.72	4.43±0.65	0.68	2.507	0.286
RHD	4.52±0.69	0.77	4.46±0.71	0.68	4.40±0.67	0.65	2.127	0.345
CHD	4.78±0.46	0.80	4.64±0.69	0.77	4.59±0.70	0.69	2.175	0.337
PCBD	4.67±0.69	0.82	4.55±0.80	0.79	4.52±0.78	0.75	1.312	0.519
DCBD	4.57±0.88	0.73	4.50±0.88	0.65	4.50±0.88	0.62	0.574	0.751
MPD	3.67±1.15	0.76	3.66±1.18	0.71	3.45±1.08	0.65	2.02	0.364
CD	3.69±1.30	0.77	3.76±1.26	0.73	3.53±1.14	0.67	0.613	0.736
QOI	3.76±0.78	0.75	3.72±0.91	0.71	3.72±0.74	0.63	0.346	0.841
IC	4.02±0.71	0.73	3.97±0.88	0.67	3.97±0.67	0.64	0.301	0.86
BI	4.29±0.75	0.78	4.05±0.85	0.75	4.26±0.69	0.68	3.092	0.213

Abbreviations: CR= Conventional RT-SPACE-MRCP; MR= Modified RT-SPACE-MRCP; BH= BH-SPACE-MRCP; LHD= left hepatic bile duct; RHD= right hepatic bile duct; CHD= common hepatic bile duct; PCBD= proximal common bile duct; DCBD= distal common bile duct; MPD= main pancreatic duct; CD= cystic duct; QOI= quality of overall image; IC= image clarity; BI= background inhibition.

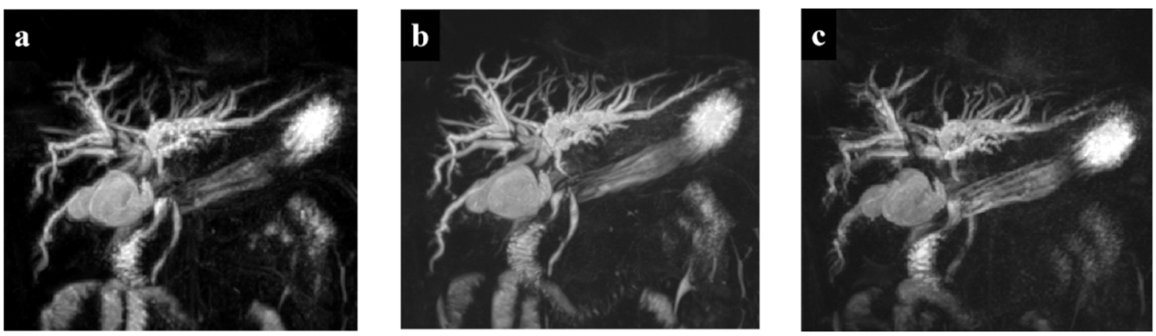

Fig. 2. 52-year-old man with gallbladder mass. The acquisition time of modified RT-SPACE-MRCP(a), conventional RT-SPACE-MRCP(b) and BH-SPACE-MRCP(c) was 38.7 s, 188 s, 18 s, respectively. The SNR, CNR, and acquisition time of three MRCP imaging sequences were significant differences among the three groups (*P*<0.05).

