

# Magnetic resonance cholangiographic evaluation of intrahepatic and extrahepatic bile duct variations

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## Abstract

Biliary anatomy and its common and uncommon variations are of considerable clinical significance when performing living donor transplantation, radiological interventions in hepatobiliary system, laparoscopic cholecystectomy, and liver resection (hepatectomy, segmentectomy). Because of increasing trend found in the number of liver transplant surgeries being performed, magnetic resonance cholangiopancreatography (MRCP) has become the modality of choice for noninvasive evaluation of abnormalities of the biliary tract. The purpose of this study is to describe the anatomic variations of the intrahepatic and extrahepatic biliary tree.

**Key words:** Aberrant; accessory; anatomy; biliary; variations

## Introduction

We, as radiologists, are all acquainted with the cross-sectional segmental anatomy of the liver. Variations in hepatic artery, portal vein, hepatic veins, and biliary tree are common and knowledge of these anatomic variations is of considerable clinical relevance as there has been an increasing trend in the radiological intervention procedures and liver transplantation surgeries.

Intrahepatic and extrahepatic bile duct variations are commonly seen. Normal biliary anatomy is seen in only 58% of the population. There are various techniques available for the visualization of biliary tree. Intravenous cholangiography often does not opacify the intra- and extrahepatic biliary tree and rarely allows a detailed visualization of the duct bifurcation. Endoscopic

retrograde cholangiopancreatography (ERCP), although very accurate, is an invasive method for imaging the biliary tree. Intraoperative cholangiography is also highly accurate; however, it is an invasive procedure and its routine use remains controversial. Magnetic resonance cholangiopancreatography (MRCP) is an excellent non-invasive imaging technique for visualization of detailed biliary anatomy. High-resolution cross-sectional, two-dimensional (2D) and three-dimensional (3D) projection images provide excellent detailed anatomy which is comparable to ERCP and intraoperative cholangiograms. In this article, we will discuss the different patterns of right and left hepatic duct variations and variations in cystic duct anatomy. We will also highlight the clinical significance of these anatomic variations.

### MRCP technique

All MR cholangiograms in our department were obtained with a Signa HDxt 3.0-T scanner volume MR (GE, Fairfield, CT, USA). A body phased-array coil with eight elements, centered below the xiphoid process, was used for signal reception. We routinely acquire coronal and axial T2-weighted (T2W) single-shot fast spin-echo (FSE) sequences, axial respiratory-triggered fat-suppressed T2W FSE sequence, and axial breath-hold

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T1-weighted (T1W) dual-echo spoiled gradient recalled-echo sequence.

MRCP is performed by using a respiratory-triggered high-spatial-resolution isotropic 3D fast-recovery FSE sequence with parallel imaging in axial and oblique coronal planes, which provides high signal-to noise ratio and excellent spatial resolution (1-mm isotropic voxels) in a relatively short acquisition time (repetition time- one respiratory cycle, echo time- 700 ms, echo space- 8.5 ms, matrix- 320 × 256, section thickness- 1.4 mm, zero-fill interpolation to 0.7, 40-70 sections, receiver bandwidth- 25 kHz, acquisition time- 3-7 min, array spatial sensitivity encoding factor two, actual voxel dimensions (mm) isotropic at 1.4\_1.4\_1.4 interpolated to 0.7\_0.7\_0.7). In addition, 2D half-Fourier single-shot FSE sequence is implemented in thick-slab and multi-section modes (image acquisition parameters: Relaxation time- 2.800 ms, effective TE- 750 ms, image

matrix- 384 × 256, field of view- 200 × 200 mm, refocusing flip angle- 180°). The resulting images are displayed as projection images of the biliary tree after a 7.13 s acquisition time. Maximum intensity projection (MIP) algorithm is used to produce a 3D cholangiogram from 3D FSE images.

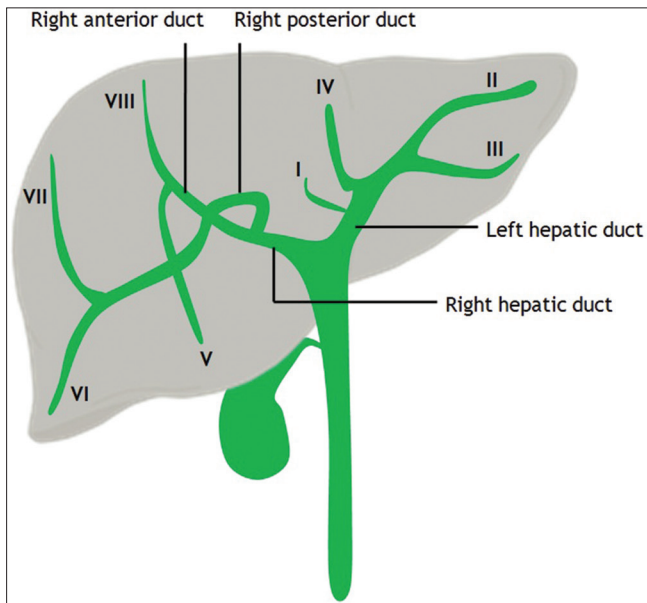


Figure 1: Pictorial diagram showing normal biliary anatomy

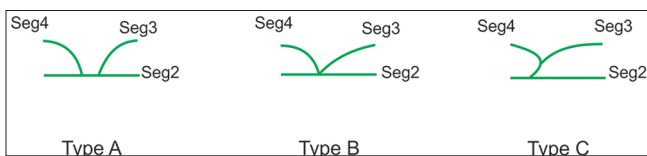


Figure 3: Pictorial diagram showing variations in the left biliary ductal system

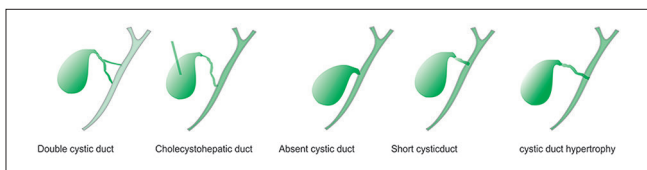


Figure 5: Pictorial diagram showing uncommon variations in the cystic duct

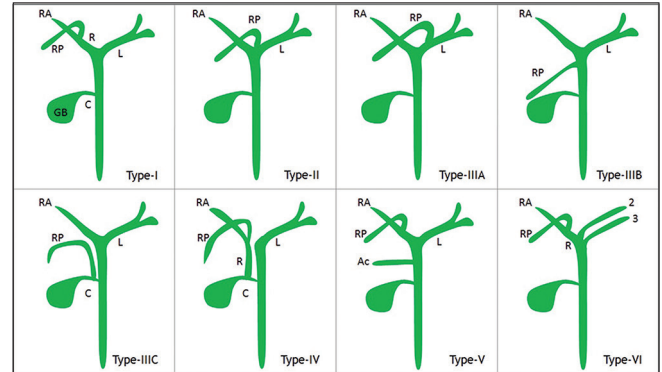


Figure 2: Pictorial diagram showing variations in the right biliary ductal system

