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ORIGINAL ARTICLE

Comparison of respiratory-triggered 3-D fast spin-echo and single-shot fast spin-echo radial slab MR cholangiopancreatography images in children

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Abstract

Background The two most commonly performed magnetic resonance cholangiopancreatography (MRCP) sequences, 3-D fast spin-echo (3-D FSE) and single-shot fast spin-echo radial slabs (radial slabs), have not been compared in children.

Objective The purpose of this study was to compare 3-D FSE and radial slabs MRCP sequences on a 3-T scanner to determine their ability to show various segments of pancreaticobiliary tree and presence of artifacts in children.

Materials and methods We reviewed 79 consecutive MRCPs performed in 74 children on a 3-T scanner. We noted visibility of major ducts on 3-D FSE and radial slabs. We noted the order of branching of ducts in the right and left hepatic ducts and the degree of visibility of the pancreatic duct. Statistical analysis was performed using McNemar and signed rank tests.

Results There was no significant difference in the visibility of major bile ducts and the order of branching in the right hepatic lobe between sequences. A higher order of branching in the left lobe was seen on radial slabs than 3-D FSE (mean order of branching 2.82 versus 2.27; P-value=0.0002). The visibility of pancreatic duct was better on radial slabs as compared to 3-D FSE (mean value of 1.53 vs. 0.90; P-value<0.0001). 3-D FSE sequence was artifact-free in 25/79 (31.6%) MRCP exams as compared to radial slabs, which were artifact-free in 18/79 (22.8%) MRCP exams (P-value=0.0001).

Conclusion There is no significant difference in the visibility of major bile ducts between 3-D FSE and radial slab MRCP sequences at 3-T in children. However, radial slab MRCP shows a higher order of branching in the left hepatic lobe and superior visibility of the pancreatic duct than 3-D FSE.

Keywords MRCP · Children · 3-D FSE · Single-shot radial slabs · 3 tesla (3 T)

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Introduction

Magnetic resonance cholangiopancreatography (MRCP) has been shown to be useful for evaluation of various pancreaticobiliary abnormalities in children [1–5]. MRCP uses heavily T2-weighted (very long echo time [TE]) sequences to visualize fluid in the pancreaticobiliary tree. At high TE (700–1,100 ms) the tissues and structures with short T2-relaxation time lose their signal completely and are not visualized. The fluid in the bile and pancreatic ducts, because of long T2 relaxation time, retains signal even at high TE and is seen on MRCP images. Typically two types of heavily T2-weighted sequences used for MRCP include 3-D fast spin-echo (3-D FSE) in the coronal plane and single-shot fast spin-echo as multiple slabs of 2–4 cm in the radiating coronal oblique plane (radial slabs) [1]. Usually 3-D FSE is acquired with respiratory triggering and takes about 5 min. The 3-D data are then reconstructed into images of the biliary tree in various planes using maximum-intensity projection (MIP) algorithm. Radial slabs are acquired with breath-hold in older children or manually during shallow but free breathing in younger children and take 2–4 min. Just one of these sequences, when it is good quality, is necessary to adequately depict the pancreaticobiliary tree. However, most institutions use both sequences in their MRCP protocol because each sequence has distinct advantages and limitations and the two often complement each other.

These sequences have been compared for their quality, visibility of ducts, and artifacts in adults [6–8]. The results of these studies are mixed, with some studies finding 3-D FSE superior and others finding radial slabs better. No such comparison has been published in children. Knowledge of the differences in the ability of these sequences to show various segments of the pancreaticobiliary tree and the typical artifacts would help clinicians choose the best sequence, rather than using both, to save table time. This evaluation might also illustrate specific advantages of each sequence for particular situations. Therefore the purpose of this study was to compare 3-D FSE and radial slabs for visualization of various segments of the pancreaticobiliary tree and presence of artifacts on consecutive MRCP studies performed in children at 3-T (3-tesla) MRI.

Materials and methods

Patients

Institutional Research Ethics Board approval was obtained for this study with waiver of patient consent. We retrospectively analysed all consecutive MRCPs at 3-T in children (0–18 years) between January 2008 and June 2011 to compare 3-D FSE MRCP and radial slab MRCP images. The patient list was obtained from a database that keeps record of all the children scanned at 3 T. We included children in whom MRCP was performed using both 3-D FSE and radial slab sequences.

