

# Reference values of MRI measurements of the common bile duct and pancreatic duct in children

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## Abstract

**Background** Magnetic resonance imaging/cholangiopancreatography (MRI/MRCP) is now an essential imaging modality for the evaluation of biliary and pancreatic pathology in children, but there are no data depicting the normal diameters of the common bile duct (CBD) and pancreatic duct. Recognition of abnormal duct size is important and the increasing use of MRCP necessitates normal MRI measurements.

**Objective** To present normal MRI measurements for the common bile duct and pancreatic duct in children.

**Materials and methods** In this retrospective study we searched all children ages birth to 10 years in our MR urography (MRU) database from 2006 until 2013. We excluded children with a history of hepatobiliary or pancreatic surgery. We stratified 204 children into five age groups and retrospectively measured the CBD and the pancreatic duct on 2-D axial and 3-D coronal T2-weighted sequences. We performed statistical analysis, using logistic and linear regressions to detect the age association of the visibility and size of the duct measurements. We used non-parametric tests to detect gender and imaging plane differences.

**Results** Our study included 204 children, 106 (52%) boys and 98 (48%) girls, with a median age of 33 months (range 0–119 months). The children were distributed into five age groups. The common bile duct was visible in all children in all age groups. The pancreatic duct was significantly less visible in the youngest children, group 1 (54/67, 80.5%;  $P=0.003$ ) than in the oldest children, group 5 (22/22, 100%). In group 2 the pancreatic duct was seen in 19/21 (90.4%), in group 3 52/55 (94.5%), and in group 4 39/39 (100%). All duct measurements increased with age ( $P<0.001$ ;  $r$ -value $>0.423$ ), and the incremental differences between ages were significant. The measurement variations between the axial and coronal planes were statistically significant ( $P<0.001$ ); however these differences were fractions of millimeters. For example, in group 1 the mean coronal measurement of the CBD was 2.1 mm and the axial measurement was 2.0 mm; the mean coronal measurement of the pancreatic duct was 0.9 mm and the axial measurement was 0.8 mm.

**Conclusion** Our study provides normative measurements for the common bile duct and pancreatic duct for children up to age 10 years. The upper limits of the CBD and pancreatic duct increase with age, and the values range 1.1–4.0 mm for the CBD and 0.6–1.9 mm for the pancreatic duct.

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## Introduction

Pancreaticobiliary diseases are not uncommon in children and can be associated with a high morbidity and mortality if not properly and promptly diagnosed [1]. MRI and MR cholangiopancreatography (MRCP) have become the non-invasive gold standard imaging examination to best evaluate

these diseases in children [2–5]. With an emphasis on decreasing radiation dose in children, sonography followed by MRCP are the preferred modalities for imaging pediatric patients [6]. Ultrasound (US) evaluation of these systems is often an initial step, followed by further evaluation with MRCP. The methodical evaluation of biliary and pancreatic ductal sizes in MRCP examinations and recognition of abnormal duct size is vital for the correct imaging diagnosis, which directs management of these children. Therefore the increasing use of MRCP necessitates normal MRI measurements of these ducts in children.

Standard pediatric normative values are available for measurements of solid organs by US based on age, weight and height for the liver, spleen and kidneys [7–9]. A few publications document US-based normal pediatric values for bile ducts, pancreatic parenchyma, and the main pancreatic duct in healthy children [10–12]. However, normative data of bile duct and pancreatic duct measurements based on MRI are not available. MRI duct measurements have been published in the adult literature, and radiologists have adopted these values along with US measurements in the interpretation of pediatric MRCP [13]. However, normal measurements of ducts have not been explored in pediatric age groups based on MRCP sequences.

We present normal MRI measurements for the intra- and extra-hepatic bile ducts and pancreatic duct in children without any underlying hepatic or pancreaticobiliary disease.

