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ANATOMIC VARIATIONS OF INTRAHEPATIC BILIARY SYSTEM AT MAGNETIC RESONANCE CHOLANGIO-PANCREATOGRAPHY: A SINGLE INSTITUTION EXPERIENCE AND A SYSTEMATIC REVIEW OF THE LITERATURE

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ABSTRACT

The twofold purpose of this study was firstly to analyse the imaging features of various anatomical variants of the intra-hepatic biliary tree using magnetic resonance cholangio-pancreatography (MRCP) and to document the prevalence of each type in our population. The second aim was to perform a systematic review in order to evaluate the prevalence of anatomic variations of the intrahepatic biliary system in different studies and with different imaging methods. Patients who underwent MRCP between January 2009 and December 2011 were included and analyzed. All examinations were obtained using 1.5 Tesla MRI and 8 channel phased-array coil. In order to compare data coming from the present study and different series published by other authors, a comprehensive literature search using the MEDLINE and Pubmed databases was performed, covering the period from January 1980 to December 2017. Among 534 patients, normal morphology of the intrahepatic biliary system (Type 1) was found in 55% of cases. The second most frequent presentation, in about 19.8% of patients, was Type 3a with right posterior duct (RPD) emptying into the left hepatic duct. Triple confluence morphology (Type 2) was found in 10.1% of cases; only 6.7% of patients presented with Type 3b variant with aberrant RPD draining into the common hepatic duct. In about 8.4% of cases, more complex biliary variants were found. At the time of this review, thirty studies employing different imaging methods were identified in the literature search, of which fifteen used MRCP, eleven used intra-operative cholangiography, three used CT-cholangiography and one ERCP. Taking into account all of the studies, the total number of patients was 14,322. Type 1 presentation ranged from 40% to 80%. A correct understanding of the biliary three anatomy through MRCP study is feasible and it may be very useful in order to plan complex hepatobiliary surgeries and to prevent iatrogenic injuries.

1. Introduction

An accurate knowledge of the normal branching pattern of intrahepatic bile ducts and their variations is of crucial importance for liver and biliary tract surgery including liver transplantation, tumor resection and laparoscopic hepatobiliary surgeries (1,2).

Moreover, the correct identification of the cystic duct - common hepatic duct (CD-CHD) junction is very important to avoid iatrogenic biliary injuries during laparoscopic cholecystectomy. Currently, Magnetic Resonance Cholangio-Pancreatography (MRCP) is an accurate non-invasive radiologic imaging considered to be the "gold standard" diagnostic tool for the pre- operative study of the biliary tree (3,4).

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Furthermore, MRCP is a safe diagnostic procedure, which is able to demonstrate the biliary anatomy with no contrast medium administration and without any exposure to ionizing radiation. Knowledge of the biliary system is associated with understanding of its embryologic development which may help to explain any anatomic variants and reveal important clinical implications.
The purpose of this study was to analyse the imaging features of various anatomical variations of intra-hepatic biliary tree anatomy by using MRCP and to document the prevalence of each type in our population. The second aim was to perform a systematic review in order to evaluate the prevalence of anatomic variations of the intrahepatic biliary system in different studies and with different imaging methods.

