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REVIEW

Magnetic resonance and retrograde endoscopic cholangiopancreatography-based identification of biliary tree variants: are there type-related variabilities among the Saudi population?

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Abstract

Purpose This study investigated biliary tree patterns in a Saudi Arabian population to identify common anatomical variations to establish a common ground for improved surgical practice and to avoid unexpected complications. We consider this type of investigation clinically important because the findings are valuable for pre-surgical planning in a broad range of procedures, including laparoscopic cholecystectomy and liver transplantation.

Methods We conducted an imaging-based retrospective cross-sectional study involving 150 patients who underwent endoscopic retrograde cholangiopancreatography and magnetic resonance cholangiopancreatography for different indications at King Fahd Hospital of the University between January 2011 and December 2014.

Results Typical right hepatic duct (RHD) tributaries were observed in 56% of patients and typical left hepatic duct (LHD) anatomy was detected in 81.4% of patients. The typical anatomical pattern for the cystic duct was found in 72% of patients.

Conclusions Our findings showed that types A1 and A3b were the two most common variations in the RHD, whereas those in LHD were types B1 (segment IV duct opens to the LHD), and B2 (segment IV duct opens to the common hepatic duct separately). Although the angular type was the most prevalent among cystic duct variations, there were many differences in the types of variations observed. The findings somewhat correlated with those of other studies, suggesting that the normal biliary tree anatomy is similar among the Saudi population and in other ethnic groups.

Keywords Biliary tree anatomy · Variation · ERCP · MRCP · Saudi Arabia

Introduction

The liver is a large organ that sits in the right hypochondrium and epigastric region and extends into the left hypochondrium [21]. The biliary tree is conventionally divided into the intrahepatic and extrahepatic bile ducts. Thus, correct intraoperative cholangiography (IOC) requires full understanding of the various potential variations in biliary tree anatomy [9]. Data from Saudi Arabia are nearly compatible with the worldwide prevalence of anatomical biliary variants in the literature [1].

Magnetic resonance cholangiopancreatography (MRCP) is an advanced and modern body magnetic resonance imaging technique based on T2-weighted sequences that facilitates the non-invasive visualization of the pancreatic and intra- and extrahepatic biliary tree. MRCP does not require

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contrast agent administration but does allow rapid and accurate delineation of the pancreaticobiliary system with a high level of spatial resolution [18]. Furthermore, MRCP produces images similar to those obtained in endoscopic retrograde cholangiopancreatography (ERCP) procedures. However, although invasive ERCP is still considered the gold-standard procedure for diagnosing biliary obstruction, MRCP is suggested as a secondary tool in cases in which ERCP is unsuccessful or contraindicated [13].

Local information regarding the role of ethnicity, sex, and age on variations in biliary tree anatomy is lacking. As such, further investigation is needed to identify the most common types and type-related factors that might influence these variations. With the above points in mind, the purpose of this study was to assess the standard anatomical structures of the biliary tree and to highlight the most common types of anatomical variations in a group of Saudi patients. Further, we analyzed the roles of sex, age, and imaging modalities and compared our findings with the results from other populations.

Methods

Patient selection

This was a retrospective cohort study of 150 Saudi patients who underwent ERCP (130 patients, 86.7%) or MRCP (20 patients, 13.3%) for different biliary complaints at King Fahd Hospital of the University, Al-Khobar, Eastern Province, Saudi Arabia, between January 2011 and December 2014. All patients were Saudis from different regions of the Kingdom. Patient selection was based on whether the biliary ductal system could be viewed and evaluated. No age limits were applied during the selection phase.

Study parameters

In all cases, the anatomical classification of the following biliary ducts was assessed from either ERCP or MRCP records. The right hepatic duct (RHD) was investigated based on right posterior hepatic duct (RPHD) and right anterior hepatic duct (RAHD) drainage according to the classification by Huang et al. [11]. The left hepatic duct (LHD) was investigated based on segment IV drainage according to the classification by Huang et al. [11], which was based on the ERCP findings in the widely used radiological workup of donor candidates. The cystic duct was investigated based on its drainage pattern, course, and existence according to the classification by Sureka et al. [22], who discussed multiple variations of the cystic duct according to their pivotal significance and preoperative assessment.

