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Published in:
Pediatric transplantation

DOI:
10.1111/petr.14002

Received: 2 November 2020 | Revised: 27 January 2021 | Accepted: 23 February 2021
DOI: 10.1111/petr.14002

ORIGINAL ARTICLE

WILEY

Assessment of hepatic artery anatomy in pediatric liver transplant recipients: MR angiography versus CT angiography

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Abstract

During LT screening, children undergo CTA to determine hepatic artery anatomy. However, CTA imparts radiation, unlike MRA. The aim was to compare MRA to CTA in assessing hepatic artery anatomy in pediatric LT recipients. Twenty-one children (median age 8.9 years) who underwent both CTA and fl3D-ce MRA before LT were retrospectively included. Interreader variability between 2 radiologists, image quality, movement artifacts, and confidence scores, were used to compare MRA to CTA. Subgroup analyses for ages <6 years and ≥6 years were performed. Interreader variability for MRA and CTA in children <6 years was comparable (k = 0.839 and k = 0.757, respectively), while in children ≥6 years CTA was superior to MRA (k 1.000 and k 0.000, respectively). Overall image quality and confidence scores of CTA were significantly higher compared to MRA at all ages (2.8/3 vs. 2.3/3, p = .001; and 2.9/3 vs. 2.5/3, p = .003, respectively). Movement artifacts were significantly lower in CTA compared to MRA in children ≥6 years (1.0/3 vs. 1.7/3, p = .010, respectively). CTA is preferred over fl3D-ce MRA for the preoperative assessment of hepatic artery anatomy in children receiving LT, both at ages <6 years and ≥6 years.

KEYWORDS
computed tomography angiography, liver transplant, MRI angiography, pediatrics

1 | INTRODUCTION

Currently, the only therapeutic option for children with ESLD is LT. Overall survival of the patient and the liver graft directly depends on several potential complications during and after transplantation. The most threatening complications are arterial and venous thrombosis, anastomotic stenosis, and kinking of vessels.[1] Other important perioperative concerns are extensive hemorrhage, infection, and early rejection. To minimize the perioperative complication risk, a thorough preoperative work-up is necessary.

Prior to LT, the anatomy and patency of the hepatic artery, portal vein, liver veins, and inferior caval vein need to be assessed. Of these, the hepatic artery anatomy is the most challenging to image. Hepatic artery variants, such as accessory vessels or replacement of the artery where the hepatic artery origin is not the coeliac trunk, have been reported to occur in up to 45% of patients.[2,3] By identifying vascular variants and vessel caliber, the hepatobiliary surgeon is able to select the largest caliber artery for anastomosis, decide on suitability for a match with a living donor graft, and plan required microvascular reconstructions.[4]

Abbreviations: CTA, computed tomography angiography; DUS, Doppler-ultrasound; ESLD, end-stage liver disease; fl3D-ce, fast low angle shot 3D contrast enhanced; ICRP, International Commission on Radiological Protection; LDLT, living donor liver transplantation; LT, liver transplantation; MRA, magnetic resonance angiography; SNR, signal to noise ratio.

DUS in children provides high resolution information on liver vascular anatomy, patency, and flow velocity.[5,6] Although diagnostic performance of a complex ultrasound is operator dependent, assessment of pediatric liver anatomy is generally highly feasible due to the small size and lean body mass of children. A study comparing DUS and CTA to operative findings for the detection of both arterial and venous vascular anomalies reported an accuracy of 92% for DUS.[7] However, they also stated that ultrasound was inferior in evaluating precise hepatic artery anatomy compared to CTA.[7] In our experience, even in optimal conditions, small but clinically relevant accessory hepatic artery branches can potentially be misinterpreted with ultrasound. A second drawback of DUS is that the transplant surgeon is not able to easily review the anatomy on DUS images.