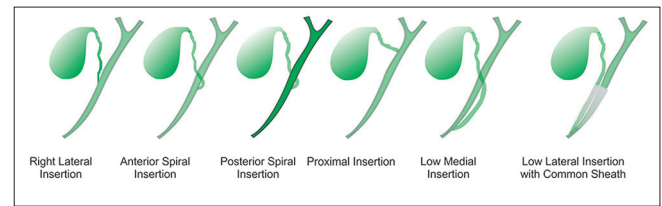


Figure 4: Pictorial diagram showing common variations in the cystic duct

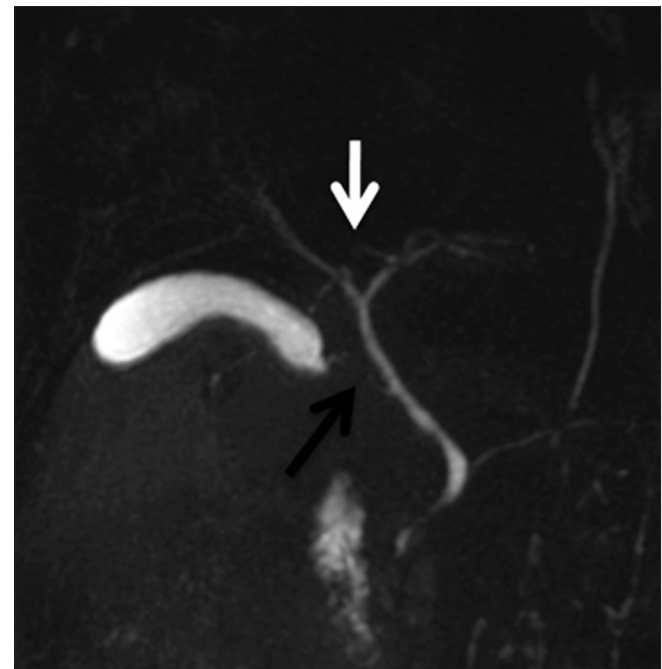


Figure 6: Normal anatomy: Projective coronal MRCP image showing fusion of the right anterior and right posterior ducts to form the right hepatic duct. Primary confluence (white arrow) is formed by fusion of the right and left hepatic ducts. Cystic duct (black arrow) joins the common hepatic duct in its lateral part to form the common bile duct

**Table 1: Branching patterns of right hepatic bile duct<sup>[6-8]</sup>**

Layout (type)	Interpretation	Percentage
Type I	Typical: RPSD joining RASD medially to form RHD	64
Type II	Trifurcation: Simultaneous emptying of the RASD, RPSD, and LHD into the CHD	5
Type III	Anomalous drainage of RPSD A- RPSD joining LHD (crossover anomaly) B- RPSD joining CHD C- RPSD joining cystic duct	17
Type IV	Aberrant drainage of RHD into the cystic duct	3
Type V	Accessory right hepatic duct	1.4
Type VI	Segments II and III duct draining individually into the RHD or CHD	-
Type VII	Others and unclassified variations	-

RPSD: Right posterior sectoral duct, RASD: Right anterior sectoral duct, RHD: Right hepatic duct, LHD: Left hepatic duct, CHD: Common hepatic duct

**Table 2: Branching patterns of left hepatic bile duct<sup>[9]</sup>**

Layout (type)	Interpretation	Percentage
Type A	Common trunk of segment II and segment III joins segment IV	69
Type B	Triconfluence of segments II, III, and IV	6
Type C	Segment II duct drains into common trunk of segment III and segment IV	20
Type D	Others and unclassified variations	5

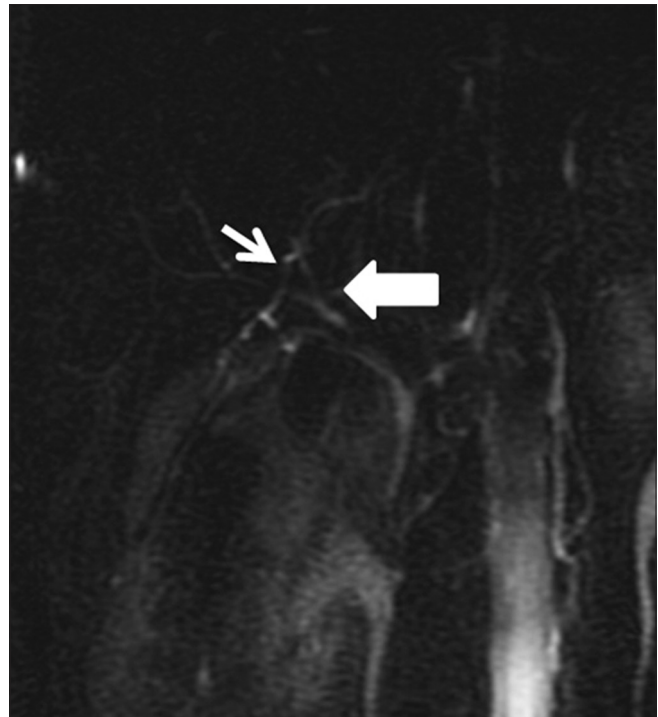
**Table 3: Branching patterns of the cystic duct<sup>[2,8-10]</sup>**

Layout (type)	Interpretation	Percentage
Type A	Long cystic duct with low insertion into the distal third of CBD	9
Type B	Medial cystic duct insertion	10-17
Type C	Parallel course of cystic duct with common hepatic duct	1.5-25
Type D	Abnormally high fusion of cystic duct with common hepatic duct	2.1
Type E	Cystic duct entering the right hepatic duct	0.7
Type F	Cholecystohepatic duct or subvesical duct	0.7
Type G	Cystic malformation of cystic duct	-
Type H	Others and unclassified variation	-