MR cholangiopancreatography technique

All MR examinations were performed on a 3-T scanner (Achieva; Philips Healthcare, Best, The Netherlands). Each MRCP study included 3-D FSE and radial slabs with the following parameters: (1) respiratory-triggered three-dimensional (3-D) T2-weighted fast spin-echo (FSE) with fat saturation (TR/TE 3,168/700–900 ms, FOV 250–380 mm, matrix 288×288 and slice thickness 2 mm with 1-mm gap) and (2) single-shot FSE radial slabs in the coronal plane (TR/TE 5,764/740 ms, FOV 250–380 mm, matrix 320×320 and slab thickness 30–40 mm). Thirteen slabs were acquired with breath-hold in older children and manually during shallower phases of respiration in younger children. Gadolinium-based contrast media and secretin were not administered.

Imaging review

All MRCP examinations were evaluated independently by a pediatric radiologist (6 years' experience) and a pediatric radiology fellow (2 years' experience). Differences were resolved by consensus. Three-dimensional FSE MRCP and radial slab images in the same child were reviewed one after another in the same session. On both 3-D FSE MRCP and radial slab images the visibility of the common bile duct, cystic duct, common hepatic duct, and main right and left hepatic ducts was noted as "yes" or "no." The number of branches (order) in the right and left lobes of the liver was noted on both sequences. The main hepatic duct in each lobe was counted as order no. 1 as shown in Fig. 1.

The visibility of the pancreatic duct on both sequences was graded as follows: 0, not visible; 1, only a segment of duct visible (most often in the head of the pancreas); 2, entire pancreatic duct is visible; and 3, entire pancreatic duct and side branches are visible (Fig. 2). The images were also reviewed for presence of artifacts.

We reviewed patient charts for relevant clinical features and indications for MRCP.

Statistical analysis

Statistical analysis was performed to compare the visibility of various pancreaticobiliary segments on both sequences and to see whether the difference was statistically significant using the McNemar test. The order of intrahepatic biliary branching in right and left lobes and the visibility of pancreatic duct were compared using the signed rank test. A separate analysis of children with a normal biliary tree was also performed to determine the ability of these two

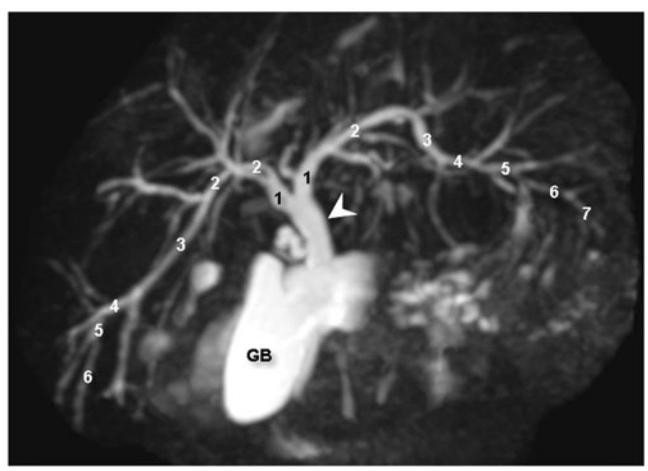

Fig. 1 Order of branching. Maximum-intensity projection (MIP) image from 3-D FSE MRCP in a 5-year-old girl shows mild dilatation of extra- and intra-hepatic ducts. 1 = right and left hepatic ducts in respective lobes. Highest order of branching in this case was 6 in the right and 7 in the left hepatic lobes. *Arrowhead* shows common hepatic duct. *GB* gallbladder