## Materials and methods

### Patient selection

This retrospective study was approved by the institutional review board and complied with the Health Insurance Portability and Accountability Act (HIPAA). Using our radiology information system and the search software integrated with our picture archiving and communication system (PACS), we searched a large group of children who underwent MR urography (MRU). We included all children birth to 10 years old who underwent a MRU from 2006 to 2013 and had no underlying pancreatic or hepatobiliary disease of any etiology. We excluded children who had an underlying pancreatic, hepatic or biliary disease (e.g., biliary atresia, pancreas divisum), surgery involving any of these organ systems (e.g., cholecystectomy), or imaging features suggestive of a primary liver, pancreas or bile duct pathology. We did not include examinations with excessive motion that degraded the evaluation of the ductal systems. Upon review of the electronic medical records, children were excluded if they demonstrated abnormal liver enzymes or pancreatic enzymes, or any symptoms such as hepatomegaly, jaundice or right upper quadrant/epigastric tenderness. In our cohort 19 children were excluded based on these criteria. The following were reasons for

exclusion: motion artifact or incomplete examination ( $n=6$ ), duplicate examinations ( $n=4$ ; in children who had more than one MRU during our study period, only the first MRU was included), deceased ( $n=2$ ), pancreas divisum ( $n=2$ ), Caroli disease ( $n=1$ ), biliary atresia status post Kasai surgery ( $n=1$ ), variation in ampullary anatomy ( $n=1$ ), lack of images ( $n=1$ ), and Prune-Belly syndrome ( $n=1$ ).

The indications for the MR urography examinations were to evaluate primary urologic diseases. These were children who came for diagnostic examinations and did not require extra imaging or additional sedation beyond what was necessary to acquire the diagnostic examination. MR urography is a common diagnostic study performed at our institution, and this examination included sequences shared by our MRCP protocol. These MRU sequences were utilized for obtaining duct measurements. In addition, this cohort included a large number of children spanning a wide range of ages from infants to pre-teens.

The children were stratified into five age groups: group 1, <12 months (0–1 year); group 2, 12–23 months (1–2 years); group 3, 24–59 months (2–5 years); group 4, 60–95 months (5–8 years); and group 5, 96–120 months (8–10 years). Taking into account uneven distribution among the ages (in months), these age groups were chosen based on the fact that changes in body size and a significant amount of growth occur in the first two age groups. In our study group the majority of children had MRU under procedural sedation or anesthesia ( $n=184$ ). Only 20 children completed the MRU without sedation (8 in group 4; 12 in group 5). All of the children in the first three age groups had to be sedated. Prandial status was not controlled in the 20 non-sedated children, but the gallbladder distention was assessed. In the sedated children who were younger than 12 months, we required fasting for 3–6 h prior to MRI. Children 12 months and older were required to fast at least 8 h.

### Image analysis and measurements

All MR urograms were performed on either an Avanto (1.5 T) or Verio (3.0 T) magnet (Siemens Healthcare, Erlangen, Germany) utilizing a 6- or 9-channel body matrix coil in combination with a 24-channel spine coil. We used the following sequences for the measurements: coronal 3-D T2-weighted sequence with fat suppression (repetition time [TR]/echo time [TE] 2,500/694 ms; slice thickness 1 mm; matrix range  $320 \times 92$ – $320 \times 320$ ) and axial high-resolution turbo spin-echo T2-weighted sequence with fat suppression (TR/TE 4,260/99 ms; slice thickness 3 mm; matrix range  $256 \times 180$ – $384 \times 357$ ). The field of view (FOV) used in our routine MRU protocols is 200 to 500 mm<sup>2</sup>. It should be noted that the coronal T2-weighted single-shot fast spin-echo (SSFSE) sequence was not acquired in an oblique projection, which is routinely performed in our dedicated MRCP protocol.

A single pediatric radiologist with 5 years of experience (K.G.) measured all of the ducts. Measurements above or below two standard deviations from the mean were re-measured by a pediatric radiologist with 14 years of experience (S.A.) and were included in the final analysis. We performed three measurements in the same location for each duct, in the axial and coronal planes. The largest measurement was included in the final analysis. Specifically, duct measurements were taken at the mid-portion of the common bile duct (CBD) and the main pancreatic duct, in the head, mid-body and tail as shown in Fig. 1. For this project we studied children with normal pancreatic duct anatomy, and the main pancreatic duct (Duct of Wirsung) was measured. Children with pancreatic duct variations were excluded. Partial or complete pancreatic duct visibility was recorded. In cases where the pancreatic duct was only partly visualized, measurements were obtained only where it was visible. The measurements were performed directly on the PACS system without magnification of the images. The window level was not adjusted to aid in the measurements of the ducts.

In the non-sedated group of 20 children in whom a prandial state was not controlled, the gallbladder distention was assessed and graded on a Likert scale of 0–3, with 0 being contracted, 1 mildly distended, 2 moderately distended, 3 very distended. This grading scale is similar to that described in the publication of normal sonographic duct measurements by Hernanz-Schulman et al. [10].