CBD: Common bile duct

*Role of hepatocyte-specific MR contrast agents*

Hepatocyte-specific gadolinium-based agents like gadobenate dimeglumine (Gd-BOPTA-Bracco Diagnostics Inc. by BIPSO GmbH – 78224 Singen (Germany) and by Patheon Italia SpA, Ferentino, Italy) and gadoxetic acid can also be used for imaging the biliary tree due to their dual route of excretion through the kidneys and the liver. The recommended dose of Gd-BOPTA is 0.1 mmol/kg (0.2 mL/kg) administered as a rapid bolus intravenous injection. To ensure complete injection of the contrast medium, injection with a saline flush of at least 5 mL is recommended. The first phase shows extracellular properties and the second phase is characterized by



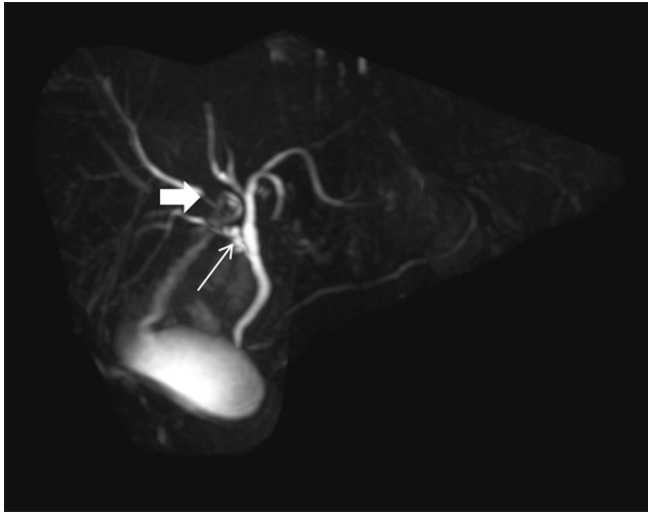
**Figure 7:** Right posterior sectoral duct opening into the left hepatic duct (Type IIIA anomaly): Coronal MRCP image showing right posterior sectoral duct (arrow) opening into the left hepatic duct (crossover anomaly). Primary confluence is formed by the right anterior sectoral duct and the left hepatic duct (arrowhead)

hepatobiliary excretion. This phase is seen after 20-40 min of contrast administration. The biliary excretion of these contrast agents allows improved visualization of the bile ducts on hepatocyte phase T1W MRCP images.<sup>[1]</sup> Gd-BOPTA has 3-5% biliary excretion and 95% of the contrast is excreted through kidneys, whereas gadoxetic acid [gadolinium ethoxybenzyl diethylenetriamine pentaacetic acid (Gd-EOB-DTPA)] has 50% biliary and 50% renal excretion. So, delayed phase imaging is done at 1-2 h while using Gd-BOPTA and at 10 min-2 hrs while using Gd-EOB-DTPA.<sup>[2]</sup> The flow artifact (which may be seen on T2W MRCP images) is usually not a problem on contrast-enhanced MR cholangiography. If T2W MRCP and contrast-enhanced MR cholangiography are to be done together, T2W MRCP should be performed before the hepatobiliary-specific contrast agent appears in the biliary tree (as these agents cause T2 shortening).

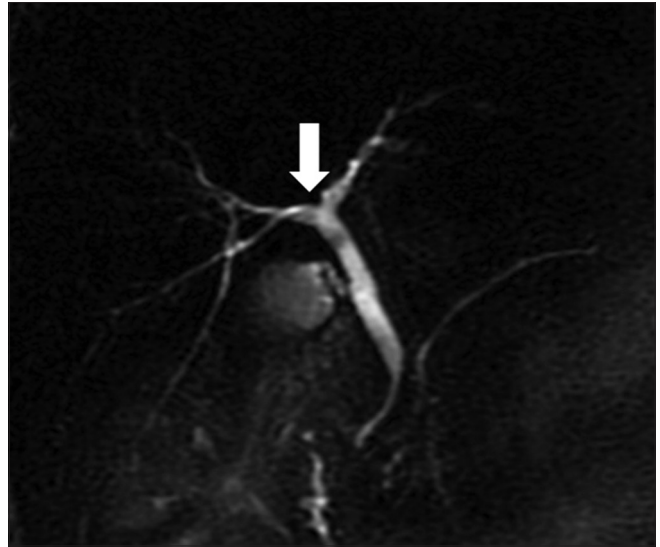
**Discussion**

**Normal anatomy of intrahepatic bile ducts**

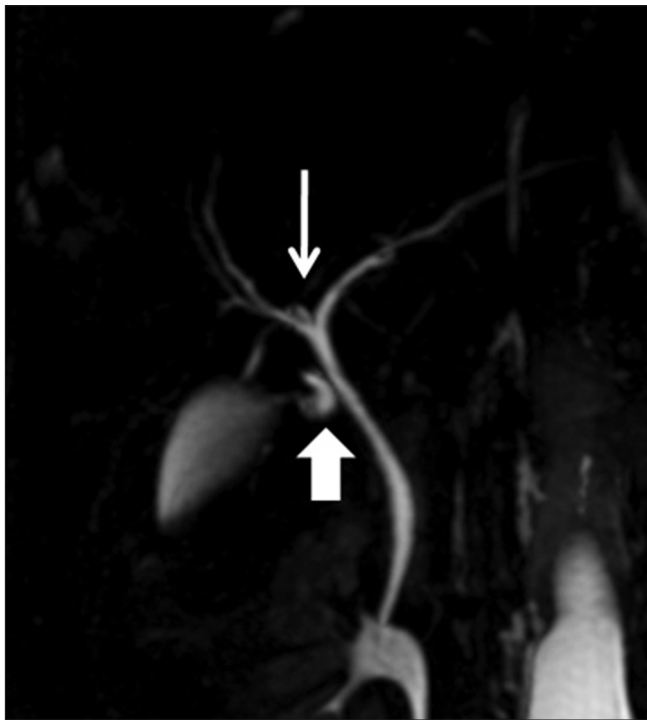
The interesting part of biliary anatomy is that the individual biliary drainage system is parallel to the portal venous supply system. Therefore, the normal biliary anatomy is similar to portal venous anatomy [Figure 1]. The right hepatic duct drains the segments of the right



**Figure 8:** Right posterior duct joining the common hepatic duct (Type IIIB anomaly) with Mirizzi syndrome: Projection reformatted MRCP image showing right posterior sectoral duct opening into the common hepatic duct (arrow). Cystic duct calculus is causing compression of the anterior and posterior segmental branches of the right posterior duct and indentation on the common hepatic duct (arrowhead)



**Figure 9:** Trifurcation anomaly (Type II): Projective coronal MRCP image showing trifurcation anomaly of biliary tree in the form of right anterior, right posterior, and left hepatic duct, forming the primary confluence (arrow)