Statistical methods

All data were coded, tabulated, and represented as frequencies with percentages before analysis using the Chi-square test or Fisher's exact test. Data, presented as means and standard deviations, were analyzed using the independent *t* test and analysis of variance. All analyses were performed using SPSS v21.0 (IBM Corp., Armonk, NY, USA). A P value < 0.05 was considered statistically significant. Statistical analyses were performed to test for correlations between sex, age, the imaging modality, and RHD variations.

Imaging equipment

A Philips BV Libra ERCP device (Philips Research, Eindhoven, The Netherlands) was used with various accessories and settings. These included a 9-inch triple-mode image intensifier, Body Smart imaging software, a laser aiming system, dose-saving pulsed fluoro mode, Full Radiology Information System/Hospital Information System compatibility, a Medcapture or paper/transparency printer, medical DVD recorder, Digital Imaging and Communications in Medicine integration, Modality Performed Procedure Step, and Single button control. All MRCP images were obtained with a MAGNETOM Symphony device (Siemens AG, Erlangen, Germany) with the following parameters: minimum 2D/3D slice thickness = 0.1/0.05 mm, field strength = 1.5 Tesla; bore size = 60 cm; system weight = 4050–5500 kg; and helium consumption with Zero Helium boil-off technology.

Results

Demographic results revealed that the mean age of the 150 patients was 37 years (range 10–79). There were 87 (58%) male patients (male:female = 1:1.38) (Table 1). Investigation of RHD anatomical variations based on the classification system by Huang et al. [11] revealed that the variants A1, A2, A3b, A4a, A4b, and A5 were detected (Fig. 1). Type A3a was not found in any patient. The A1 variation was found in 84 (56%) participants, variant A2 in 20 (13.3%),

Table 1 Summary of demographic information of study participants

Sex	Imaging modality		
	ERCP	MRCP	Total
Male	55	8	63 (42%)
Female	75	12	87 (58%)
Total	130 (86.7%)	20 (13.3%)	150 (100%)

ERCP endoscopic retrograde cholangiopancreatography, *MRCP* magnetic resonance cholangiopancreatography

and variant A3b in 43 (28.7%). The A4a variant was detected in a single male patient (1.59%). In contrast, the A4b and A5 variants were found in two female participants each (1.15%). Pearson's correlation coefficient revealed an insignificant relationship between RHD and sex or age ($P=0.263$, $P=0.491$, respectively). Differences in the variations of the LHD between MRCP and ERCP were also insignificant ($P=0.689$).

Investigation of LHD anatomical variations based on the Huang et al. [11] classification system revealed that variants B1, B2, and B3 were observed in the population (Fig. 2). The B1 variant was found in 124 (82.4%) participants, the B2 variant in 17 (11.3%) participants, and the B3 variant in nine (6%). However, variant B4 [segment IV drains into the common hepatic duct (CHD)] and B5 (segment IV joins segment II) were not detected in any patients (Fig. 2). Pearson's correlation coefficient revealed an insignificant correlation of LHD variants with sex and age ($P=0.434$, $P=0.086$, respectively). Differences in the variations the LHD between MRCP and ERCP were also insignificant ($P=0.517$).

Investigation of cystic duct anatomical variations based on the classification system by Sureka et al. [22] revealed four variants. Variants (A), (B), (C), and (D) were detected (Fig. 3). Variants (E), (F), (G) and (H) were not found. Variant (A) was the most common type and found in 108 (72%) participants, (B) in 15 (10%), (C) in six (4%), and (D) in seven (4.7%). However, 14 patients had cholecystectomy and were included in the post-cholecystectomy group. Pearson's correlation coefficient revealed an insignificant correlation of LHD with sex or age ($P=0.634$, $P=0.715$, respectively). Differences in the variations of the cystic duct between MRCP and ERCP were also insignificant ($P=0.638$).

Finally, we compared these results to those from previous studies that identified various anatomical variants of RHD and LHD according to the classification system by Huang et al. [11] (Tables 2 and 3) or the Al-Jiffry [1] classification system (in the case of the cystic duct) (Table 4).