Based on limited studies in children, CTA appears to be the most suitable method to determine hepatic artery anatomy prior to LT in children.[8,9] CTA is fast, provides high resolution imaging, and is generally more accessible than MRA. However, CTA imparts a radiation dose, which is thought to increase the lifetime risk of malignancy, especially in children.[10] On the other hand, MRA is very susceptible to movement artifacts. While children younger than 6 months can be scanned using the 'feed and wrap' method,[11] and children aged 6 years and older can lie reasonably still, to avoid movement artifacts MRA generally requires anesthesia between the ages of 6 months and 6 years for prolonged examinations.[12] The necessity for radiation-based diagnostics such as CTA should regularly be reassessed to determine if other non-radiation techniques such as MRA can replace them, whilst also taking into account the need for anesthesia in MRA. Even so, it is important that a high accuracy technique such as CTA is not replaced by MRA only to avoid radiation, at the expense of lower image quality with potentially more movement artifacts.

Comparative studies of CTA and MRA in children are rare because it is ethically difficult to justify children to undergo two separate imaging studies, especially when general anesthesia and intravenous contrast are needed. This is reflected by the sparse literature for assessment of hepatic artery anatomy in children, with only one study consisting of 58 children with biliary atresia (median age 12 months) advocating CTA instead of MRA.[9] Although indicative, their results cannot be readily extrapolated to older and larger children in whom MRA may perform better.

In order to test the hypothesis that CTA is preferred over MRA in both young and older children, we compared MRA to CTA for the assessment of hepatic artery anatomy in pediatric liver transplant recipients.

2 | METHODS

This study was performed at our national pediatric LT center. Patients were selected from our prospectively maintained institutional database, and the data were retrospectively analyzed. The study was approved by the local institutional review board (IRB number: 201900703), and the need for patient informed consent was waived.

TABLE 1 Demographics of included patients

Patients (*n*)	21
Age at time of CTA, median years (IQR)	8.9 (0.9–11.8)
Gender (male: female)	10:11
CTA (*n*)	21
MRA (*n*)	21
Time between CTA and MRA, median days (IQR)	16 (−45 to 174)

Abbreviations: CTA, computed tomography angiography; IQR, Interquartile range; LT, Liver transplantation; MRA, magnetic resonance; *n*, number; *n*, number of patients.

Children fulfilling the following criteria were included in the study: (a) LT performed between 2002 and 2019; (b) preoperative CTA available prior to LT; and (c) preoperative abdominal gadolinium enhanced MRA performed prior to LT. At our institute, the current standard preoperative work-up consists of CTA for hepatic artery anatomy, and both CTA and DUS for analysis of vascular patency, venous anatomy and abdominal variants. MRI/MRA is only generally performed for characterization of focal liver lesions.

Twenty-one patients (11 females) were identified with a median age at the time of CTA of 8.9 years (IQR 0.9–11.8 years, Table 1). Nine children were <6 years old, 12 children ≥6 years old. The median interval between CTA and MRA was 16 days (IQR −45–174 days). For MRA, all children <6 months were scanned using the feed and wrap technique (*n* = 5), all children between 6 months and 6 years were scanned under general anesthesia (*n* = 3). Above the age of 6 years, no specific measures were taken other than careful instruction of patients and caretakers (*n* = 12). For CTA, no children underwent a feed and wrap technique or anesthesia. The primary diseases necessitating LT in the study population can be found in Appendix 1. Indications for MRI/MRA were characterization of focal liver lesions in children with cirrhosis (*n* = 10), pre-LT MRA in combination with CTA (*n* = 8), known hepatoblastoma (*n* = 2), and assessment of extension of portal vein thrombosis in a child with cirrhosis (*n* = 1).

2.1 | MRA and CTA technique

MRA sequences were acquired on 1.5 T (*n* = 19) or 3 T (*n* = 2) MRI machines. Specific MRI machines can be found in Appendix 2. MRA consisted of fl3D-ce sequences with a median ST of 2.5 mm (IQR 2–3 mm). Further details of the performed MR sequences are given in Appendix 3.

CTA exams were performed without sedation and with breath-hold if possible. Patients were scanned from diaphragm to iliac crest. CT machines are listed in Appendix 4. Tube potential (kV) and tube current (mAs) were adjusted according to patient weight (Appendix 5). Dose-length-product (DLP) was retrieved and converted to mSv to reflect effective dose according to the ICRP standards.[13] Median CTA radiation dose was 0.46 mSV (IQR 0.19–0.91 mSv). Isotropic datasets were available for all patients. Median slice thickness was 1.5 mm (IQR 1–2 mm). Axial reconstructions were provided, and radiologists were allowed to make further multiplanar reconstructions as they saw fit.