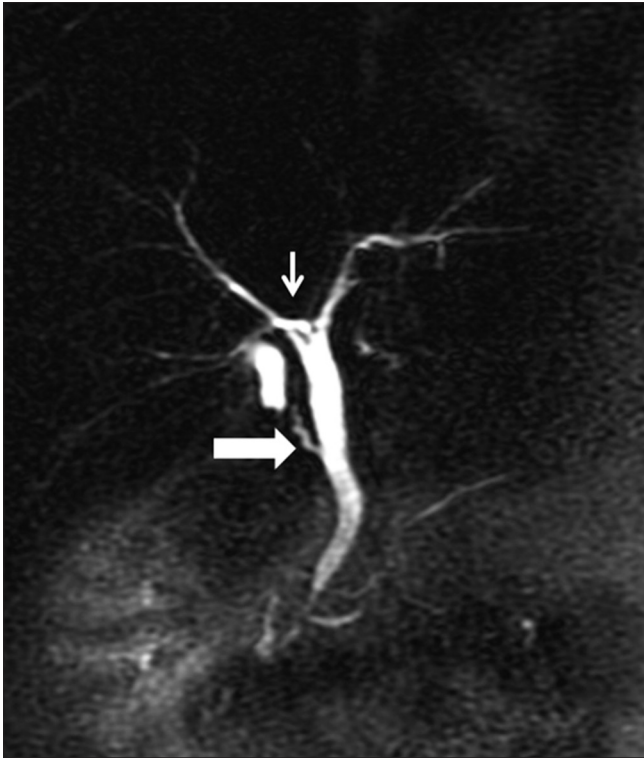
**Figure 10:** Trifurcation anatomic variation (Type II) with high insertion of cystic duct: Coronal MRCP image showing trifurcation anomaly of biliary confluence (arrow). Also note the high lateral insertion of prominent cystic duct (arrowhead)

liver lobe (V–VIII). The right hepatic duct has two major branches: The right posterior duct draining the posterior segments, VI and VII, and the right anterior duct draining the anterior segments, V and VIII.<sup>[3-5]</sup> The right anterior duct has a more vertical course, whereas the right



**Figure 11:** Trifurcation anomaly with ansa pancreatica: Coronal MRCP image showing trifurcation of biliary confluence (arrow) with ansa pancreatica variation as the duct of Santorini (arrowhead) forms a sigmoid curve as it courses to the duct of Wirsung

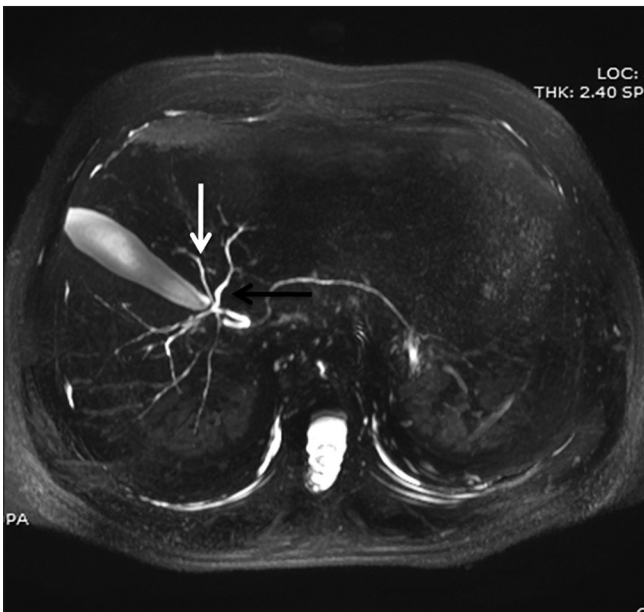
posterior duct has an almost horizontal course. The right posterior duct usually runs posterior to the right anterior duct and fuses with it from a left (medial) approach to form the right hepatic duct [Figure 2]. The left hepatic duct is formed by segmental tributaries draining segments II-IV [Figure 3].



**Figure 12:** Crossover anomaly with spiral course of the cystic duct: Coronal MRCP image showing right posterior duct opening into the left hepatic duct (arrow) with spiral tortuous course of the cystic duct (arrowhead)



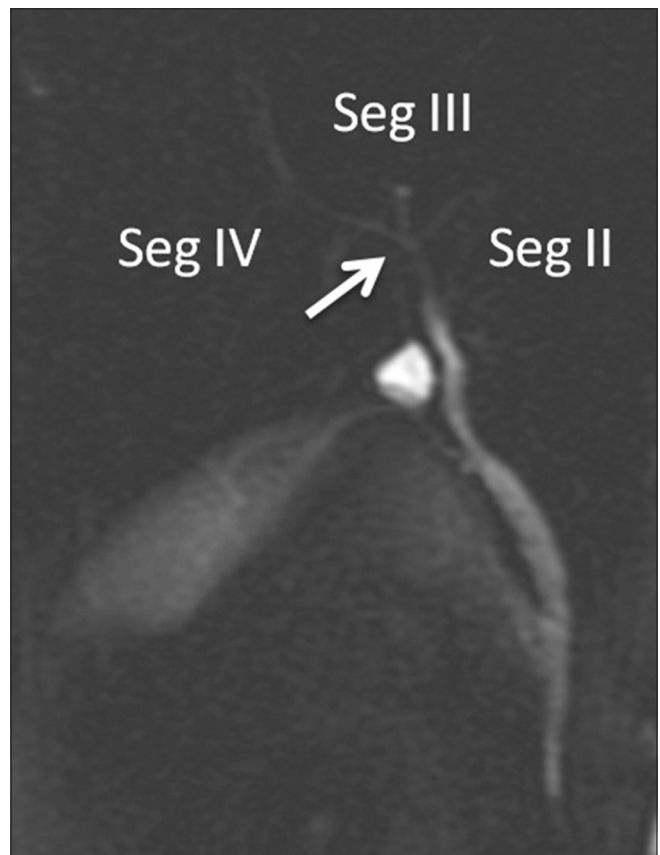
**Figure 13:** Coexisting Type III and Type V anomalies in a patient: Coronal MRCP image showing aberrant opening of right posterior duct into left hepatic duct (arrow) and accessory right hepatic duct opening into common hepatic duct (curved arrow)