2. Material and methods

We retrospectively analysed patients who underwent MRCP between January 2009 and December 2011; all examinations were obtained using 1.5 Tesla MRI and 8 channel phased-array coil. For the current analysis, we included MRCP examinations obtained using two dimensional (2D) Single Shot Fast Spin Echo (SSFSE) sequences and three dimensional (3D) Fast Recovery Fast Spin Echo (FRFSE) acquisitions. 2D SSFSE were obtained using both thin acquisitions and thick slab sequences ; these were centered on hepatic hilum and/or biliary-pancreatic ducts confluence. 3D FRFSE sequences were respiratory-triggered and/or obtained in a breath-hold modality.
Technical features of our MRCP protocol are listed in Table 1.
Examinations with incomplete or inadequate protocol were excluded from the current analysis. The main exclusion criteria were: 1) poor quality imaging due to artifacts damaging 2D SSFSE and/or
3D FRFSE acquisitions; 2) the presence of any intra-abdominal fluid collections, with poor visualization of hepatic area ; 3) history of prior hepatobiliary surgery or cholecystectomy; 4) incomplete examinations for patients with no MRCP sequences.
For each patient, two gastrointestinal radiologists reviewed MRCP acquisitions at a dedicated workstation. They analyzed the morphology of the intrahepatic bile ducts, recording variations with respect to the Yoshida classification (1), and registered the morphology and the course of the cystic duct. The most frequent anatomic variants of the biliary tree, according to the mentioned classification are detailed here. The normal morphology of intrahepatic bile ducts is defined as
Type I: the right posterior duct (RPD) usually runs posterior to the right anterior duct (RAD) and fuses it from a left (medial) approach to form the right hepatic duct. The left hepatic duct is formed by segmental tributaries, draining segments II-IV. (Figure 1).
Type II: RPD, RAD and the left hepatic duct joining at the same point, the so-called triple confluence (Figure 2).
Type III a: the RPD emptying on the left hepatic duct (Figure 3).
Type III b: aberrant RPD draining directly into the common hepatic duct (Figure 4).
Type III c, which results in anomalous drainage of the right posterior duct into the cystic duct, as shown in Figure 6b/c.
Type IV is defined as complete drainage of the right hepatic duct into the cystic duct.
Type V includes an accessory duct that drains part of the right lobe, more in detail in subtype 5a, the accessory duct empties into the common hepatic duct (as shown in Figure 6a), instead in subtype 5b it joins with the right hepatic duct.
Type VI has an individual drainage of the II and III segments of the left liver, that usually form a unique left hepatic duct, into the right hepatic duct or into the common hepatic duct.
To conclude Type VIII includes unclassified, combined or more complex biliary variants.
The cystic duct may also present variations in its morphology with cranial or caudal emptying and implantation may be medial, posterior, anterior or lateral, related to the wall side of the common bile duct; however, its course may appear convoluted or parallel, as shown in Figure 5.
The study conformed to the principles outlined in the Declaration of Helsinki. A written informed consent was obtained from all patients before radiologic examination.
In order to compare data coming from the present study and the literature, a comprehensive literature search of the MEDLINE and Pubmed databases was performed, covering the period from January 1980 to December 2017 according to PRISMA guidelines (http://www.prisma-statement.org/). The following keywords were used for the bibliographic search: intra-hepatic biliary tree, bile ducts, biliary system, magnetic-resonance cholangio-pancreatography, biliary anatomy, anatomic variations. All studies containing material relevant to the topic were considered. All the studies included in this systematic review used the same Yoshida classification for biliary anatomy. Retrieved studies were reviewed by the authors, and the data extracted using a standardized collection tool. The data were analyzed using descriptive statistics.

	THICKNESS	*GAP*	*TIME REQUIRED*
THICK SLAB 2D SSFSE	50 mm	n/a	1-2 sec for slice/2 min
THIN-SECTION 2D SSFSE	3 mm	0-1 mm	20-25 sec
RESPIRATORY-TRIGGERED 3D FRFSE	2-3 mm	1 mm	2-3 min
BREATH-HOLD 3D FRFSE	3 mm	0-1 mm	24-27 sec

Table 1. Parameters used in our MRCP protocol. (SSFSE: Shot Fast Spin Echo sequences; FRFSE: Fast Recovery Fast Spin Echo acquisitions.)

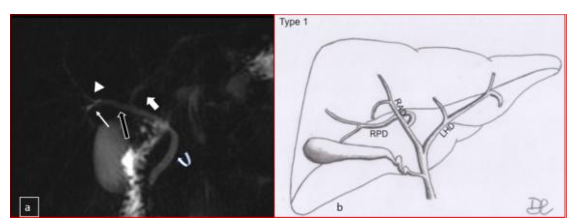

Figure 1. 1a. MRCP sequences depict intrahepatic biliary tree anatomy. This figure shows type I variant with right posterior (RPD) (white arrow) and right anterior duct (RAD) (arrowhead) that join to form the right hepatic duct (empty arrow). Right hepatic duct joined to the left hepatic duct (full arrow) to form the common hepatic duct (curved arrow). 1b. Didactical illustration, Type I.