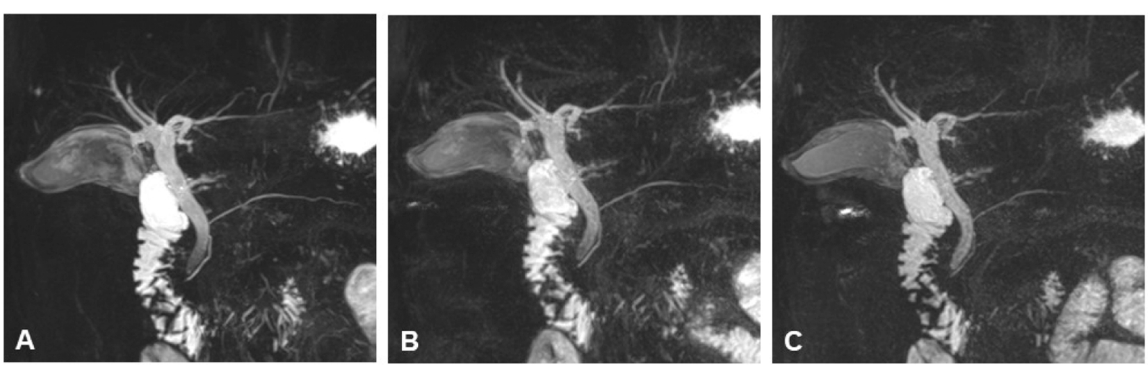

Fig. 3. 51-year-old man with gallbladder stones. The acquisition time of modified RT-SPACE-MRCP(a), conventional RT-SPACE-MRCP(b) and BH-SPACE-MRCP(c) was 61 s, 202 s, 18 s, respectively. The SNR, CNR, and acquisition time of three MRCP imaging sequences were significant differences among the three groups (*P*<0.05).

RT-SPACE had better quantitative image quality than conventional RT-SPACE, including SNR, and CNR, while there was no statistical difference regarding the quality of overall image, image clarity, background inhibition, and visualization of the pancreatic and biliary system (Fig. 1). Compared to conventional RT-SPACE, we significantly reduced the scan time with modified RT-SPACE while also retaining the comparable image quality. Furthermore, MRCP image quality can be comparable in one breath-hold by resisting movement artifact, for patients with irregular respiratory patterns, which facilitated the acquisition of MRCP scans with acceptably high-quality images. Although BH-SPACE had the shortest acquisition time, the quantitative image quality (including SNR and CNR) was poor, the modified RT-SPACE can be preferred for patients who cannot hold their breath.

In our results, we have shown that conventional RT-SPACE can be used instead of modified RT-SPACE as well as even BH-SPACE, which can provide images of comparable quality in a much shorter period of time. However, modified RT-SPACE and BH-SPACE may also solve the problem with non-predictable time to scan, and reduce risks of exam failure for these patients, thus eventually improving workflows and lowering the cost of MRI of the pancreatic and biliary ducts. A personalized plan is ideal for obtaining good diagnostic images more effectively according to patients' circumstances.

We should also note that there were some limitations to this research. Firstly, our study involved a relatively small number of patients and therefore further studies involving larger numbers of patients are needed to verify the proposed results. Secondly, each patient's TR and TE values were calculated automatically, so technical parameters vary from patient to patient. Thirdly, the diagnostic efficacy of the three sequences for pancreatic and biliary duct disease was not evaluated. There was no pathological result as the gold standard for diagnosis. Fourth, previous studies had shown that 3D MRCP based on deep learning reconstruction achieved higher SNR, and CNR without sacrificing image quality and that the image quality of BH MRCP combined with deep learning was better than RT MRCP [23–25]. Subsequent studies will incorporate deep learning to compare image quality and diagnostic efficacy between BH MRCP and modified RT MRCP.

10. Conclusions

In conclusion, conventional RT-SPACE can be replaced by improved RT-SPACE as well as even BH-SPACE, which can offer the equivalent image quality of RT-SPACE in a much shorter period of time. It is necessary to select the appropriate MRCP sequence according to the patient's situation to save scanning time, improve the examination success rate, and also enable the patient to have a better examination experience.

Ethics approval and consent to participate

This study involved human participants and all of the procedures were in conformity with the provisions of the Declaration of Helsinki (as revised in 2013). The ethical committee of Xi'an Daxing Hospital (Xi'an, China) approved this study (No. Dxll2019–347). In addition, we obtained all patients' informed consents.

Funding

This study was funded by the Key R&D Program Projects in Shaanxi Province (No. 2023-YBSF-055).

CRediT authorship contribution statement

Yue Qin: Supervision, Project administration. **Lei Wang:** Writing – review & editing, Conceptualization. **Juan Tian:** Data curation. **Dayong Jin:** Formal analysis. **Xin Li:** Writing – original draft. **Liyao Liu:** Investigation. **Yongli Ma:** Investigation. **Yanqiang Qiao:** Investigation. **Yinhu Zhu:** Formal analysis. **Yifan Qian:** Data curation.

Declaration of Competing Interest

The authors have declared that there were no conflicts of interest on their behalf.

Data availability

On reasonable requests, data can be obtained from the corresponding author.

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