2.2 | Data collection

CTA and MRA studies were read separately in a random order by two radiologists (RD, 7 years' dedicated pediatric LT imaging experience, and RH, 3 years' dedicated pediatric LT imaging experience) using a clinical picture archiving and communication system (PACS, Carestream). Studies were anonymized and readers were blinded to other imaging studies. Direct comparison with the matching CTA or MRA was not allowed.

Readers were asked to assess the following variables: (a) anatomy of the hepatic arteries according to the Michels classification as a way to describe variations in anatomy for the purpose of this study[2,3]; (b) movement artifacts (none, some, clinically relevant); (c) overall image quality of the study (poor, intermediate, good); and (d) level of confidence in accurately specifying hepatic artery anatomy (low, intermediate, high). Variables b-d were used to compare the quality of MRA with CTA.

2.3 | Statistics

Continuous variables were summarized using mean and standard deviation (SD) when normally distributed, and using median and IQR when not normally distributed.

Cohen's kappa statistics (κ) was calculated to assess interreader and intramodality agreement for arterial anatomy and was classified as poor for $\kappa < 0.20$, fair for κ 0.21–0.40, moderate for κ 0.41–0.60, good for κ 0.61–0.80, and excellent for κ 0.81–1.00.[14]

The overall image quality scores from both readers were averaged and were subsequently compared between CTA and MRA using the Wilcoxon signed-rank test. Level of confidence for the accurate assessment of hepatic artery anatomy and movement artifacts were assessed similarly.

Results were given for all ages, as well as categorized for children <6 years and those ≥6 years old. The age cut off was set at 6 years old because children <6 years old underwent either general anesthesia or the feed and wrap method during the scan, whereas children ≥6 years old were only asked to lie still with the help of parents and distraction techniques.[11,12] Comparisons between subgroups were made using the student's T-Test.

All statistical analyses were performed using SPSS for Windows (version 26, IBM). The level of significance was set at $\alpha < 0.05$.

3 | RESULTS

3.1 | Interreader variability for MRA and CTA

For all ages combined, interreader agreement for CTA was higher than MRA (*k* 0.889 vs. *k* 0.484, respectively, Table 2). At ages <6 years old the difference between CTA and MRA was not substantial (*k* 0.757 vs. *k* 0.839), while at ages ≥6 years old the difference was apparent (*k* 1.000 vs. *k* 0.000). Figure 1 demonstrates a concordant case, and Figure 2 shows a discrepant case.

Regarding MRA, there were 6 (28.6%, 6/21 studies) inconclusive cases due to inability to reliably assess the anatomy by one (*n* = 5) or both readers (*n* = 1).

Regarding CTA, there was one (4.8%, 1/21 studies) discrepancy between the readers concerning Michels classification type 9 (ie, common hepatic artery originating from the superior mesenteric artery) versus type 1 (ie, conventional anatomy) in a child aged 6.7 months.

3.2 | Image quality, movement artifacts, and confidence of correct hepatic artery anatomy designation

CTA was superior to MRA in terms of study image quality (mean 2.8/3 vs. 2.3/3, respectively, $p = .001$), both in the total study population, and in the age-subgroups (Table 3). Image quality of MRA in children aged <6 years was significantly inferior to MRA

TABLE 2 Variability of hepatic artery anatomy assessment on CTA and MRA

	CTA, between readers	MRA, between readers
All ages		
Total number of patients (*n*)	21	21
Agreement (*n*)	20/21	15/21[a]
Disagreement (*n*)	1/21	6/21
kappa	0.889	0.484
<6 years		
Total number of patients (*n*)	9	9
Agreement (*n*)	9/10	8/9[a]
Disagreement (*n*)	1/10	1/9
kappa	0.757	0.839
≥6 years		
Total number of patients (*n*)	12	12
Agreement (*n*)	12/12	7/12
Disagreement (*n*)	0/12	5/12
kappa	1	0.000