#### Statistical analysis

We used the Shapiro-Wilk test to assess normal distribution of the data. Because most data were not normally distributed, nonparametric tests were used. We calculated the median, minimum and maximum values with 5th and 95th percentiles of ductal size according to age. We evaluated any associations between age and visibility of the ducts using logistic regressions. We used linear regressions to detect the association

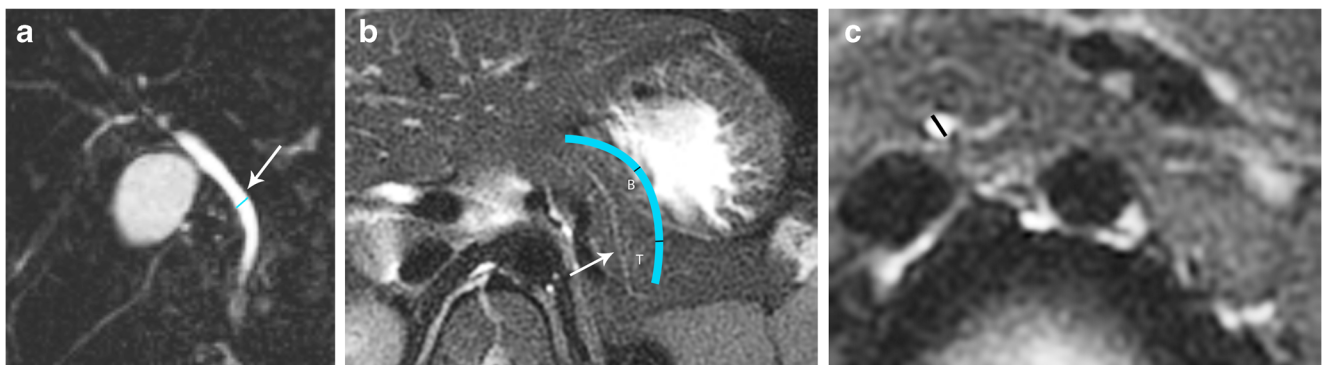
between age and size of the ducts. In addition, we used the Kruskal-Wallis test to evaluate for a change in measurements between the stratified age groups. Using the Mann-Whitney test, we assessed the relationship between gender and duct measurements. Wilcoxon tests were performed to compare the differences between coronal and axial measurements.

#### Results

The original data set included 223 children who had undergone MR urography. Nineteen children were excluded based on the criteria, yielding a final study group of 204 children: 106 (52%) boys, 98 (48%) girls, median age 33 months (range 0–119 months). The number of children in each of the five age groups was as follows: 67 in group 1 (age <12 months); 21 in group 2 (age 12–23 months); 55 in group 3 (age 24–59 months); 39 in group 4 (age 60–95 months); and 22 in group 5 (age 96–120 months). In the sedated children ( $n=184$ ) the prandial state was controlled. In the 20 non-sedated older children, in whom the prandial state was not controlled, grading of the gallbladder distension resulted in the majority 11/20 (55%) having a very distended gallbladder, 8/20 (40%) a moderately distended gallbladder and 1/20 (0.05%) a minimally distended gallbladder. None of the non-sedated children had a contracted gallbladder.

The common bile duct was visible in all children in all age groups. As presented in Table 1, the range of upper limits (95%) for common bile duct measurements for each age group was 3.0 mm (group 1), 2.7 mm (group 2), 3.1 mm (group 3), 3.5 mm (group 4) and 4.0 mm (group 5).

However, there was an association between age and visibility of the pancreatic duct where the pancreatic duct was visualized in 54/67 (80.5%) children in group 1 (age <12 months) compared with group 5 (age 96–120 months), where it was seen in all 22/22 (100%) children. This was statistically significant ( $P<0.003$ ).



