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Small Field-of-View T2-Weighted MRI of the pancreas in a Screening Setting for Hereditary Pancreatic Cancer: Improving Image Quality Through Radial K-Space Sampling

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Abstract

Background: Radial k-space sampling is compared with conventional cartesian k-space sampling in small field-of -view respiratory-triggered Turbo Spin Echo (TSE) T2-weighted imaging of the pancreas regarding image quality and artifacts in a screening program for hereditary pancreatic cancer.

Methods: Small field-of-view radial and cartesian k-space sampled respiratory triggered TSE images were acquired in 40 healthy mutation carriers undergoing annual screening for pancreatic cancer. Two radiologists evaluated images for motion artifacts, anatomical sharpness, pancreatic duct conspicuity and sharpness of vessels using a five-point Likert scale (1=very poor, 5=excellent) and reported their preferred sequence. Contiguousness between slices was quantified by segmentation of the superior mesenteric vein and determining the continuity of the vessel wall on consecutive slices by determining the deviation of the superior mesenteric vein center points.

Results: All categories except in-plane motion artifacts yielded statistically significant differences ($p<0.001$). Radial sampling performed better in slice contiguousness, anatomical sharpness and sharpness of vessel walls. Pancreatic duct conspicuity was higher on the cartesian approach. Slice contiguousness had an average score of 4.53 ± 0.71 for radial and 3.46 ± 0.76 for cartesian TSE. Radial sampling was preferred in 65 cases (81.3%). The average deviation of the superior mesenteric vein center points was 1.45 mm (interquartile range (IQR) 1.08 – 2.06) on radial TSE and 2.31 mm (IQR 1.65 – 3.30) on cartesian TSE, $p < 0.001$.

Conclusion: Radial k-space sampling yields better overall image quality and contiguousness between slices compared to cartesian sampling in high-resolution respiratory triggered T2-TSE of the pancreas.

Keywords: Radial k-space sampling; Turbo Spin Echo;

Introduction

Despite ongoing research and attempts to improve prognosis, pancreatic cancer remains one of the most lethal malignancies and is expected to become the leading cause of cancer-related deaths by 2030 [1]. Earlier detection of pancreatic cancers can drastically improve survival, as stage I tumors have a far better prognosis than higher stage disease [2]. Screening for pancreatic cancer in the general population is not feasible mainly due to the relatively

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low incidence. However, screening in high-risk individuals can be feasible.

In our institution, a group of mutation carriers with a 15-20% lifetime risk of developing pancreatic cancer undergo annual surveillance of the pancreas with MRI, resulting in improved outcomes compared to pancreatic cancer in the general population [3]. Other institutions have also reported favourable outcomes of screening high-risk individuals [4]. A screening setting requires an optimized MRI protocol with high-resolution images with minimal artifacts. We previously reported on the use of a T1-weighted sequence with a pre saturation pulse to increase contrast between healthy and abnormal pancreatic tissue, better facilitating the detection of early pancreatic cancers [5].

T2-weighted imaging is crucial in the evaluation of cystic lesions and ductal abnormalities, as well as in the depiction of the general anatomy of the pancreas and peripancreatic structures. The pancreas is a challenging organ for imaging with MRI. Movement due to breathing, gastrointestinal peristalsis, the cardiac cycle and vascular pulsations can all induce motion artifacts. This results in blurred edges, ghosting artifacts and intravoxel phase dispersion [6]. To limit respiratory artifacts, breath-hold T2 weighted imaging can be performed using a half-Fourier single-shot fast spin echo technique (HASTE, SSFSE, single-shot TSE). This technique, however, has found limited adoption for detailed imaging of the pancreatic anatomy due to limited spatial resolution.

Belt- and camera-based respiratory triggering has significantly improved image quality of multishot fast spin echo for T2-imaging of the abdomen. In patients with an irregular breathing pattern, however, movement between slices in the cranio-caudal direction ("jumping slices") may occur and can cause lesions to be missed or to be misinterpreted.

Common fast spin echo techniques use a Cartesian (rectilinear) grid to acquire data from the k-space matrix. In radial acquisitions (PROPELLER - GE, BLADE - Siemens and MultiVane - Philips), the k-space is sampled by a series of angular spokes overlapping at the center. The resulting oversampling of the k-space center produces a high signal-to-noise ratio. Another major benefit is the ability to reduce motion artifacts by comparing the data of different spokes for consistency and correcting or even rejecting spokes with anomalous data due to motion. Several studies have demonstrated improved image quality and lesion detection in the upper abdomen and liver by utilizing radial k-space sampling [7–12].