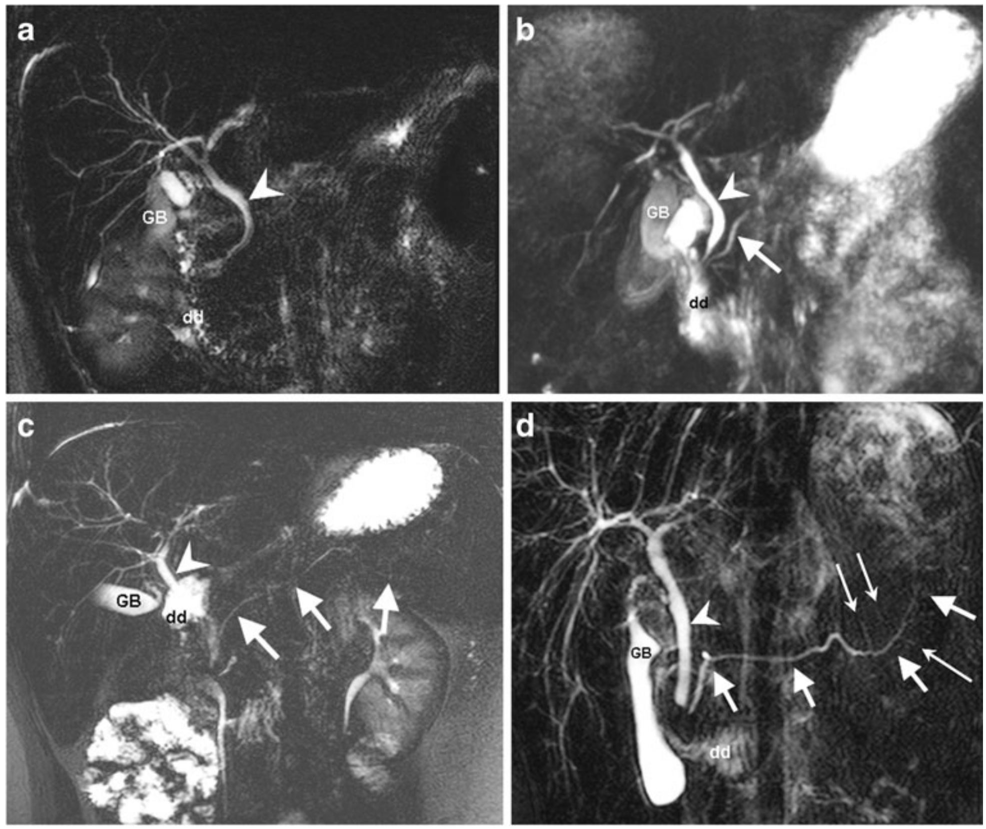

Fig. 2 Grading of visibility of the pancreatic duct (PD). **a** Grade 0 = PD is not visible at all. **b** Grade 1 = a segment of PD is seen in the head region (*arrow*). **c** Grade 2 = entire PD is seen (*arrows*). **d** Grade 3 = entire PD (*thick arrows*) and a few side branches (*long thin arrows*) are seen in the distal body and tail of the pancreas (16-year-old boy). *Arrowhead* denotes the common bile duct. *dd* duodenum, *GB* gallbladder

sequences to show duct segments in a normal biliary tree. Statistical analysis was performed using software SAS 9.3 (SAS Institute Inc., Cary, NC).

Results

This retrospective study included 79 MRCP studies in 74 children (44 boys and 30 girls, ages 19 days to 18 years, average 11 years). Sixteen out of 79 MRCP studies were performed in children younger than 5 years (12 under sedation/anesthesia and 4 awake), 8/79 exams were performed in children ages 5–8 years (all awake) and the remaining 55/79 exams were performed in children older than 8 years (53 awake and 2 under anesthesia in a same child).

Major indications for MRCP included evaluation for suspected or known primary sclerosing cholangitis, pancreatitis, choledochal cyst and calculus disease. Sixteen of 79 (20.3%) MRCP studies did not show any abnormality of pancreaticobiliary tree.

Visibility of biliary tree segments

MRCP studies that showed common bile duct, common hepatic duct, cystic duct, right hepatic duct and left hepatic duct on both sequences are summarized in Table 1. The percentage of "yes" (visibility) on each sequence for all duct segments was compared using the McNemar test. The difference between 3-D FSE and radial slabs sequences in showing the segments of the biliary tree was greatest for the cystic duct: 69.6% (3-D FSE) vs. 77.2% (radial slabs).