**Fig. 1** Normal measurements taken on an MR urogram in a 4-year-old boy with a solitary kidney. **a** Coronal 3-D T2-weighted sequence shows measurements of the mid-portion of the common bile duct (blue line, arrow). **b** Axial T2-weighted sequence with fat suppression shows the

normal pancreatic duct (arrow). The parallel blue line illustrates the pancreatic duct and how it was measured in the body (B) and tail (T) of the pancreas; **c** Axial T2-weighted sequence with fat suppression depicts how the common bile duct was measured (black line) in the axial plane

**Table 1** Normative values of the common bile duct based upon age

Age group	n	Mean (mm) +/- SD	Range (mm)	Percentiles (mm)		
				5th	50th	95th
Age group 1 (0 to <12 months)	67	2.1 +/- 0.5	1.1–3.2	1.3	2.1	3
Age group 2 (12–23 months)	21	2.1 +/- 0.4	1.3–2.7	1.3	2.2	2.7
Age group 3 (24–59 months)	55	2.5 +/- 0.4	1.7–3.3	1.7	2.4	3.1
Age group 4 (60–95 months)	39	2.8 +/- 0.4	1.9–3.8	2.1	2.8	3.5
Age group 5 (96–120 months)	22	3.1 +/- 0.4	2.3–4.0	2.4	3.1	4

SD standard deviation

The pancreatic duct was seen in 19/21 (90.4%) children in group 2, 52/55 (94.5%) in group 3, and 39/39 (100%) in group 4.

The pancreatic duct, when visualized, was documented as being partly or completely visible. In the youngest children, in group 1, the pancreatic duct was completely visualized only in 42/55 (76.4%), whereas the percentage of complete visibility was higher in older children. The pancreatic duct was completely visualized in 19/19 (100%) children in group 2, 48/52 (92.3%) children in group 3, 37/39 (94.9%) children in group 4 and 18/22 (81.8%) children in group 5. However, no association was statistically demonstrated between age and partial or complete pancreatic duct visibility ( $P=0.290$ ). When the pancreatic duct was partly visible, its most common location was in the head of the pancreas. As presented in Table 2, the upper limits of normal (95%) for pancreatic duct measurements in the head of the pancreas for each age group

are 1.3 mm (group 1), 1.5 mm (group 2), 1.5 mm (group 3), 1.7 mm (group 4) and 1.9 mm (group 5).

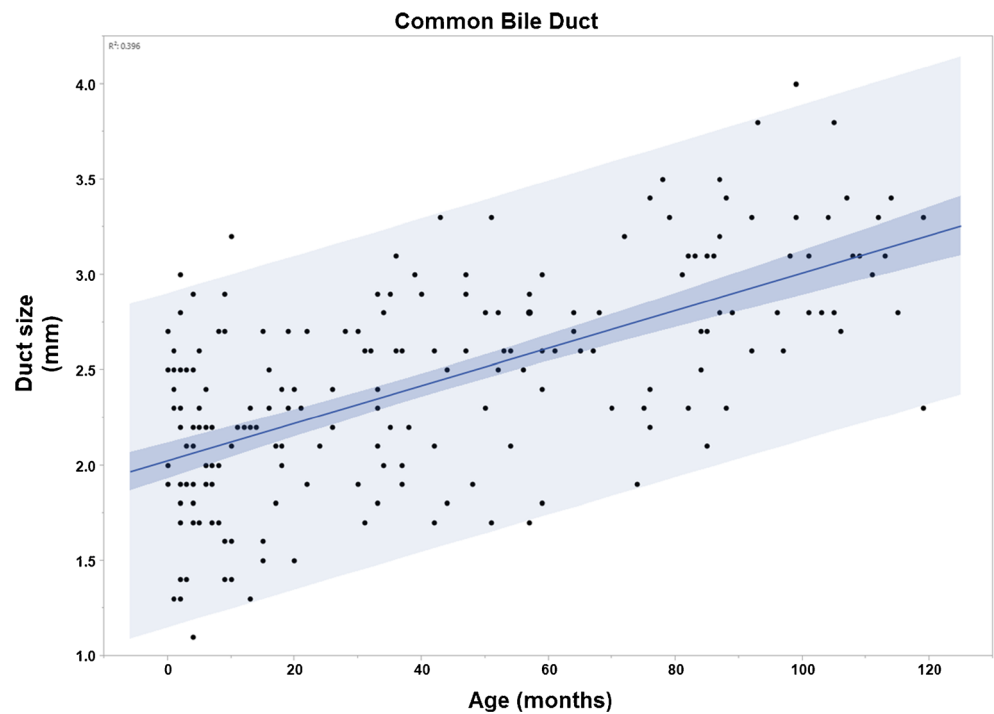
No statistical difference was established between gender and overall bile or pancreatic duct measurements ( $P$ -values > 0.398). With linear regression, there is a statistically significant increase in size of the common bile duct and pancreatic duct with increasing age ( $P > 0.001$  and  $r$ -values ranging from 0.423 to 0.727). The median, minimum, maximum, 5th percentile values, 95th percentile values, and standard deviations of the common bile duct and pancreatic duct sizes are described in Tables 1 and 2. The sizes of the common bile duct and pancreatic duct were plotted with the age groups of the children, and results are provided in Figs. 2 and 3. There was a statistically significant ( $P < 0.001$ ) incremental increase in duct size between each of the stratified age groups, as well.