In screening for pancreatic cancer, artifact-free and high-resolution imaging is essential. To our knowledge, no studies have investigated the impact of radial k-space sampling on image quality in imaging of the pancreas.

In this study, we aim to compare radial multi shot fast spin echo with conventional cartesian multi shot fast spin–echo in terms of five different measures of image quality for small field-of-view high-resolution respiratory-triggered T2-weighted imaging of the pancreas.

Methods

Patients

This retrospective study was performed in a surveillance cohort of hereditary pancreatic cancer on healthy subjects with a CDKN2A-p16-Leiden mutation. In this surveillance cohort, all mutation carriers are screened annually with MRI of the pancreas. In 2019, the axial T2-sequence of the MRI protocol was changed from a conventional, cartesian k-space sampled fast spin echo to a radial sequence. Forty consecutive scanned subjects were enrolled, who had been scanned with cartesian T2-fast spin echo and then with radial T2-fast spin echo in the following screening round in and around 2019.

MRI

Examinations were performed on a 3 Tesla system (Philips Ingenia; Philips Medical Systems, Best, The Netherlands) using a 32-channel torso coil. The high-resolution axial 2D T2-TSE sequences (both cartesian and radial acquisition) were run using respiratory triggering and a zoomed small field of view (220 mm) surrounding the pancreas. Aliasing was prohibited by using parallel imaging (SENSE). The acquisition plane was angled to the course of the pancreatic body and tail, in which the pancreatic tail is usually located more superiorly than the pancreatic head and body (figure 1). The zoomed acquisition provides high-resolution images of the pancreas and peripancreatic structures, while the angulation ensures a good view of the body and tail while reducing the number of slices that must be imaged. Both 2D T2 cartesian TSE and radial (MultiVane) TSE series were additionally acquired with fat suppression (FS). The scan parameters were as follows (cartesian/radial T2-TSE): TR 1195/2725 msec, TE 80/148 msec, ETL 94/50, and no. phase encoding steps 157/184. A similar field of view (220 mm), matrix size (320x320) and slice thickness (3 mm) were used for both sequences. T2-contrast weighting slightly differed (different TR and TE) due to restraints by the combination of respiratory triggering and radial k-space sampling.

Image analysis

Images were evaluated in a blinded fashion by two abdominal radiologists with 7 and 25 years of experience in abdominal imaging. Two sets of images were presented: radial and cartesian T2-TSE with and without FS. The reviewers independently evaluated the images for 1) contiguousness between slices, 2) in-plane motion artifacts, 3) anatomical sharpness of pancreatic parenchyma and blood vessels, 4) pancreatic duct conspicuity and 5) anatomical sharpness of vessel walls on the FS images, using a five-point scale for quality in which 1 = very poor, 2 = poor, 3 = fair, 4 = good

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and 5 = excellent. The visibility of pancreatic cysts was also noted. Last, while still blinded, the reviewers compared the two acquisition techniques of each subject and documented which examination they preferred overall for both the images with and without fat suppression.

To quantify the contiguousness between slices, custom in-house built vessel analysis software was used to semiautomatically segment the lumen of the superior mesenteric vein (SMV). A radiologist performed segmentations of the SMV from a level just inferior to the splenomesenteric confluence until the vein passed the horizontal part of the duodenum or until the confluence of the two major intestinal trunks of the SMV. Using linear regression, a line fit was performed through the lumen centers of the segmented slices, after which the average deviation of the center points from the line fit was calculated and recorded.

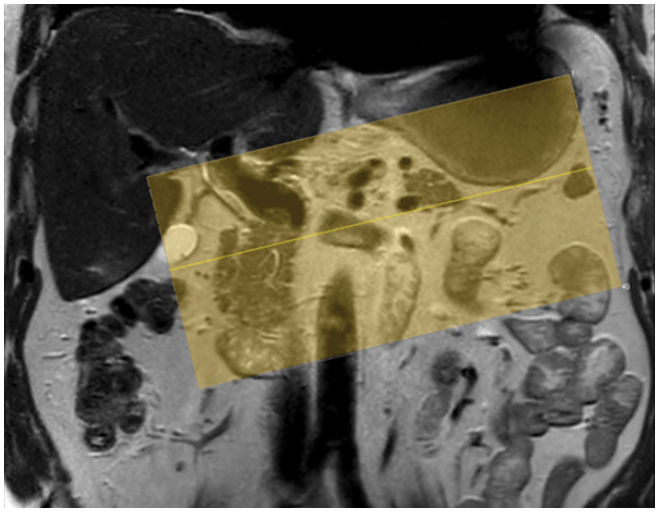

Figure 1: Coronal T2 of the upper abdomen showing the scan volume and angulation of the axial T2 weighted sequences.