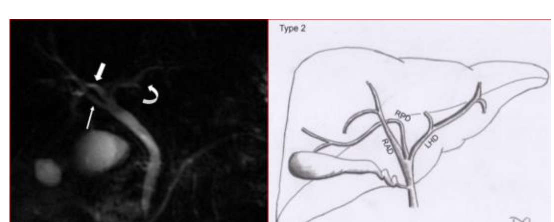

Figure 2. 2a. Type II consists of RPD (full arrow), RAD (white arrow) and LHD (curved arrow) draining at the same point into the common hepatic duct. 2b. Didactical illustration, Type II.

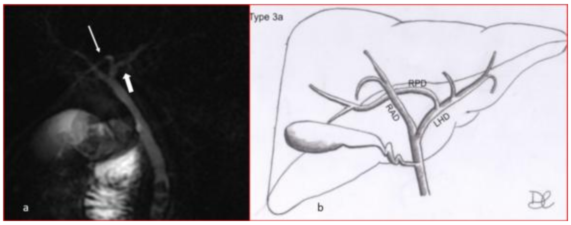

Figure 3. 3a. Type IIIa consists of RPD (white arrow) draining into the left hepatic duct (full arrow). 3b. Didactical illustration, Type IIIa.

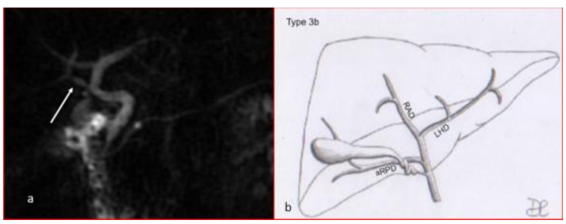

Figure 4. 4a. In Type III b we found an aberrant RPD (arrow) draining into the common hepatic duct. 4b. Didactical illustration, TypeIII b.

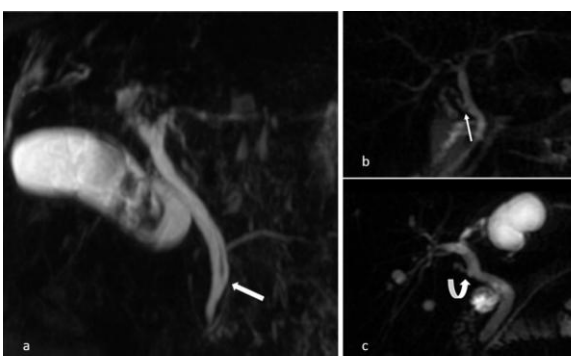

Figure 5. 5a. Cystic duct (full arrow) emptying in the distal third of the common hepatic duct, with parallel course on the medial wall. 5b. A normal implant of the cystic duct (white arrow), on the middle third of the common hepatic duct, on the lateral side wall. 5c. A high implant of the cystic duct (curved arrow) on the cranial third of the common hepatic duct with a convolute course.

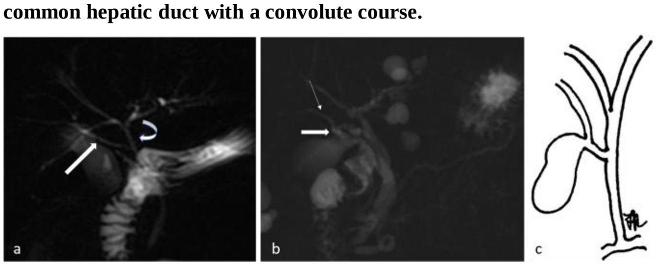

Figure 6. Complex biliary tree variants. a. An accessory RPD (full arrow) draining into the common hepatic duct (curved arrow). b. Another rare biliary tree variant with an aberrant right hepatic duct (white arrow) opening into the cystic duct (full arrow). Biliary stone is noted in the common hepatic duct. c. Didactical illustration of hepatocystic duct.

3. Results

Among 534 patients, including 288 males and 246 females, a normal morphology of intrahepatic biliary system (Type I) was found in 55% of cases. The second most frequent presentation, in about 20% of patients, was Type III a with RPD emptying on the left hepatic duct. The triple confluence morphology (Type II) was found in 10.1% of cases.