Table 1 Comparison of 3-D FSE and radial slabs in visualizing various segments of biliary tree (total number of MRCP studies = 79)

Number	Segment of biliary tree	Visible on 3-D FSE in MRCP studies, *n* (%)	Visible on radial slabs in MRCP studies, *n* (%)	*P*-value by McNemar test
1	Common bile duct	77 (97.5%)	77 (97.5%)	1
2	Cystic duct	55 (69.6%)	61 (77.2%)	0.23788
3	Common hepatic duct	76 (96.2%)	76 (96.2%)	1
4	Right hepatic duct	74 (93.7%)	76 (96.2%)	0.625
5	Left hepatic duct	73 (92.4%)	73 (92.4%)	1

MRCP magnetic resonance cholangiopancreatography, *FSE* fast spin-echo

Table 2 Comparison of order of bile duct branching in hepatic lobes and visibility of pancreatic duct on 3-D FSE and radial slabs (n=79)

Number	Order	Mean	Standard deviation	Median	Minimum	Maximum	Signed rank test *P*-value
1	RIGHT lobe order of branching on 3-D FSE	3.04	1.46	3.00	0.00	7.00	0.1100
	RIGHT lobe order of branching on radial slabs	3.27	1.28	3.00	0.00	7.00	
2	LEFT lobe order of branching on 3-D FSE	2.27	1.16	2.00	0.00	6.00	0.0002
	LEFT lobe order of branching on radial slabs	2.82	1.24	3.00	0.00	5.00	
3	PANCREATIC DUCT visibility on 3-D FSE	0.90	0.90	1.00	0.00	3.00	<0.0001
	PANCREATIC DUCT visibility on radial slabs	1.53	0.97	2.00	0.00	3.00	

FSE fast spin-echo

However, this difference was not statistically significant (P=0.23788), and neither was the difference in visibility of other segments between sequences.

Order of bile duct branching in hepatic lobes and visibility of pancreatic duct

The order of branching seen on 3-D FSE and radial slabs in right and left hepatic lobes is compared in Table 2. The differences in the order of branching were compared using the signed rank test. In the right lobe, there was no significant difference in the visibility of order of branching between radial slabs and 3-D FSE; mean order of branching was 3.27 versus 3.04, respectively (P-value=0.1100). In the left lobe, radial slabs showed higher order of branching than 3-D FSE; mean order of branching was 2.82 versus 2.27, respectively. This difference was statistically significant (P-value=0.0002). The visibility of the pancreatic duct was better on radial slabs (mean value of 1.53) as compared to 3-D FSE (mean value of 0.90). This difference was statistically significant (P-value<0.0001). Only one case with grade 3 visibility of the pancreatic duct (visibility of entire PD with side branches) was normal. Other cases had either chronic pancreatitis or anomalous side branch.

Analysis of 16 normal MRCP studies

Sixteen of 79 (20.2%) MRCP studies showed no significant abnormality of the pancreaticobiliary tree. A separate comparison for visibility of duct segments and order of branching was performed for this normal group and is shown in Tables 3 and 4. Age of these 16 children (12 boys, 4 girls) ranged from 1 month to 16 years (average 12 years). There was no significant difference between 3-D FSE and radial slabs in showing various segments of the biliary tree. However, radial slabs were significantly superior in showing order of branching in both lobes as well as in showing the pancreatic duct.

Artifacts

Three-dimensional FSE showed at least one artifact in 54/79 (68.4%) MRCP studies and no artifacts in the remaining 25/79 (31.6%). Similarly, radial slabs showed at least one artifact in 61/79 (77.2%) MRCP studies and no artifacts in the remaining 18/79 (22.8%). The difference in the frequency of artifacts on the two sequences was statistically significant (P-value=0.0001).