Statistical analysis

Statistical tests were performed with SPSS Statistics version 28.0.1 (IBM, Armonk, New York, United States). The five subjective image parameters were compared with a Wilcoxon signed-rank test with Bonferroni correction. Interobserver agreement of the image parameters was assessed through a weighted kappa statistic and a weighted percent agreement. The average deviation of the central luminal line coordinates from the line fit was compared with a Wilcoxon signed-rank test. A p value of <0.05 was considered statistically significant.

Results

The results of the subjective image analysis are presented in Table 1. All but the 'in-plane motion artifacts' category yielded statistically significant differences (p<0.001).

Radial T2 TSE performed better in the categories 'contiguousness between slices', 'anatomical sharpness of pancreatic parenchyma and blood vessels' and 'anatomical sharpness of vessel walls' on T2 FS. Cartesian T2 TSE performed better in 'pancreatic duct conspicuity'. The largest difference was seen in the anatomical sharpness of vessel walls on T2 FS, in which the average score was 4.01 for radial T2 TSE and 1.92 for cartesian T2 TSE. Contiguousness between slices also showed a large difference, with an average score of 4.53 for radial TSE and 3.46 for cartesian TSE. This effect is easily demonstrated in sagittal multiplanar reconstructions at the level of the superior mesenteric vein of the two different sequences (Figure 2).

The average deviation of the central luminal line points to the line fit showed a median distance of 1.45 mm (interquartile range (IQR) 1.08 – 2.06) on radial TSE and a median distance of 2.31 mm (IQR 1.65 – 3.30) on cartesian TSE, p < 0.001.

Table 1: Results of Subjective Image Analysis

	Contiguousness	Motion artifacts	Parenchyma and blood vessels sharpness	Pancreatic duct conspicuity	Sharpness of vessel walls on T2 FS
radial	4.53 ± 0.71	4.01 ± 0.85	4.07 ± 0.79	3.86 ± 0.84	4.01 ± 0.83
cartesian	3.46 ± 0.76	3.84 ± 0.72	3.65 ± 0.60	4.40 ± 0.59	1.92 ±0 .78
P value*	<0.001	0.435	<0.001	<0.001	<0.001

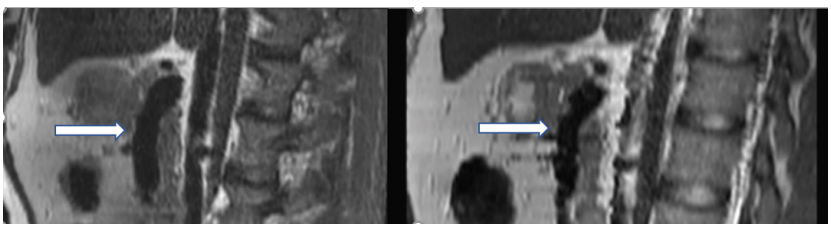

Figure 2: Sagittal reconstruction at the level of the SMV (arrow) on radial T2 TSE (left) and cartesian T2 TSE (right) in the same subject. The smooth contours of the SMV and other structures on radial TSE compared to the cartesian TSE reconstruction demonstrate improved contiguousness between slices on radial TSE.

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Figures 3 and 4 show examples of the crisp and detailed images of the pancreas and surrounding structures on radial TSE images, while cartesian TSE images are more blurred. The radial and radial FS images show the wall of the aorta and the superior mesenteric artery in detail, with fewer ghosting artifacts compared to cartesian T2-TSE and better delineation of the vessel walls.

Pancreatic cysts were recorded on both radial T2 TSE and cartesian T2 TSE 24 times for the observers combined (see table 2). In four instances, cysts were visible on cartesian TSE but not on radial TSE, and in one instance, a cyst was only visible on radial TSE but not on cartesian TSE.