Only 6.7% of patients presented Type3b variant with aberrant RPD draining into the common hepatic duct; it was found that, in the presence of this variation, in 42% of patients with Type III b variant, the cystic duct drained directly into the aberrant duct. In about 8.4% of cases, more complex biliary variants were found (Figure 6). More in detail, these less common biliary variants were classified by Yoshida et al. (1). All anatomic presentations of the intrahepatic biliary tree are summarized in Table 2. Regarding the anatomy of the cystic duct, in 57% of patients a normal anatomy was observed, with 44% of cases showing implantation on the posterior side wall of the common bile duct, as reported in Table 3. In 14.8% of patients, the implantation of the cystic duct was cranial; in 16.6% of cases, the cystic duct joined the caudal portion of the common bile duct. In about 12% of cases, the course of the cystic duct was not depicted on MRCP images: consequently, we reported these conditions as "unclassified". By analyzing the course of the cystic duct in relation to the common hepatic duct, a parallel course was detected in 36.7% of patients and a convolute course in 26.4% of cases.

At the time of this review, thirty studies were identified by the literature search (5-32), of which fifteen were MRCP studies, eleven intra-operative cholangiography studies, three CT-cholangiographic reports and one ERCP study, as summarized in Table 4. Taking all of the studies into account, the total number of patients was 14,322. Type 1 presentation ranged from 40% to 80%. The largest study was published by Puente et al (5) in 1983 with a sample size of 3,845 patients using cholangiography, the smallest was by Ayuso et al (12) in 2004 on only 25 patients with MRCP.

Intrahepatic bile ducts	*No of patients*	*Percentage (%)*
Normal	293	55%
RPD on LHD	106	20%
Triple confluence	54	10.1%
Aberrant RPD	36	6.7%
Others	45	8.4%
Type IV	14	2.6%
Type Va	12	2.2%
Type Vb	11	2.0%
Type VI	8	1.5%

Table 2. Anatomical variants of intrahepatic biliary system at MRCP (RPD: right posterior duct; LHD: left hepatic duct)

Cystic duct implantation	*No. of patients*	*Percentage (%)*
Normal	302	57%
Cranial	79	14,8%
Caudal	89	16.7%
Unclassified	64	12%
Side-wall insertion		
Posterior	235	44%
Medial	67	12.5%
Lateral	206	38.5%
Anterior	11	2%
On aberrant RPD	15	2.8%
Cystic duct course		
Parallel	196	36.7%
Convolute	141	26.4%
Unclassified	197	36.9%

Table 3. Anatomic variations of the cystic duct at MRCP.