Discussion

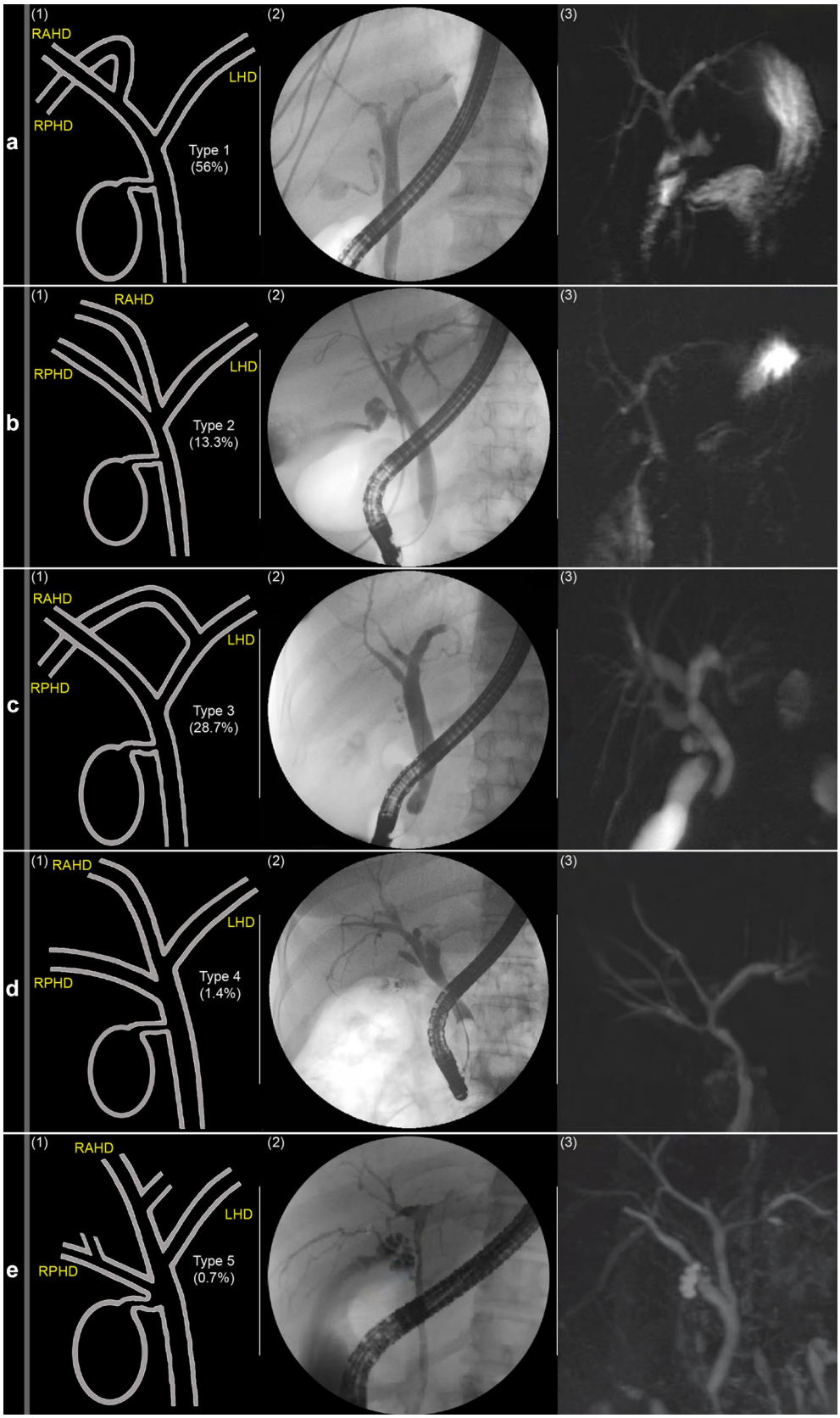
Knowledge of typical ductal anatomy and variations is crucial for pre-surgical planning, including laparoscopic cholecystectomy and liver transplantation surgeries, to minimize the risk of intra- and postoperative complications, such as bile leakage, bile peritonitis, biliary stricture, obstructive jaundice, cholangitis, and liver abscess [4]. Therefore, to better understand the variability in biliary drainage, a brief review of biliary tract embryology is needed.