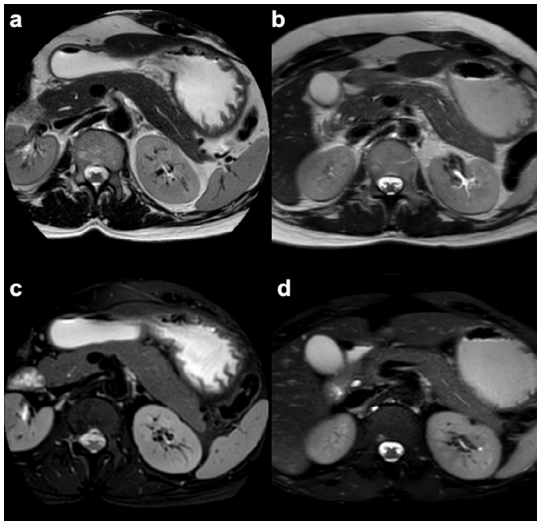

Figure 3: Examples of small field of view T2-weighted MRI of the pancreas in the same patient, including fat-suppressed images. The acquisition plane of the sequences is angled to the course of the pancreatic body and tail. a) radial TSE, b) cartesian TSE, c) radial FS, d) cartesian FS.

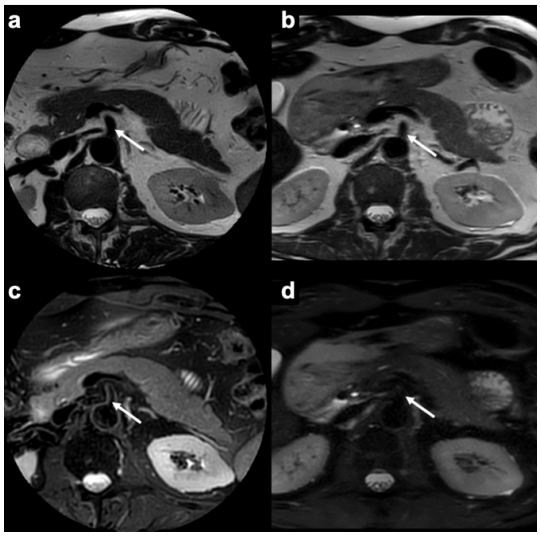

Figure 4: Example of small field of view T2-weighted MRI of the pancreas in another patient at the level of the superior mesenteric artery (SMA) (arrow). On the fat-suppressed radial FS sequence (c), the SMA is clearly visible with excellent delineation of the vessel wall. a) radial, b) cartesian, c) radial FS, d) cartesian FS.

Table 2: Visibility of pancreatic cysts on cartesian T2 TSE and radial T2 TSE

	cartesian scans without detected cysts	cartesian scans with detected cysts
radial scans without detected cysts	51	4
radial scans with detected cysts	1	24
P value	0.375	

Overall, the blinded observers preferred the radial TSE sequences over the cartesian TSE in 65 cases (81.3%).

Table 3 shows the interobserver agreement. The highest kappa value was 0.534 in the contiguousness between slices category, and the lowest kappa value was 0.338 in the in-plane motion artifact category.

Table 3: Interobserver agreement

Category	Weighted kappa value	P value	Weighted percent agreement
Contiguousness	0.534	<.001	0.884
Motion artifacts	0.338	<.001	0.856
Sharpness of parenchyma and blood vessels	0.421	<.001	0.888
Pancreatic duct conspicuity	0.382	<.001	0.878
Sharpness of vessel walls on T2 FS	0.496	<.001	0.8

Discussion

Pancreatic cancer has a dismal survival in part due to lack of symptoms in the early stages of the disease, leading to cancers being detected at an advanced stage in the general population. Early detection and resection is the only way to potentially cure the disease at present. MRI has proven to be an essential tool for early detection in high-risk individuals.

T2-weighted MRI (and MRCP) is excellent for depicting pancreatic and bile duct anatomy and abnormalities and is preferred over CT in the diagnosis and follow-up of pancreatic cystic neoplasms [13]. Optimal in-plane resolution enables proper appreciation of pancreatic anatomy and surrounding structures. Furthermore, it allows for better detection of small abnormalities. To do this, we use a zoomed T2 sequence angulated to the course of the pancreatic body and tail. The pancreatic tail usually courses superior toward the splenic hilum. This provides an excellent view of the pancreas

with increased spatial resolution. As another benefit, fewer slices are needed to cover the organ compared to pure axial acquisition. In contrast, most pancreatic MRI protocols worldwide use an axial large field of view of the entire upper abdomen.