Abbreviation: *n*, number of patients.
[a]In 1 case both readers agreed that the anatomy was not assessable

FIGURE 1 CTA and MRA in a 3-year-old boy. 3D reconstruction and native images, CT (slice thickness 3 mm) on the left, MR (slice thickness 2 mm) on the right. Michels type 3 anatomy (replaced right hepatic artery originating from the superior mesenteric artery, arrows) correctly identified on both modalities

quality in children ≥6 years old (mean 1.9/3 vs. 2.5/3, respectively, p = .013).

Movement artifacts were generally considered mild for CTA and MRA (mean 1.2/3 and 1.5/3, respectively). In children ≥6 years old, CTA had significantly less movement artifacts than MRA (mean 1.0/3 vs. 1.7/3, respectively; p = .003). The difference between the MRA movement artifact score in children aged <6 years and the MRA movement artifact score of children aged ≥6 years (mean 1.2/3 vs. 1.7/3, respectively) was not statistically significant.

The reader confidence score for determining hepatic artery anatomy was significantly higher for CTA compared to MRA, both in the total study population (mean 2.9/3 vs. 2.5/3, p = .001) and in the age-subgroups (Table 3). The difference between the MRA confidence score of children aged <6 years and the MRA confidence score of children aged ≥6 years (mean 2.3/3 and 2.5/3, respectively) was not statistically significant.

4 | DISCUSSION

The aim of the current study was to compare MRA to CTA in assessing hepatic artery anatomy in children who need to undergo an LT. Overall better interreader variability, higher image quality scores, higher confidence levels, and lower movement artifact scores were observed for CTA compared to MRA. Importantly, this study showed that CTA is preferable over MRA both in children aged younger than 6 years, and those aged 6 years and older.

To the best of our knowledge, this is the first study in a population of pre-LT children >6 years old that underwent both MRA and CTA to assess hepatic artery anatomy. A current lack of studies in this population may be due to ethical reasons, as it is difficult to justify—especially when intravenous contrast and general anesthesia are necessary—to prospectively perform both imaging studies in children. By demonstrating that CTA is superior to currently employed MRA sequences, this study justifies the use of radiation-based CTA both in younger and older children, instead of non-radiation MRA as the alternative. These results are important for daily clinical practice in specialized pediatric liver transplant hospitals.

It is likely that CTA performed better than MRA because of its superior spatial resolution. Superior spatial resolution is especially relevant in children <6 years old, because these smaller children have smaller blood vessels, and therefore require higher spatial resolution compared to those aged 6 years and older. This notion is supported by a lower perceived image quality for MRA in children aged <6 years compared to children aged ≥6 years old. However, despite the higher image quality for MRA in older children, a poor interreader agreement for MRA in the older age group suggests that the perceived higher image quality alone does not mean that hepatic artery anatomy assessment is done better. Therefore, MRA is also less suitable than CTA in this older age group.