Study	Year	Country	No of patients	Imaging technique	Intrahepatic biliary anatomy Type 1. Type 2. Type 3 (a/b).
Puente et al (5)	1983	Chile	3,845	Cholangiography	2.217 426 673 (a=496/b=177) 57.6% 11.1% 17.5% (a=12.9%/b=4.6%)
Yoshida et al (1)	1996	Japan	1,094	Cholangiography	741 193 153 67.7% 17.7% 13.9%
Cheng et al (6)	1997	Taiwan	210	Cholangiography	138 35 31 65.7% 16.7% 14.7%
Nakamura et al (7)	2002	Japan	120	Cholangiography	78 11 29 65% 9.2% 24.2%
Kitagawa et al (8)	2003	Taiwan	170	Cholangiography	113 36 31 (a=26/b=5) 66.5% 21.2% 18.2% (a=15.3%/b=2.9%)
Choi et al (9)	2003	Korea	300	Cholangiography	188 29 53 (a=34/b=19) 62.7% 9.7% 17.7% (a=11%/b=6%)
Ohkubo et al (10)	2004	Japan	110	Cholangiography	71 6 21 64.5% 5.4% 19.1%
Lee et al (11)	2004	USA	108	MRCP	78 6 20 72.2% 5.6% 18.5%
Ayuso et al (12)	2004	Spain	25	MRCP	10 1 8 40% 4% 32%
Wang et al (13)	2005	USA	62	CT-Cholangiography	35 7 19 (a=11/b=8) 56% 11% 30.6% (a=18%/b=13%)
Chen et al (14)	2005	USA	56	MRCP	33 7 15 (a=10/b=5) 58.9% 12.5% 26.8% (a=17.9%/b=8.9%)
Macdonald et al (15)	2005	USA	39	Cholangiography	24 3 85 (a=7/b=1) 61.5% 7.7% 20.5% (17.9%/b=2.6%)
Kitami et al (16)	2006	Japan	158	CT-Cholangiography	115 8 25 72.8% 5.1% 15.8%
Vidal et al (17)	2007	France	45	MRCP	36 2 4 (a=1/b=3) 80% 4.4% 8.9% (a=2.2%/b=6.6%)
Cho et al (18)	2007	Japan	60	CT-Cholangiography	38 14 8 (a=7/b=1) 63.3% 23.3% 13.3% (a=12%/b=2%)
Sirvanci et al (19)	2007	Turkey	61	Cholangiography	46 5 10 (a=8/b=2) 75.4% 8.2% 16.4% (a=13.1%/b=3.3%)
Song et al (20)	2007	Korea	111	MRCP	67 9 30 (a=8/b=22) 60.4% 8.1% 27% (a=7.2%/b=19.8%)
Karakas et al (21)	2008	Turkey	112	MRCP	61 16 35 (a=24/b=11) 54.5% 14.3% 31.2% (a=21%/b=10%)
Kim et al (22)	2008	Korea	33	MRCP	25 1 3 75.8% 3% 9.1%
Sharma et al (23)	2008	India	253	Cholangiography	134 29 64 (a=46/b=18) 52.9% 11.5% 25.3% (a=18.2%/b=7.1%)
De Filippo et al (24)	2008	Italy	350	MRCP	202 27 35 (a=23/b=12) 57.7% 7.9% 10% (a=6.7%/b=3.3%)
Kashyap et al (25)	2008	USA	36	MRCP	24 4 8 66.6 % 11.1% 22.2%
Cucchetti et al (26)	2011	Italy	200	Cholangiography	129 28 40 (a=24/b=16) 64.5% 14% 20% (a=12%/b=8%)
Uysal et al (27)	2014	Turkey	1,011	MRCP	803 81 115 (a=42/b=73) 79.4% 8% 11.4% (a=4.2%/b=7.2%)
Chaib et al (28)	2014	Brazil	2,032	MRCP	1,247 296 396 (a=272/b=124) 61.3% 14.5% 19.5% (a=13.3%/b=6.1%)
Gupta et al (29)	2016	India	458	MRCP	301 56 84 (a=64/b=20) 65.7% 12.2% 18.4% (a=14%/b=4.4%)
Nayman et al (30)	2016	Turkey	2,143	MRCP	1329 202 394 (a=245/b=149) 62% 9% 18% (a=11%/b=7%)
Sarawagi et al (31)	2016	Poland	224	MRCP	124 26 71 (a=62/b=9) 55.3% 9.3% 31.7% (a=27.6%/b=4%)
Taghavi et al (32)	2017	Iran	362	ERCP	163 78 61 (a=48/b=13) 45% 21.5% 16.9% (a=13.3%/b=3.6%)
Current study	2019	Italy	534	MRCP	293 54 142 (a=106/b=36) 54.9% 10.1% 27% (a=20%/b=6.7%)

Table 4. Review of studies reporting intrahepatic biliary anatomic variants according to Yoshida classification. (MRCP : Magnetic Resonance Cholangio-Pancreatography ; CT : Computed Tomography ; ERCP : Endoscopic Retrograde Cholangio-Pancreatography.)

4. Discussion

An accurate knowledge of intra- and extrahepatic biliary anatomy is of crucial importance in liver and biliary surgeries. Peri-operative complications related to biliary system damage represent one of the most common reasons for morbidity and mortality in these complex interventions (33-39).

The understanding of the biliary anatomy begins with the appreciation of its embryologic development (40). The normal development of intrahepatic bile ducts requires balanced epithelial–mesenchymal interactions, which proceed from the hepatic hilum toward its periphery along the branches of the developing portal vein. There are many theories about the development of the intrahepatic bile ducts. The first theory holds that the intrahepatic biliary tree would derive from a progressive ingrowth of the epithelium of the extrahepatic biliary ducts. Another theory postulates that the entire intrahepatic bile draining system develops from hepatoblastic cells under the stimulation of growth factors and cytokines. This theory is widely accepted. Lack of remodeling of the so-called ductal plate appears to be associated often with abnormalities in the branching pattern of intrahepatic biliary system and of the portal vein (39-40). Indeed, after the birth, the branching patterns of intrahepatic biliary ducts are not completely defined and this may explain the variations of anatomy of the intrahepatic biliary tree, such as the anomalous drainage of sectorial ducts or the presence of aberrant or accessory bile ducts. Various diagnostic methods can be used to evaluate the biliary anatomy in the preoperative period (conventional T2-weighted MRCP, contrast-enhanced T1-weighted MRCP, and multidetector row CT-cholangiography) or during surgery (intraoperative cholangiography, fluorescent cholangiography, laparoscopic ultrasound) (41-45).