Movement between different slices is one of the biggest hindrances in reading abdominal MR images. Motion not only occurs in the axial plane, reducing the contiguousness between slices but also occurs in the cranio-caudal plane and can cause sections of the pancreas to be missed on imaging. In this analysis, radial T2 TSE increases slice contiguousness compared to cartesian T2 TSE. This result was echoed by the quantitative method of measuring slice contiguousness by using the SMV as the reference, in which radial TSE showed a decreased median movement between slices in the axial plane compared to cartesian TSE.

Pancreatic duct conspicuity was on average rated higher on cartesian TSE, but duct conspicuity was still reasonable on radial TSE. Additionally, it should be noted that our full MRI protocol includes an MRCP sequence, which further secures visualization of the pancreatic duct and allows for the detection of more subtle duct abnormalities.

There was no statistically significant difference between cartesian T2 TSE and radial T2 TSE in the 'in-plane motion artifacts' category, although one of the benefits of radial k-space acquisition is a potential for reducing in-plane motion artifacts. Considering the performance of both sequences in this category, this demonstrates that current T2 TSE acquisitions are already capable of good image quality. Radial TSE performed significantly better in the categories of 'anatomical sharpness of pancreatic parenchyma and blood vessels' and 'anatomical sharpness of vessel walls' on T2 FS, highlighting the ability of radial TSE to provide more anatomical detail. The largest difference was noted in the sharpness of vessel walls on T2 FS. Delineation of blood vessels is significant because the resectability of pancreatic cancer relies heavily on contact of the tumor with the major blood vessels around the pancreas [14]. The image quality improvement of radial TSE with FS compared to cartesian TSE with FS might enable better assessment of vascular contact in pancreatic cancer.

Apart from the ability to detect cysts, in which no statistically significant difference was found between cartesian TSE and radial TSE, we did not perform a comparison in the detection of pancreatic lesions. However, in our view, this is not a major limitation. An MRI of the pancreas is a multiparametric examination. T2 is excellent for detecting cysts but is probably not the prime sequence that enables the detection of solid lesions, as we found in a previous analysis of our cohort [5]. In clinical practice, the combination of different sequences determines the sensitivity of MRI for detecting pancreatic lesions.

Other limitations of this study should also be mentioned. First, this is a subjective analysis of image quality. There is a clear variation in the rated scores of the observers with only fair to moderate agreement according to the weighted kappa statistics, highlighting the subjective nature of judging image quality. Nevertheless, due to the weighted percent agreement of at least 80 percent for each category and the clear statistically significant differences between cartesian TSE and radial TSE, we believe radial T2 TSE provides a definite improvement in image quality. Second, although the patients were recruited prospectively, this is a retrospective comparison of cartesian and radial TSE sequences of the same healthy subject acquired one year apart, not simultaneously. This could reduce the comparability between images. However, all images were acquired on the same MRI scanner with very comparable image parameters and without changes in hardware or software. Third, the parameters of the acquisition techniques resulted in different effective echo times and slightly different signal intensities of the pancreatic tissue between radial and cartesian TSE images.

Conclusion

In conclusion, radial k-space sampling yields better contiguousness between slices and overall image quality than cartesian sampling in high-resolution respiratory-triggered 2D T2-weighted imaging of the pancreas.

Declarations

Ethics approval and consent to participate:

This retrospective evaluation of the radial T2-weighted MRI sequence, representing a technical advancement over its predecessor, was done on data obtained as part of the screening program for hereditary pancreatic cancer. Participants had provided written informed consent before enrolment in the surveillance program. This surveillance program was approved by the institutional review board of the Leiden University Medical Center (MEC P00.107; P21.006) and was registered at the Netherlands Trial Register (NL9158). Additional ethics approval for this specific retrospective study was waived by the ethics committee. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for Publication: Not applicable.

Data Availability: All relevant data generated or analyzed during this study are included in this published article.

Competing Interests: None of the authors have a conflict of interest

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Authors' contributions:

B.B. : conceptualization, methodology, formal analysis, investigation, data curation, writing (original draft, review & editing, visualization

A.B. : Formal analysis, investigation, data curation, writing – original draft

S.F. : conceptualization, methodology, writing – review & editing

A.W. : writing – review & editing, supervision, project administration,

R.G. : methodology, software, writing – review & editing

M.W. : conceptualization, methodology, formal analysis, investigation, writing – review & editing, visualization, supervision.

All authors have approved the submitted version and have agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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