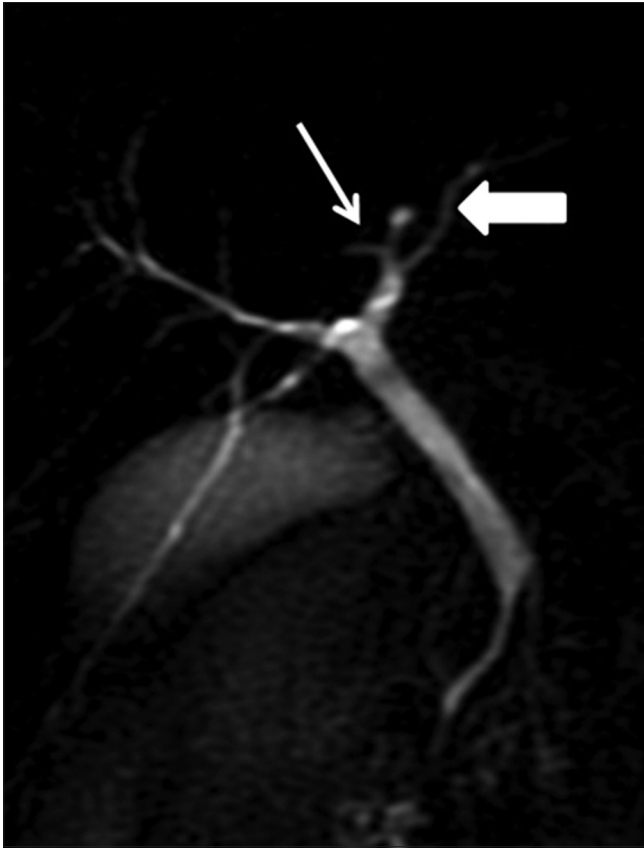
**Figure 14:** Quadrifurcation anatomic variation: Projective axial MRCP image showing quadrifurcation of primary biliary confluence into right anterior, right posterior, segment IV duct (white arrow) and common trunk of segment II and segment III (black arrow)

**Normal anatomy of extrahepatic bile ducts**

The fusion of right and left hepatic ducts forms the common hepatic duct. The right hepatic duct is usually shorter than the left hepatic duct. Biliary confluence angle is said to be



**Figure 15:** Trifurcation of left ductal system (Type B): Oblique MRCP image showing trifurcation of segment IV, segment II, and segment III duct



**Figure 16:** Type C anomaly of left hepatic duct: Coronal MRCP image showing segment II duct (arrowhead) draining into common trunk of segment III and segment IV (arrow)

narrow when the angle is less than 90°. The bile duct draining the caudate lobe usually joins the origin of the left or right hepatic duct.<sup>[3-6]</sup> The cystic duct classically joins the common hepatic duct below the confluence of the right and left hepatic ducts [Figures 4 and 5]. The normal cystic duct measures 2-4 cm in length and 1-5 mm in diameter. It contains the spiral valves of Heister and frequently follows a tortuous course. This normal biliary anatomy is thought to be present in 58% of the population.<sup>[6]</sup>

#### Common and uncommon anatomic variations

With the help of work done by Choi *et al.*, Benson *et al.*, previous eminent researchers, and our own experience, we have tried to simplify the classification of biliary anatomy and its variations. Variations of right and left hepatic ducts and cystic ducts are described in Tables 1-3.<sup>[6-11]</sup>

Normally, the right posterior sectoral duct passes posterior to the right anterior sectoral duct and joins it from the left to form the right hepatic duct (Type I) [Figure 6]. The most common anatomic variation in the branching of the biliary tree involves the fusion of right posterior sectoral duct with the left hepatic duct [Figure 7]. Other variations encountered are right posterior sectoral duct opening into the common hepatic duct [Figure 8] or

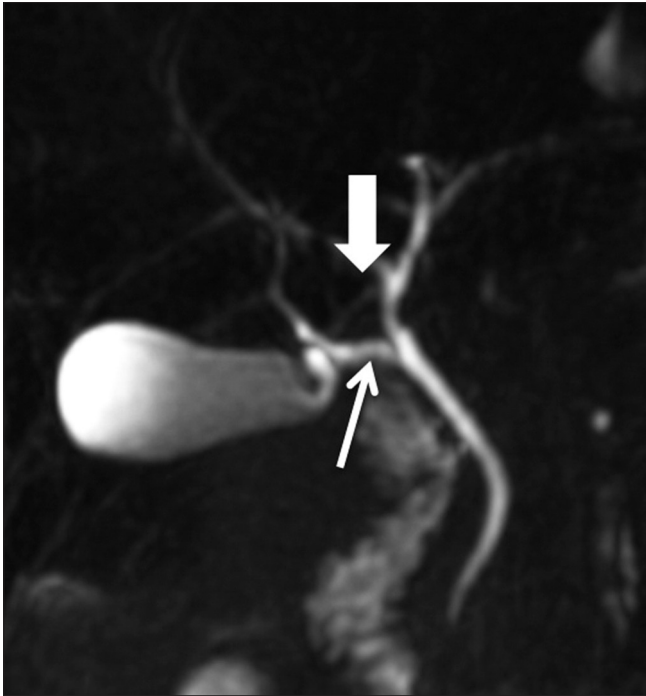


**Figure 17:** Two accessory right ducts opening into common hepatic duct (Type V variation): Coronal MRCP image showing two accessory right ducts opening into common hepatic duct (arrows)

cystic duct and trifurcation anomaly [Figure 9]. More than one anomaly coexisting can also be seen like two accessory right ducts opening into common hepatic duct, trifurcation anatomic variation (Type II) with high insertion of cystic duct [Figure 10], trifurcation anomaly with ansa pancreatica [Figure 11], crossover anomaly with spiral course of cystic duct [Figure 12], coexisting Type III and Type V anomaly [Figure 13], and quadrifurcation anomaly [Figure 14]. Normal left-sided biliary ductal anatomy consists of a common trunk of segment II and segment III duct which joins the segment IV duct (Type A). Other variations are triconfluence of segment II, III, and IV duct [Figure 15] and segment II duct draining into a common trunk of segment III and segment IV duct [Figure 16].