**Table 2** Normative values of the pancreatic duct (PD) sizes based upon age

Age group	Duct	n	Mean (mm) +/- SD	Range (mm)	Percentiles (mm)		
					5th	50th	95th
Age group 1 (0 to 12 months)							
	PD at the head	67	0.8 +/- 0.2	0.6–1.3	0.6	0.9	1.3
	PD at the body		0.7 +/- 0.2	0.5–1.6	0.6	0.6	1.2
	PD at the tail		0.7 +/- 0.2	0.5–1.1	0.6	0.6	1.1
Age group 2 (12–23 months)							
	PD at the head	21	1.0 +/- 0.3	0.6–1.5	0.6	1	1.5
	PD at the body		0.9 +/- 0.3	0.6–1.5	0.6	0.9	1.5
	PD at the tail		0.8 +/- 0.2	0.6–1.4	0.6	0.9	1.4
Age group 3 (24–59 months)							
	PD at the head	55	1.1 +/- 0.3	0.6–1.7	0.6	1.2	1.5
	PD at the body		1.1 +/- 0.3	0.6–1.7	0.6	1.2	1.5
	PD at the tail		1.1 +/- 0.3	0.6–1.5	0.7	1.1	1.4
Age group 4 (60–95 months)							
	PD at the head	39	1.4 +/- 0.3	0.7–2.1	0.9	1.4	1.7
	PD at the body		1.3 +/- 0.2	0.7–1.7	0.7	1.4	1.7
	PD at the tail		1.3 +/- 0.2	0.7–1.8	0.9	1.3	1.7
Age group 5 (96–120 months)							
	PD at the head	22	1.4 +/- 0.3	0.9–1.9	0.9	1.4	1.9
	PD at the body		1.4 +/- 0.3	0.9–1.9	0.9	1.3	1.9
	PD at the tail		1.4 +/- 0.3	0.9–1.9	0.9	1.3	1.9

SD standard deviation

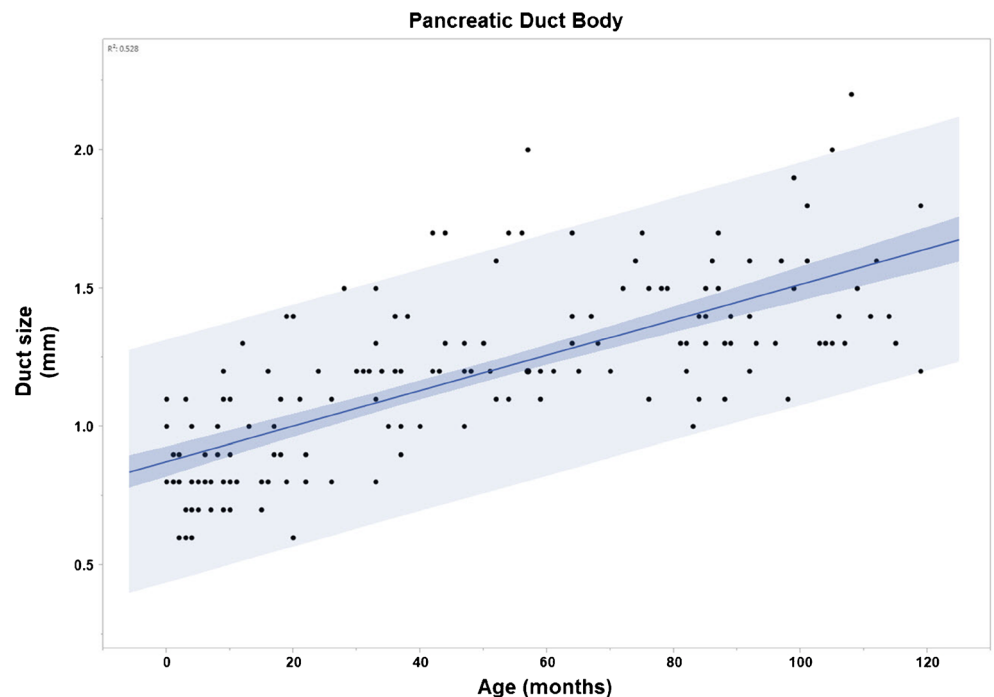
**Fig. 2** Common bile duct, size vs. age. Scatter plot of the common bile duct measurements shows a relationship between duct size and patient age. There is a gradual increase in size of the common bile duct with age that is statistically significant (linear regression:  $P < 0.001$ ;  $r$ -value 0.629)