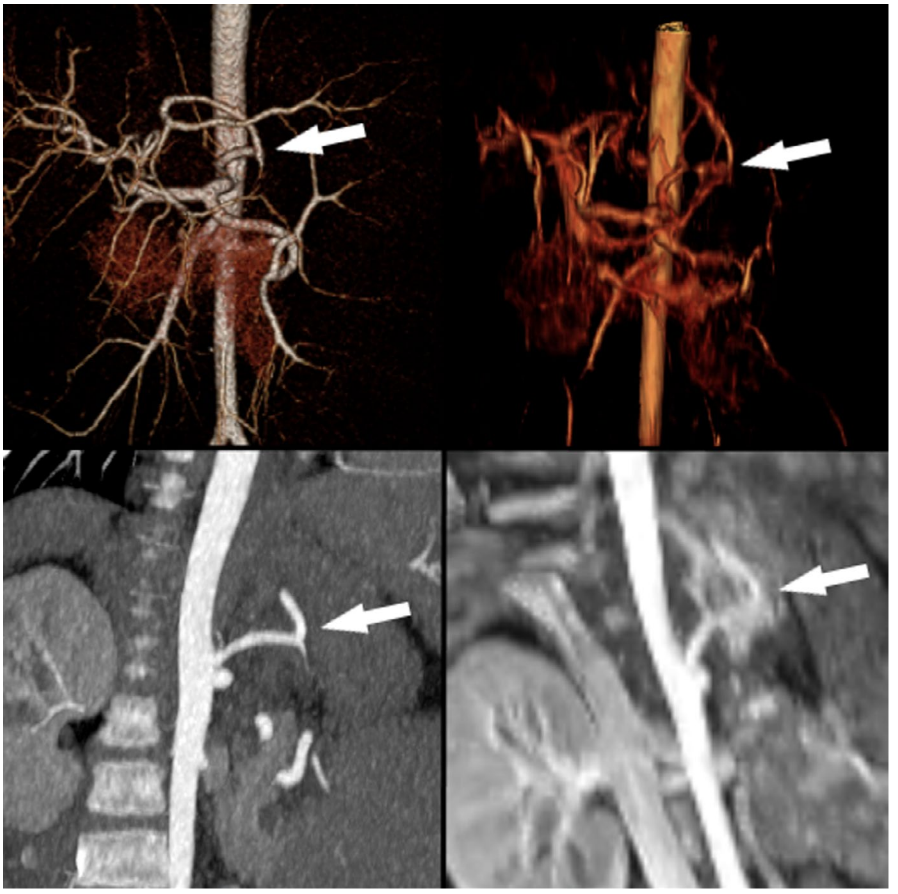

FIGURE 2 CTA and MRA in a 10-year-old boy. 3D reconstruction and native images, CTA on the left, MRA on the right. Michels type 2 anatomy (replaced left hepatic artery originating from the left gastric artery, arrow) is clearly visible on 1 mm slice thickness isotropic CTA and was correctly detected on CTA by both readers. On 3 mm slice thickness MRA one reader could not confidently assign the Michels type, whereas the other did conclude Michels type 2. The coronal-oblique reconstruction demonstrates the replaced artery (arrows)

TABLE 3 Comparison of CTA and MRA: study image quality, movement artifacts, and confidence in determining hepatic artery anatomy[a]

	CTA, mean (SD)	MRA, mean (SD)	*p* value
Study image quality (scale 1–3; poor to good)			
All ages	2.8 (0.4)	2.3 (0.6)	.001
<6 years	2.6 (0.5)	1.9 (0.6)	.016
≥6 years	2.9 (0.2)	2.5 (0.5)	.031
Movement artifacts (scale 1–3; none to clinically relevant)			
All ages	1.2 (0.5)	1.5 (0.5)	.188
<6 years	1.4 (0.7)	1.2 (0.4)	.285
≥6 years	1.0 (0.2)	1.7 (0.5)	.010
Confidence in hepatic artery anatomy (scale 1–3; low to high)			
All ages	2.9 (0.2)	2.5 (0.7)	.003
<6 years	2.8 (0.4)	2.3 (0.7)	.024
≥6 years	3.0 (0.0)	2.5 (0.7)	.039

Abbreviations: CTA, computed tomography angiography; MRA, magnetic resonance angiography; SD, standard deviation.
[a]Scores averaged between two radiologists.

Movement artifacts seemed to be of limited impact in the current study, with overall low movement artifact scores. However, the small but significant difference of CTA compared to MRA in children aged 6 years and older may still be part of the reason that CTA performed better in this older age group. Optimal patient and parent preparation using a mock MRI, virtual reality glasses or a play specialist, may potentially improve movement artifacts in older children, and for some children the age at which general anesthesia is necessary might be decreased.[12]

In order to objectively compare CTA and MRA, and to add important information to previous pediatric and adult studies which only focused on discrepancies in vascular anatomy,[7,15,16] we employed interrater variability. Although this aided in comparing CTA and MRA, interrater variability alone is insufficient, which was exemplified by an MRA case in which both readers agreed that they could not assess hepatic artery anatomy, but which was not reflected in Cohen's kappa test. We therefore also employed image quality scores, in a similar fashion as Yu et al.,[9] and added further quality scores for confidence level and movement artifacts. Pediatric LT literature comparing CTA to MRA for the assessment of hepatic artery anatomy is sparse. The only previous pediatric study comparing CTA to MRA dates from 2009 and showed an accuracy of preoperative CTA of 93% versus 84% for MRA in 57 children with biliary atresia with a median age of 12 months.[9] Our results support their findings, and add that CTA also performs better than MRA in older children.