#### Aberrant and accessory bile ducts

An aberrant bile duct has an anomalous confluence pattern and is the only bile duct draining a particular segment of the liver. An accessory bile duct is an additional bile duct draining a particular area of the liver [Figures 17 and 18]. Accessory hepatic ducts are present in 2% of the patients. Few authors have also described "pericholecystic bile ducts," but the nomenclature is complex and controversial. Ducts of Luschka are thin

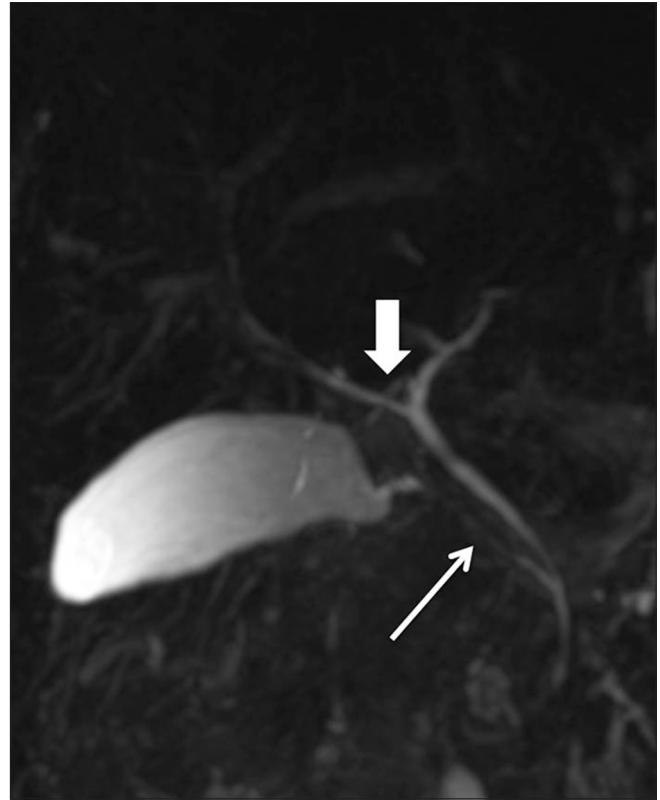


**Figure 18:** Coronal MRCP image showing aberrant opening of right posterior sectoral duct into common bile duct (arrow). High insertion of cystic duct is seen opening at the confluence (arrowhead)

ducts of 1-2 mm in diameter running in cystic fossa, and they do not drain liver parenchyma. These ducts have blind ends distally. Proximally, they are connected with the right hepatic, the common hepatic duct or, rarely, the cystic duct. Cystohepatic duct is an aberrant bile duct usually draining the right liver parenchyma and courses through the gallbladder fossa. It may have its opening in the cystic duct or in the right hepatic duct. Cholecystohepatic duct is a rare aberrant hepatic duct draining a portion of the right lobe and coursing through the Calot's triangle [anatomic space bordered by the common hepatic duct medially, the cystic duct laterally, and the cystic artery (liver) superiorly]. It opens directly into gallbladder lumen. Extreme rare anatomic variations like complete interposition of the gallbladder (both the right and left hepatic ducts drain directly into the gallbladder) and vaginal ductuli (small communications between two bile ducts or cystic duct) have also been described.<sup>[12]</sup>

#### *Cystic duct variations*

Variations in cystic duct insertion are also frequently seen. Parallel course of cystic duct is one of the commonest variations in cystic duct insertion. It is defined as cystic duct coursing parallel to the common hepatic duct for at least a 2 cm segment [Figure 19]. Next most common variation is medial insertion of the cystic duct, i.e. drainage of the cystic duct into the left side of the common hepatic duct [Figure 20] followed by low cystic duct insertion,



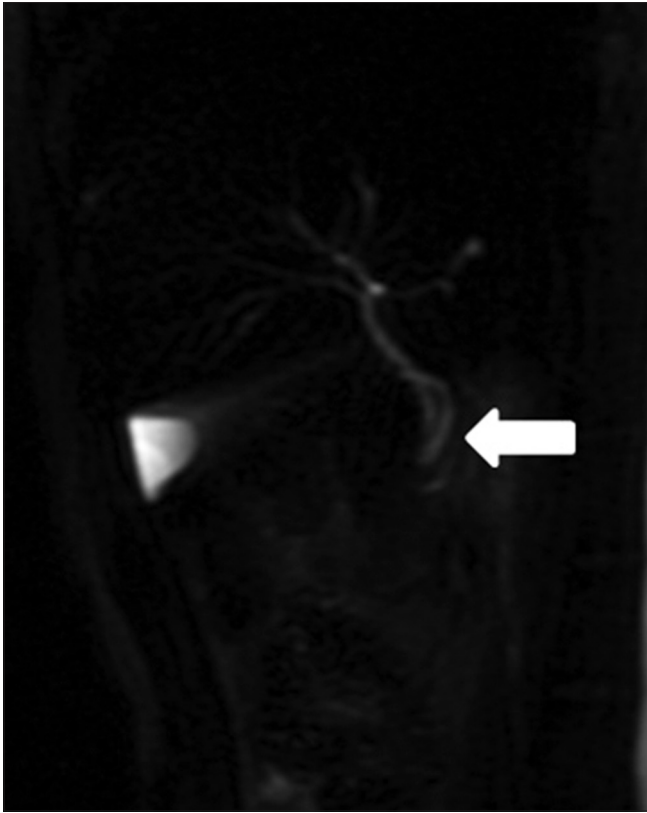
**Figure 19:** Coronal MRCP image showing parallel course of cystic duct (arrow) with crossover anomaly of right posterior duct (arrowhead)

which is seen as fusion of the cystic duct with the distal third of the extrahepatic bile duct. Other variations in cystic duct insertion are spiral course of the cystic duct [Figures 21 and 22] and high fusion of the cystic duct with the common hepatic duct [Figure 23]. Short cystic duct is defined as cystic duct having a length of less than 5 mm. Cystic duct hypertrophy is seen when the diameter of cystic duct is more than 5 mm. Maheshwari *et al.* have defined a new entity known as cystic malformation of the cystic duct which could be a distinct Type VI choledochal cyst [Figure 24].<sup>[11]</sup> Hepaticocystic duct is an anomalous duct draining directly into the cystic duct.<sup>[13]</sup> Cholecystohepatic duct is a term given to a duct passing through the gallbladder fossa. Other uncommon variations are double cystic duct, absent cystic duct, and cystic duct entering the right hepatic duct [Figure 25].