Major artifacts on 3-D FSE included breathing and patient motion in 21/79 MRCPs (Fig. 3), inhomogeneity in 3/79, phase wrap in 2/79, stomach ghosting in 5/79 (Fig. 4) and moire fringe (curvilinear alternate dark and bright bands caused by field inhomogeneity or radiofrequency interference) in 1/79. Major artifacts on radial slabs included breathing artifacts on most slabs (>5/13 slabs) in 27/79 cases; breathing artifacts in a few slabs (<5/13 slabs) in 21/79; patient motion artifacts in 5/79; and inhomogeneity, chemical shift and poor image quality because of excess

Table 3 Comparison of 3-D FSE and radial slabs in visualizing various segments of the biliary tree on normal MRCP studies (n=16)

Number	Segment of biliary tree	Visible on 3-D FSE in normal MRCP studies, n (%)	Visible on radial slabs in normal MRCP studies, n (%)	*P*-value by McNemar test
1	Common bile duct	16 (100%)	16 (100%)	1
2	Cystic duct	9 (56.3%)	12 (75%)	0.375
3	Common hepatic duct	16 (100%)	15 (93.8%)	0.3173
4	Right hepatic duct	14 (87.5%)	15 (93.8%)	0.5637
5	Left hepatic duct	14 (87.5%)	15 (93.8%)	0.5637

MRCP magnetic resonance cholangiopancreatography, *FSE* fast spin-echo

Table 4 Comparison of order of bile duct branching in hepatic lobes and visibility of the pancreatic duct on normal 3-D FSE and radial slabs (n=16)

Number	Order	Mean	Standard deviation	Median	Minimum	Maximum	Signed rank test *P*-value
1	RIGHT lobe order of branching on 3-D FSE	2.25	1.13	2.50	0.00	4.00	0.0371
	RIGHT lobe order of branching on radial slabs	3.00	1.10	3.00	0.00	4.00	
2	LEFT lobe order of branching on 3-D FSE	1.63	0.96	2.00	0.00	3.00	0.0068
	LEFT lobe order of branching on radial slabs	2.56	1.15	2.50	0.00	4.00	
3	PANCREATIC DUCT visibility on 3-D FSE	1.00	0.89	1.00	0.00	3.00	0.0156
	PANCREATIC DUCT visibility on radial slabs	1.75	0.77	2.00	0.00	3.00	

FSE fast spin-echo

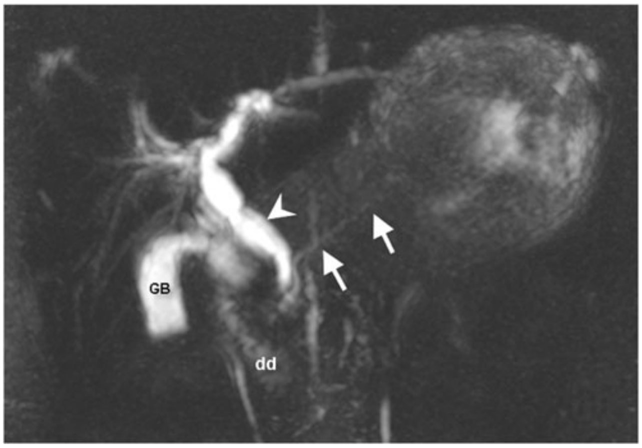

Fig. 3 Breathing artifacts. Maximum-intensity projection image from 3-D FSE magnetic resonance cholangiopancreatography (MRCP) in a 5-year-old boy shows blurring of duct margins and poor visibility of smaller ducts because of breathing artifacts. There is dilatation of the extrahepatic duct (*arrowhead*) in this child with choledochal cyst. *Arrow* denotes the pancreatic duct. *dd* duodenum, *GB* gallbladder, *FSE* fast spin-echo

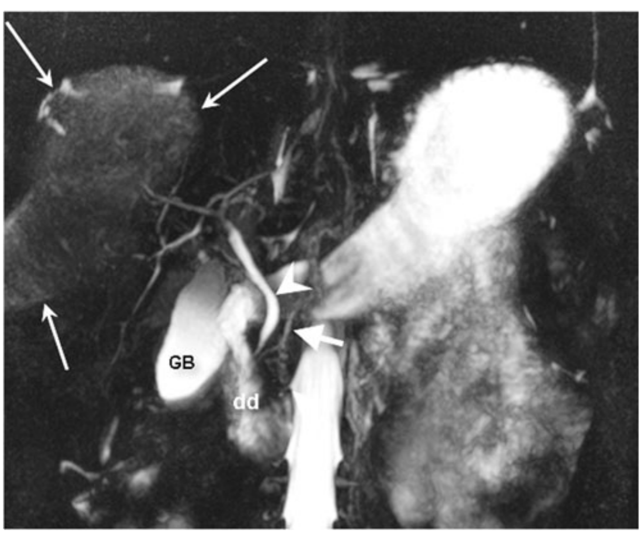

Fig. 4 Stomach ghosting. Maximum-intensity projection image from 3-D FSE magnetic resonance cholangiopancreatography (MRCP) in a 14-year-old girl shows ghosting of fluid-containing stomach (*long arrows*) over the right hepatic lobe. *Arrowhead* indicates the common bile duct; *thick arrow* indicates the pancreatic duct. *dd* duodenum, *GB* gallbladder, *FSE* fast spin-echo