Currently, MRCP is considered the method of choice for the study of the biliary system, effectively taking the place of cholangiography for diagnostic purposes (2-4). However, thanks to several improvements in spatial and temporal resolution over recent years, MRCP has allowed for the investigation of the morphology of the biliary system in a non-invasive modality – avoiding exposure to ionizing radiations (2-4). This study shows that the intra-hepatic biliary system and its variations may be evaluated safely and non-invasively by MRCP. Familiarity with segmental hepatic biliary anatomy presents an important clinical application: it is essential for both staging and localization of intrahepatic liver or biliary tumors (33). In Klatskin’s tumors, for example, the therapeutic approach and outcomes are directly correlated with the biliary extension of the disease and MRCP examination allows a non-invasive determination of the staging of the disease. Moreover, the non-invasive evaluation of the intrahepatic biliary tree plays an important role before percutaneous or endoscopic approaches. It is very important to recognize the presence of variations in biliary anatomy in order to avoid inappropriate or incomplete drainage of the obstructed bile ducts. Furthermore, the careful evaluation of the biliary anatomy is essential before hepatic resections. For example, when performing a left hepatectomy for a pediatric living transplant donor, it is crucial to recognize eventual aberrant drainage of the right sectorial duct (anterior or posterior) into the left hepatic duct, because ligation of these ducts will produce biliary cirrhosis of the relative liver segments.

In the current study, we found that the most frequent morphological presentation of bile ducts was the pattern classified as "Type I"; according to the literature data this pattern ranges from 40% to 80% (5-32). The second most common presentation was Type 3a in 20% of cases. An important piece of data in the current study regards the aberrant RPD (observed in 6.7% of cases): it has been found that almost half of these patients (2.8%) showed the cystic duct draining into the aberrant RPD. The percentage reported in our analysis is higher than the value referred by Nayman et al (30), which classified this biliary variant as "Type 18". This variant was in fact reported in only one patient (0.05%). It is essential to distinguish and recognize all biliary variants, even the rarest, to plan hepatobiliary surgery accurately.

An accurate knowledge of the cystic duct-common hepatic duct junction anatomy is another important issue during laparoscopic cholecystectomy, which is actually the standard approach to treat cholelithiasis and gallbladder diseases (46-49). Bile duct injury (BDI) represents the most serious complication of laparoscopic cholecystectomy, with an incidence of 0.3-0.7% resulting in a significant impact on quality of life, overall survival and frequent medico-legal sequelae. Indeed, it has been demonstrated that the primary cause of BDI is the misinterpretation of biliary anatomy in 71% to 97% of all cases (48-49).

Biliary injury often occurs when a Type IIIb anatomic variant is present, in which the aberrant RPD may be misidentified as the cystic duct. Nowadays, the routine use of MRCP pre-operatively in order to better delineate the biliary anatomy is still an important matter of debate. In 2010, Bahram M et al (50) evaluated the influence of pre-operative MRCP on the management of patients with cholelithiasis before laparoscopic cholecystectomy. They found biliary abnormalities in 3 patients investigated pre-operatively with MRCP, this knowledge is considered very important in guiding surgeons in biliary surgery, in order to avoid iatrogenicbile duct injuries (50). Contrarily, Schmidt R et al (51) found only 10 abnormalities of biliary anatomy among 541 cases investigated with MRCP before cholecystectomy, registering limited sensitivity values (ranging from 38.5% to 50%). Therefore, MRCP is not routinely recommended to better delineate biliary anatomy prior to laparoscopiccholecystectomy. Single-institution data and retrospective analysis were the main limitations of this study.

5. Conclusions

MRCP is an effective, reliable, and non-invasive imaging method for evaluating the intra-hepatic biliary system and its anatomic variations. The correct knowledge of biliary tree anatomy before surgery is essential in accurate surgical planning of complex hepatobiliary operations, thereby reducing morbidity and mortality.

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