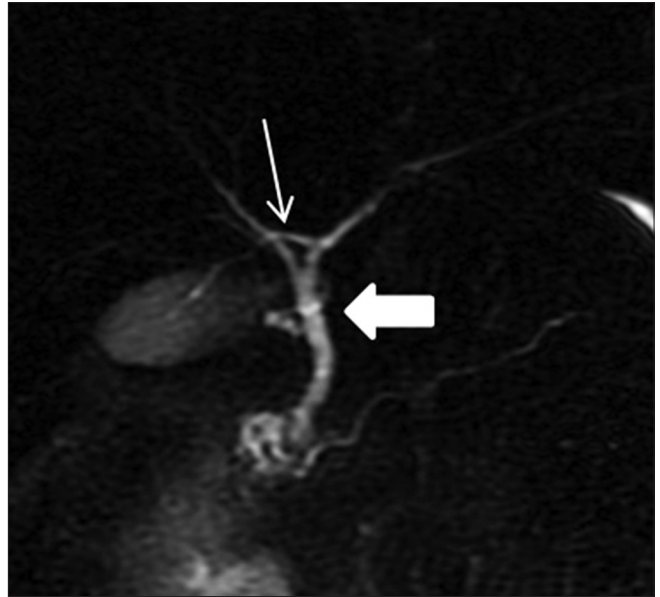
#### **Clinical significance**

##### *Hepatobiliary surgeries*

Knowledge of biliary anatomy is extremely important in hepatobiliary surgeries.<sup>[14]</sup> Preoperative assessment of potential liver donors requires detailed hepatic vascular and biliary anatomy. Currently, right lobe is most commonly used for adults and either the entire left lobe or liver segments II and III (left lateral segment) is used for pediatric recipients. So, detailed understanding of the biliary tree, especially the distance of primary confluence from right



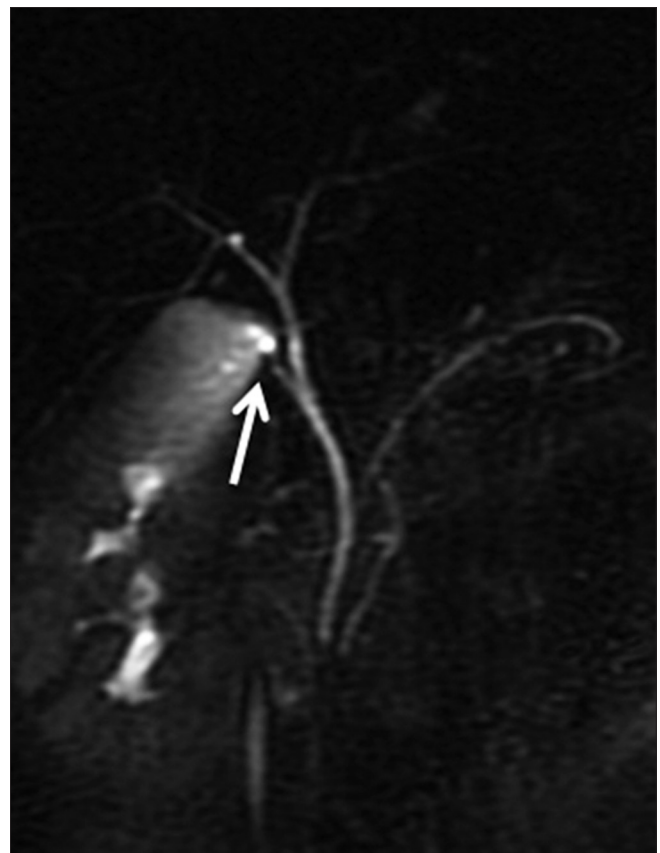
**Figure 20:** Low medial insertion of cystic duct (Type B variation): Oblique MRCP image showing low medial insertion of the cystic duct (arrow)



**Figure 21:** Crossover anomaly with spiral cystic duct: Projective coronal MRCP images showing right posterior sectoral duct opening into the left hepatic duct (white arrow). Also note anterior spiral insertion of the cystic duct (arrowhead)

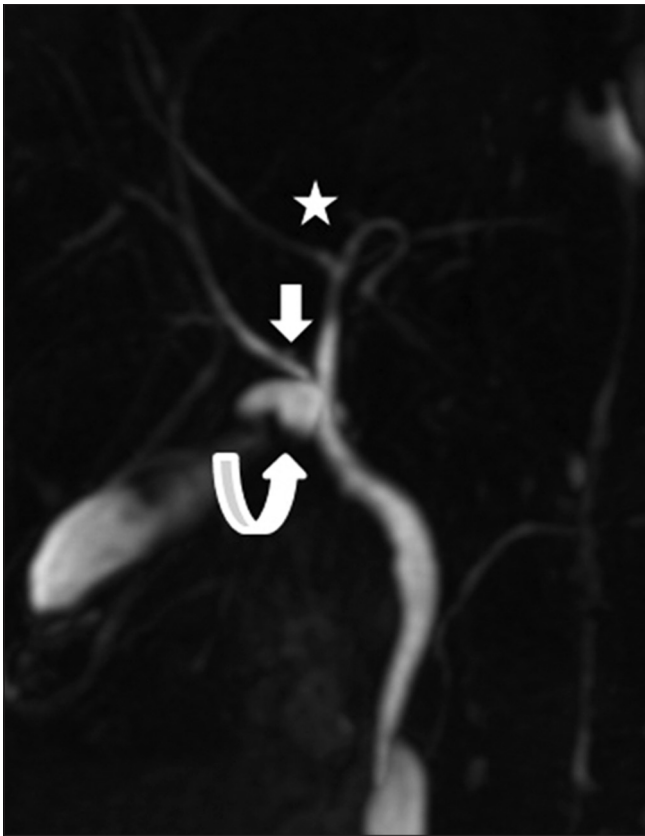


**Figure 22:** Cholelithiasis with posterior spiral course of cystic duct with medial insertion: Coronal MRCP image showing hypointense calculi in the gallbladder and posterior spiral course of the cystic duct (arrow) with medial insertion



**Figure 23:** High cystic duct insertion: Coronal MRCP image showing high insertion of cystic duct (arrow) in upper third of common hepatic duct





**Figure 24:** High insertion of cystic duct (Type D) with cystic dilatation of cystic duct: Coronal MRCP image showing abnormal high fusion of cystic duct into the common hepatic duct (Type D) with cystic dilatation of the cystic duct (curved arrow). Also note the narrow angle of primary biliary confluence (arrow) and triconfluence of left ductal system (asterix)