When assessing the plane of imaging and duct measurements, we identified a statistically significant difference between measurements in the coronal and axial planes for the common bile duct and pancreatic duct ( $P$ -values  $< 0.001$ ). The common bile duct measured larger in the coronal plane. The actual difference in measurements between axial and coronal planes is on the order of fractions of millimeters. For example, in group 1 the common bile duct had a mean coronal

measurement of 2.1 mm compared to an axial measurement of 2.0 mm. Similarly, in group 1 the pancreatic duct mean measurement in the coronal plane was 0.9 mm as opposed to 0.8 mm in the axial plane. Subjectively based on visual inspection alone, the pediatric radiologists found the axial images superior for evaluation of the pancreatic duct and the coronal images superior for evaluation of the common bile duct.

**Fig. 3** Pancreatic duct, size vs. age. Scatter plot of the pancreatic duct measurements shows the relationship between duct size and patient age. There is a gradual increase in size of the pancreatic duct with age that is statistically significant (linear regression:  $P < 0.001$ ;  $r$ -value 0.727)





## Discussion

Many pediatric liver and pancreatic disorders can affect the hepatobiliary and pancreatic ducts. Published normative data on biliary and pancreatic duct measurements have been assessed by US. However, the pancreatic duct is not generally seen on US when using standard common 3- to 5-MHz sector transducers and can only be visualized using a high-resolution transducer, with which the pancreatic duct can be seen within the pancreatic body [11]. US evaluation of pancreatic duct size was performed by Chao et al. [12], who compared the pancreatic duct size in normal children and in children with pancreatitis. Measurement of the common bile duct has also been established in the pediatric population utilizing US. The common bile duct in neonates and children was found to be smaller (not measuring more than 2.5–3.0 mm) than that in adults [10].

MR cholangiopancreatography (MRCP) has become the noninvasive gold standard for evaluation of the pancreatic and bile ducts, and it is complementary to US in the evaluation of pancreaticobiliary anomalies. MRCP data in children have established the feasibility of performing MRCP [14]. In addition, the literature has shown efficacy and value of 3T imaging in duct visibility, especially the third- and fourth-order intrahepatic duct branches; MRCP studies have also compared commonly used T2-weighted sequences [15–18]. Therefore, we know that MRCP is an excellent method in evaluating ducts in children, but there has been no established reference for MRI duct measurements. Our study is unique in that the evaluation of the normal pancreatic and common bile duct was performed using MR sequences in our institutional MRCP protocol, although they may not be commonly used sequences at other centers. Familiarity with the normative values of duct sizes across age groups will enable us to better recognize duct abnormalities. This becomes particularly important when there is only minimal duct size variation from pathology.

In addition to providing normative data of duct measurements, we have shown important information regarding the visibility of the pancreatic duct in young children, particularly in infants. It is presumed that the pancreatic duct is difficult or impossible to visualize in infants and small children without the use of MRI enhancements such as secretin. Secretin-enhanced MRCP has been reported to improve visualization of the pancreatic duct [14, 15, 19, 20]. Yet our MRI data, obtained without secretin, show that in the youngest age group (younger than 12 months) the pancreatic duct could be visualized in 80.5% of cases. When it was seen in these small children, it was likely to be seen in its entirety.

When examining the duct size with age, the CBD increases in size with age, and the size increase is relatively slow over time. This mirrors what has been described in the sonographic literature in children; however, the MRI measurements are overall larger than those obtained by US. Hernanz-Schulman

et al. [10] found the mean CBD measurement in children birth to 12 months to be 0.74 mm, whereas our data show the mean CBD measurement to be 2.0 mm in this same age group. This discrepancy may be attributed to the fact that the duct resolution on US is greater than on MRI/MRCP.