body fat in one case each. Dark, grainy images with poor signal were noted in 19/79 MRCP studies on 3-D FSE as compared to only 5/79 on radial slabs (Fig. 5).

Discussion

MR cholangiopancreatography is an important non-invasive and radiation-free test in the assessment of a variety of pancreaticobiliary abnormalities in children [1–5]. MRCP at higher field strengths such as 3 tesla is likely to be used more often because of its better signal-to-noise ratio. A typical MRCP examination usually includes both 3-D FSE and radial slabs. These sequences each have advantages and limitations. Three-dimensional FSE is usually acquired with respiratory triggering and can be affected by respiratory misregistration. It might not work in children with irregular breathing that causes significant image degradation by

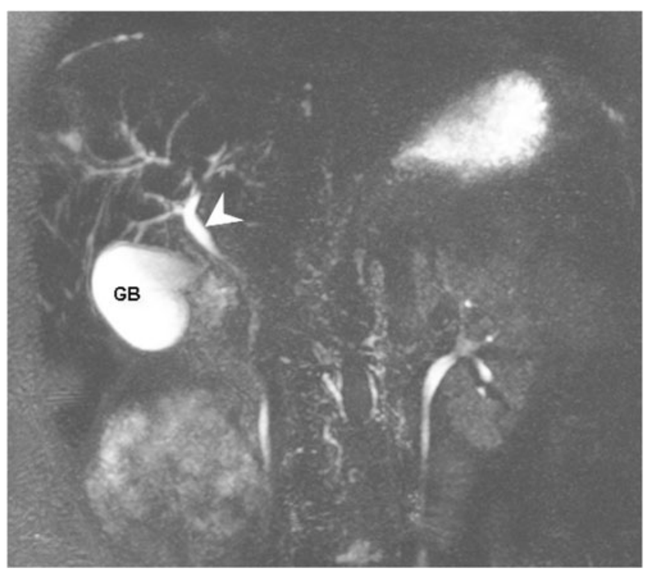

Fig. 5 Dark images with poor signal. Maximum-intensity projection image from 3-D FSE magnetic resonance cholangiopancreatography (MRCP) in an 8-year-old boy shows obscuration of most of the smaller ducts in the left lobe and the distal common bile duct from poor signal and darkening of the image. *Arrowhead* indicates common hepatic duct. *GB* gallbladder, *FSE* fast spin-echo

breathing artifacts. However, when acquired without significant breathing artifacts, it provides higher signal-to-noise ratio because each excitation in 3-D imaging covers the entire volume, adding signal averaging with each phase-encoding step [9]. Conversely each radial slab is acquired in a single breath-hold, which eliminates respiratory misregistration, and this method provides an overview of the pancreaticobiliary tree. Limitations of radial slabs include image blur from long echo train lengths, flow artifacts and in-plane volume averaging of ducts. Even though theoretically 3-D FSE has the ability to provide better signal-to-noise ratio, it is not always practical to achieve a high SNR because motion artifacts are often distributed in a complex fashion throughout the imaging volume [9]. On the other hand radial slabs are more likely to be acquired without significant motion artifacts thus providing better signal-to-noise ratio.