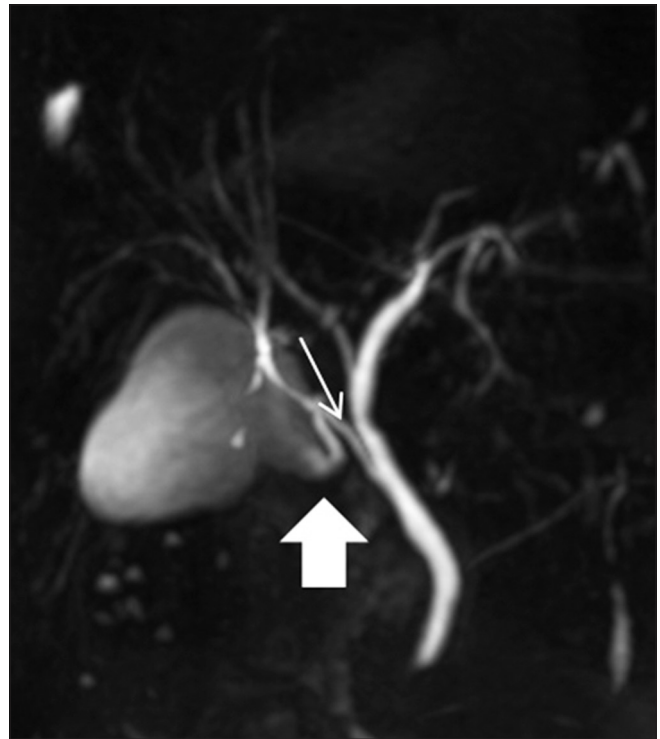
and left secondary confluence, distance of segment IV duct to primary confluence along with anatomy of segment II and III ducts is of pivotal significance to avoid biliary complications in the intraoperative and early postoperative period.<sup>[15,16]</sup> It is also crucial to recognize aberrant and accessory drainage of the ducts, crossover and trifurcation anomalies because ligation of these ducts may result in biliary cirrhosis.

#### *Evaluation before biliary interventional procedures*

In deciding the best approach and to avoid inappropriate or incomplete drainage of the obstructed bile ducts.

#### *Before gallbladder surgeries*

Laparoscopic techniques have become the standard approach for cholecystectomy. Preoperative identification of variant anatomy of cystic duct insertion can avoid injury to the cystic duct and the common bile duct. It is better to leave a cystic duct remnant [Figure 26] in low insertion, although there may be delayed complications like post-cholecystectomy syndrome [Figure 27] and injury during subsequent endoscopic procedures.<sup>[3,17,18]</sup> To avoid



**Figure 25:** Cystic duct opening into the right posterior duct: Coronal MRCP image showing anomalous opening of the cystic duct into the right posterior sectoral duct (arrowhead). Also, there is aberrant opening of right posterior duct into common hepatic duct (arrow). Primary confluence is formed by right anterior duct and left hepatic duct with narrow biliary confluence angle

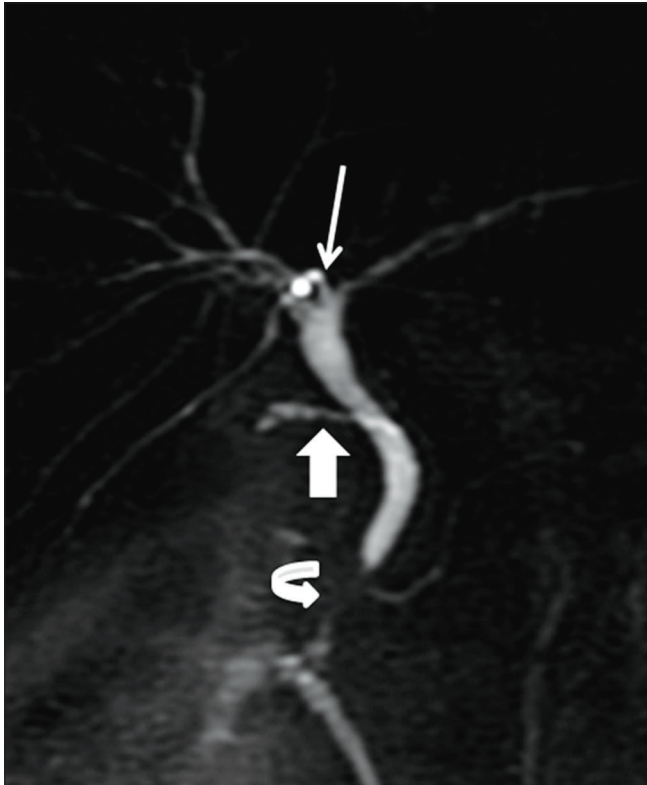
the “hidden cystic duct” syndrome, laparoscopic surgeons prefer “critical view technique” over the “infundibular technique” of laparoscopic cholecystectomy in case of inflammation/aberrant anatomy and tortuous spiral course of the cystic duct.<sup>[19]</sup> High cystic duct insertion can lead to inadvertent ligation of the cystic duct and subsequent development of a stricture in the common hepatic duct.

#### *Aberrant and accessory ducts*

Presence of aberrant duct anatomy can bother the surgeon. He/she may inadvertently ligate or resect the duct. Resection of these ducts is one of the main causes of self-limiting bile leaks after cholecystectomy. Ligation of an accessory bile duct may not cause recurrent cholangitis or focal fibrosis of the liver.<sup>[18,19]</sup> Ligation of duct of Luschka has no consequences as it is an end duct that drains an isolated segment, whereas resection of this duct can lead to bile leaks.

#### *Biliary confluence angle*

Measuring biliary confluence angle on MRCP images may often be unreliable due to wide range of variations [Figure 28]. However, the biliary confluence angle may be a clue for hilar masses, parenchymal atrophy of the liver, and periportal



**Figure 26:** Cystic duct remnant: Coronal MRCP image showing cystic duct remnant (arrowhead) post-cholecystectomy. Also note the crossover anomaly of right posterior duct opening into the left hepatic duct (arrow). Anomalous pancreaticobiliary junction is also seen (curved arrow)



**Figure 27:** Post-cholecystectomy syndrome with choledocholithiasis: Coronal MRCP image showing hypointense signal within the common bile duct (arrowhead) and the cystic duct remnant (arrow) suggestive of calculi with upstream biliary dilatation



**Figure 28:** Narrow biliary confluence angle: Coronal MRCP image showing narrow biliary confluence angle (curved arrow) and high cystic duct insertion (arrow)

space lesions. The usefulness of biliary confluence angle is important in follow-up of patients. A severe deviation from normal limits in these patients on follow-up imaging justifies additional investigation for hilar hepatobiliary lesion with conventional T1W and T2W MR images.

Anatomic variations of the biliary tract are usually also accompanied by variations in the portal venous system and the hepatic arterial system, which are also important in hepatobiliary surgeries. More specifically, portal venous anomalies have been demonstrated to significantly correlate with anomalous biliary drainage.<sup>[19]</sup>

### Conclusion

Increasing trend in advancements in hepatobiliary surgeries and liver transplantation procedures requires aggressive workup of biliary anatomy in these patients. Detailed knowledge of normal anatomy, and common and uncommon variations is of utmost importance for radiologists who are reporting these MRCP images. One should not only look at 2D and 3D MRCP images but also correlate these findings in multiplanar reconstruction planes and source images.

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