In our study, the pancreatic duct size also increased with age, which is similar to findings by Chao et al. [12] in normal children. However, we found the mean pancreatic duct measurements on MRI to be smaller than those obtained by US. For example, in groups 2 and 3 (ages 12–23 months and 24–59 months) the mean diameters of the pancreatic duct in the mid-body of the organ were 0.9 mm and 1.1 mm, respectively. However, using US measurements, Chao et al. [12] reported a mean of 1.1 mm in children 1–3 years old and 1.4 mm in children 4–6 years, with an overall range across 0–10 years of 0.9–1.9 mm [12]. Our range of pancreatic duct measurements was 0.74–1.3 mm. We cannot equally compare US with MRI data. There are inherent differences in the equipment, technology, performance of studies, and method of duct measurement. US data by Chao et al. [12] were based on a single measurement of the pancreatic duct in the mid-body of the pancreas, and our data were based on three separate pancreatic duct measurements in the head, body and tail of the pancreas [10]. On ultrasound, the anterior-to-posterior wall of the duct was used for measuring. On MRI, we may not actually be seeing the wall of the duct. If the MRI sequences are fat-suppressed, we often see the lumen of the duct and not actually the wall of the duct. Without fat suppression, the wall can be identified and measurements include the walls, perhaps yielding more accurate results. The signal within the lumen of the duct serves as a guide to the borders of the structure. Therefore, MRI measurements could result in an underestimate or, as in the case of the CBD, an overestimate of the actual size of the duct.

Our study had other limitations. This study was performed retrospectively because there was no justification for subjecting young children with no known disorder of the biliary or pancreatic ducts to MRCP or sedation. The literature on US measurements is based on prospective data. Another limitation of conducting the study retrospectively is that the patient population was skewed with larger numbers of patients in the lower age groups. Our patient age stratification may have also contributed to the greater number of younger children. The study could have included a larger cohort of children in the older age group to provide homogeneity to the study population. Our patient population was derived from children undergoing MRU. The argument could be made that this patient population is not truly normal because they were being evaluated for genitourinary abnormalities. However, our exclusion criteria helped streamline our population so that we had children who did not have a primary biliary, pancreatic or hepatic abnormality. That allowed us to simulate a normal population for the measurements of the ducts. Although the prandial state of the 20 non-sedated children was not controlled, the

gallbladder was moderately to very distended in all except one and was not likely to have a negative impact on overall CBD measurements [10]. Although the measurement differences between the axial and coronal planes were statistically significant ( $P < 0.001$ ), these differences were small, on the order of fractions of a millimeter.

An additional limitation includes inaccuracy in measurements, especially when measuring ducts smaller than a millimeter, and this may account for the differences between our findings and those in the ultrasound literature. The resolution of the images was a limitation for accurate measurements at the sub-millimeter level, especially considering we did not have the optimal slice thickness or sequences for measurement of the CBD and pancreatic duct, such as maximum-intensity projection radial (centered at the CBD) and coronal oblique (aligned to the pancreatic duct) T2-weighted images. This is a retrospective study based on MRI primarily for the urinary tract. However, the fact that sequences similar to our institutional MRCP protocol were employed provided a unique opportunity for evaluating the pancreaticobiliary ducts in a large cohort of pediatric patients without any disease of these ducts. The sequences were designed to visualize the urinary tract, and accordingly the slice thickness and resolution were optimized for the urinary tract, not for the CBD or pancreatic duct. This would have an effect on our absolute measurements of very small ducts. Therefore, our results need to be viewed with this limitation in mind. Ultrasound does have a higher resolution and the absolute measurements for the smaller ducts may be more accurate using US. However, in daily practice we are often faced with making diagnostic decisions regarding the biliary and pancreatic ducts based on MRI/MRCP examinations. Thus our tables of duct measurements may serve as approximate guides for differentiating abnormal from normal.

## Conclusion

MRCP has become an important noninvasive imaging modality in the evaluation of pancreaticobiliary diseases in children of all ages. Normative MRI data of CBD and pancreatic duct measurements in children up to 10 years of age may provide a useful reference for radiologists. The CBD is the most visible duct across all ages and the pancreatic duct, although difficult to see in children younger than 12 months, was confidently identified in a significant proportion of the smallest children. The upper limits of the CBD and pancreatic duct increase with age, and the values range 1.1–4.0 mm for the CBD and 0.6–1.9 mm for the pancreatic duct.

**Conflicts of interest** None

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