The current study has several limitations. First, because CTA and MRA are rarely both performed preoperatively in children undergoing LT, a long inclusion period was necessary to optimize the size of the study population of this retrospective study. This resulted in a variation of CT and MRI machine, minor variations in fl3D-ce MRA sequence and CTA settings, and thinner slice thicknesses for CTA compared to MRA. Although this limits comparison of the two modalities to some extent, the differences in slice thickness do represent clinical practice. Improving MRA slice thickness and voxel size should be attempted, but this will require a compromise between acquisition time, spatial resolution, and SNR. Higher resolution imaging takes longer and will therefore be more susceptible to movement artifacts. Long acquisition times may also result in poorly executed breath holds (lasting up to 20 seconds), and less accurate contrast phases (ie, not only the arteries but also the veins can contain gadolinium). With 3 T MR machines currently being more widely available, these may replace 1.5 T MR machines to acquire more signal whilst achieving shorter acquisition times.[17] In addition, an important recent innovation in MRA technique is time-resolved MRA based on keyhole imaging using radial sampling schemes (eg, time-resolved imaging with stochastic trajectories, TWIST, Siemens Healthcare). This technique, which allows for a contrast-enhanced MRA to be performed in 1–5 s, has recently been shown to perform equally to CTA in adults for the assessment of hepatic artery anatomy.[18] Consequently, it should also be subject of future research in children.[19]

Because the current study shows with sufficient evidence that fl3D-ce MRA techniques are insufficient, this may provide appropriate justification to study modern time-resolved contrast-enhanced MRA techniques for this purpose in these children.

Although patients were retrospectively selected, selection bias was not introduced because we compared CTA and MRA based on incidental anatomical variations of hepatic artery anatomy, which were independent of the clinical indications to perform the studies.

Ultimately the transplant surgeon needs to be extensively informed, and understand, the exact vascular anatomy in order to create a “mental roadmap” in preparation of surgery. At our center, transplant surgeons study the imaging preoperatively both together with a radiologist and by themselves, and they are comfortable with isotropic CTA. When performed, the surgeon considers MRA to be more challenging to interpret, and if MRA would play a larger role in preoperative imaging this issue should be taken into account.

Another limitation is the lack of a gold standard of hepatic artery anatomy. Ideally this would consist of intraoperative assessment of the anatomy. However, the vascular anatomy was not consistently registered in sufficient detail in the surgical reports to act as an optimal reference standard for the purposes of this study. Although interreader variability supplemented with interpretation scores allowed for reasonable comparison of these modalities instead, this limitation should be taken into account.

Finally, pre-LT work-up not only consists of hepatic artery anatomy, but also of assessment of anatomy and patency of the portal vein, liver veins, inferior caval vein, and other abdominal anatomy aspects such as collateral vessels, spleen, and kidney anatomy. Because the hepatic artery cannot be reliably assessed by DUS,[7] and because the hepatic artery anatomy generally is the most difficult question to answer both at CT and MR exams, the current study specifically focused on arterial anatomy.

In conclusion, despite its radiation dose, CTA is currently preferred over fl3D-ce MRA for the preoperative assessment of hepatic artery anatomy in children needing LT, both in children aged <6 years and ≥6 years. However, with the aim of reducing radiation exposure, technical advances improving MRA—such as time-resolved contrast-enhanced MRA techniques—should be investigated to replace CTA as the primary cross-sectional modality in the pre-LT work-up in children.

CONFLICT OF INTEREST

There were no conflicts on interest.