Studies comparing 3-D FSE and radial slabs in adults have mixed results, with some finding 3-D FSE superior and others finding radial slabs superior in depiction of ducts and in image quality [6–8]. In our study there was no significant difference in the ability of these sequences to show major duct segments and the order of branching in the right hepatic lobe. However, statistically significant superiority of radial slabs was seen in showing higher order of branching in the left hepatic lobe and visibility of the pancreatic duct. A possible explanation is that radial slabs are more likely to be acquired without significant artifacts, especially in children who are more prone to motion. Thus radial slabs are likely to provide better signal-to-noise ratio for smaller ducts in more examinations as compared to the 3-D FSE. Because of its proximity to the heart, the left lobe of the liver is more prone to motion. Both the left hepatic lobe and the pancreas, being midline structures, are also likely to get more artifacts from bowel as well as anterior abdominal wall motion. This statistically significant difference in visibility of order of branching in the left lobe, however, might not be clinically significant in most cases.

The 3-D FSE was free of significant artifacts in 31.6% of cases while radial slabs were free of significant artifacts in 22.8% of cases. The most common artifacts were caused by patient motion and breathing. We saw fewer artifact-free radial slabs than expected. This may be related to acquisition of radial slabs in smaller children during shallower phases of respiration in which it is more likely for one or more of the 13 slabs to be affected by breathing artifact. This, however, does not affect the overall quality of radial slabs because it is also likely that one or more of the 13 slabs obtained will be artifact-free.

Dark, grainy images with poor signal were noted much more commonly with 3-D FSE (24%) as compared to radial slabs (6.3%). This is contrary to the fact that 3-D FSE is more likely to have better signal-to-noise ratio. The precise reasons for this finding are not clear. Possibly the combination of field inhomogeneity and the dielectric effects at 3 T affect the 3-D FSE more than the single-shot FSE. It might be in part caused by motion artifacts from irregular breathing getting distributed over the entire 3-D volume, as discussed above. There is a learning curve for new users during the initial quality-optimization phase of a 3-T scanner. Artifacts can be reduced significantly with attention to the technique, good coaching of children on breathing and fasting at least 4 hours prior to the exam.

Our study provides comparison of 3-D FSE and radial slab MRCP sequences in children for the first time. Moreover, this study is done at 3 T, which is likely to be used more often for MRCP in the future based on its superior quality to 1.5 T, as shown in adult studies [10–13]. Using this information, clinicians may decide to use just one sequence rather than both, reducing the table time by approximately 5 min. Even one of these sequences with good quality images is sufficient to assess the anatomy of the pancreatobiliary tree. The choice of which sequence to use depends on the user and the clinical question. If the priority is visualization of the pancreatic duct or left hepatic ducts then radial slab is likely to be more useful. The use of secretin may improve visualization of pancreatic duct (PD) [1]. However, 3-T scanners have improved visualization of the pancreatic duct [10, 13], which may obviate the need for secretin. In the 16 MRCP studies showing normal ducts, the entire pancreatic duct was seen in most cases, indicated by the median score of 2 for the visibility of pancreatic duct. This is usually sufficient to exclude ductal anomalies and changes of chronic pancreatitis.

Our study has several limitations. This is a retrospective study in which both sequences were reviewed at the same time. Reviewing of both sequences one after another might have introduced bias about visibility of ducts on the later-reviewed sequence. The study involved consecutive children who had various pathology and ductal abnormalities. Abnormally dilated ducts in some of our cases might have limited our ability to compare as such. Nonetheless in 16/79 (20.2%) cases the pancreaticobiliary tree was of normal caliber without significant ductal abnormality. On separate analysis of this small but normal group the statistically significant difference persisted between the two sequences in showing order of hepatic duct branching and visibility of the pancreatic duct.

Conclusion

There is no significant difference in the visibility of major bile ducts on 3-D FSE and radial slab MRCP sequences performed at 3 T. Radial slab shows a higher order of branching in the left hepatic lobe and superior visibility of the pancreatic duct as compared to 3-D FSE in children. Radial slab is also more likely to have significant artifacts than 3-D FSE. Either of these sequences when of adequate quality is sufficient to assess the pancreaticobiliary anatomy. This allows for the possibility of skipping a sequence to save approximately 5 min of table time. Three-dimensional FSE with respiratory triggering might be the first choice in smaller children given their propensity to move. Radial slabs may be acquired first in older children and are likely to be diagnostic because of the ability of older children to breath-hold. Because the visibility of the pancreatic duct is better on radial slabs, they can also be acquired first when pancreatic duct abnormality is suspected.

Conflicts of interest None

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