AUTHOR CONTRIBUTION

Martijn V. Verhagen was involved in concept and design, data analysis, and writing. Riksta Dikkers was involved in concept and design, data collection, and writing. Ruben H. de Kleine was involved in writing and supervision. Thomas C. Kwee was involved in concept and design, writing, and supervision. Hubert P.J. van der Doef was involved in writing and supervision. Robbert J. de Haas was involved in concept and design, data collection, data analysis, and writing.

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How to cite this article: Verhagen MV, Dikkers R, de Kleine RH, Kwee TC, van der Doef HPJ, de Haas RJ. Assessment of hepatic artery anatomy in pediatric liver transplant recipients: MR angiography versus CT angiography. *Pediatr Transplant*. 2021;00:e14002. https://doi.org/10.1111/petr.14002

APPENDIX 1

Primary diseases of included patients necessitating liver transplantation

Primary diseases	*n* (%)
Biliary atresia	9 (24.9)
Alagille syndrome	2 (9.5)
PFIC	2 (9.5)
Hepatoblastoma	2 (9.5)
PSC	2 (9.5)
Congenital liver fibrosis, unknown cause	1 (4.8)
Alport disease	1 (4.8)
ARPKD with liver fibrosis	1 (4.8)
Familial liver disease, unknown cause	1 (4.8)
Total	21

Abbreviations: ARPKD, autosomal recessive polycystic kidney disease; *n*, number of patients; PFIC, progressive familial intrahepatic cholestasis; PSC, primary sclerosing cholangitis.

APPENDIX 2

MRI machines

Name	Brand	fl3d-ce type	Field strength (T)	Number of patients
Sonatavision	Siemens[a]	fl3d-ce unspecified	1.5	6
Avanto	Siemens	VIBE	1.5	4
Aera	Siemens	VIBE	1.5	3
Achieva	Philips[b]	THRIVE	1.5	3
Ingenia	Philips	THRIVE	1.5	2
Skyra	Siemens	VIBE	3	2
Vision	Siemens	fl3d-ce unspecified	1.5	1
Total				21

Abbreviations: fl3d-ce, fast low angle shot 3 dimensions contrast enhanced; MRI, magnetic resonance imaging; T, tesla; THRIVE, T1 High Resolution Isotropic Volume Excitation; VIBE, volumetric interpolated breath-hold examination.[a] Siemens Healthineers. [b] Philips.

APPENDIX 3

fl3D-ce MRA sequence

	MRA (fl3D-ce)
Scanning plane	Axial/Cor/isotropic
Gadolinium-chelate/Iodine contrast	yes
Contrast phase	Arterial
Field strength, median T (IQR)	1.5 (1.5–3)
Echo Time, median ms (IQR)	3.9 (2.1–4.4)
Repetition Time, median ms (IQR)	1.7 (0.9–2.1)
Flip Angle, median degrees (IQR)	10 (10–17)
Sampling, median % (IQR)	73.5 (66.0–97.8)
Slice thickness, median mm (IQR)	2.5 (2–3)
Matrix, median	258 × 304

Abbreviations: Cor, coronal; fl3D-ce, fast low angle shot 3 dimensions contrast enhanced; IQR, interquartile range; MRA, magnetic resonance angiography; T, tesla.

APPENDIX 4

CT machines

Name	Brand	Number of detector rows	Number of patients
Force	Siemens[a]	2 × 128	8
Sensation 64	Siemens	64	6
Sensation 16	Siemens	16	5
Definition AS	Siemens	64	2
Total			21

Abbreviation: CT, computed tomography.[a] Siemens Healthineers.

APPENDIX 5

CTA settings

	CTA
Scanning plane	Axial/Isotropic
Iodine contrast	Yes
Contrast phase	Arterial
Tube potential, kV, median (IQR)	80 (75–100)
Tube current, mAs, median (IQR)	58 (38.5–97.5)
DLP, median mGy/cm (IQR)	31 (12.5–60.5)
Effective dose, mSv, median (IQR)	0.46 (0.19–0.91)
Slice thickness, median mm (IQR)	1.5 (1–3)

Abbreviations: CTA, computed tomography angiography; DLP, dose-length product; Gy, Gray; IQR, interquartile range; kV, kilovoltage; mAs, milliampere-seconds; mSv, milli Sievert.