The beginning of the fourth embryonic week is considered as the developmental phase for the liver, hepatic ducts, gallbladder, and extrahepatic biliary system. Nevertheless, the beginning of the fourth embryonic week is deemed as an endodermal expansion from the ventral aspect of the most caudal part of the foregut. The gallbladder and the cystic duct are formed from the ventral portion of the diverticulum, while the cranial portion of the diverticulum invades the septum transversum as the liver primordium. The liver primordium increases to form the liver cells and the epithelial lining of the intrahepatic biliary ducts. Thus, these increased cells form the hepatic ducts, which are initially shaped as a plexus. Later, many of these ducts interact to compose the definitive hepatic duct pattern, but one or more may persist as ducts draining a small part of the liver. This phase occurs in the 4th–5th embryonic week. The anomalous bile ducts exist as a result of abnormal resorption of the initially plexiform arrangement of the hepatic ducts. [17, 20].

In this study, the typical intrahepatic ductal anatomy of the RAHD and RPHD joining to form the RHD (type A1) was present in 56% of patients, thus, considered the most common anatomic variation of RHD. These results were comparable to the findings of Al-Jiffry [1], who noted a 59% rate of this type in a Saudi population. Moreover, this anatomical type was found in similar percentages in the Anatolian Caucasians and Turkish populations [14, 19]. Higher percentages were recorded in Korean and Egyptian populations [6, 24]. From the above, there are discrepancies in the incidence of type A1 RHD among different populations and techniques; however, it appears to be the most prevalent type of RHD anatomy (Table 2).

In this study, the RHD was absent in 13.3% of cases; in these cases, the RAHD and RPHD ducts joined the LHD directly to form the CHD (type-A2 RHD/trifurcation). This triple confluence where the RHD is absent was not that common in our study. This finding was not consistent with that of the recent Brazilian review by Chaib et al. of 2042 patients in the period between 1996 and 2011 that ranked this anomaly among the most common confluence variants from 1996 to 2011 [3].

Although we detected no cases of A3a RHD, the most prevalent (28.7% of cases) anomalous variation in this study was type-A3b RHD, in which the RPHD opens directly into the LHD, and this finding was consistent with that reported in other studies [6, 14, 19, 24]. In contrast, prior national record from Al-Jiffry [1] found type-A3b RHD in only 4% and type-A3a RHD in 2.2% of patients using the traditional IOC. This could be attributed to under-optimum conditions in performing IOC, although it provides a high-quality view of the biliary tract [19]. However, due to the inconvenient conditions during the surgery, this method may not always be performed successfully. Nonetheless, recent investigators claim that the MRI technology is still developing, and it may replace IOC and shorten the duration of the surgery in the future, especially with an evaluation accuracy reaching 91.5% in comparison to that of IOC [15, 23].


a
(1)
RAHD
LHD
RPHD
Type 1
(56%)
(2)
(3)
b
(1)
RAHD
RPHD
LHD
Type 2
(13.3%)
(2)
(3)
c
(1)
RAHD
LHD
RPHD
Type 3
(28.7%)
(2)
(3)
d
(1) RAHD
LHD
RPHD
Type 4
(1.4%)
(2)
(3)
e
(1)
RAHD
LHD
RPHD
Type 5
(0.7%)
(2)
(3)

◂**Fig. 1** Demonstration of the recorded types of right hepatic duct, according to the Huang et al. [11] classification system. **a** Type A1 RHD: (1) the typical anatomical appearance of the biliary system, RAHD and RPHD join together to form the RHD. (2) Type A1 selective image of ERCP. (3) Type A1 selective image of MRCP. **b** Type A2 RHD: (1) a trifurcation anomaly of the biliary confluence, RHD is absent, and the RAHD and RPHD directly join the confluence with the LHD, to form the CHD. (2) Type A2 selective image of ERCP (3) Type A2 selective image of MRCP. **c** Type A3b RHD: (1) anomalous drainage of the RPHD into the LHD (RPHD draining directly into the LHD). (2) Type A3b selective image of ERCP. (3) Type A3b selective image of MRCP. **d** Type A4 RHD: (1) drainage of the RPHD directly into the CHD. (2) Type A4 selective image of ERCP. (3) Type A4 selective image of MRCP. **e** Type A5 RHD: (1) anomalous drainage of the right posterior segmental duct into the cystic duct. (2) Type A5 selective image of ERCP. (3) Type A5 selective image of MRCP

During laparoscopic cholecystectomy, RPHD can be observed for the cystic duct; besides, its injury can be isolated or associated with that of the common bile duct (CBD) that can result in side effects, such as obstruction or bile leakage, biliary fistula, biloma, abdominal pain, peritonitis or cholangitis, and atrophy of the hepatic posterior sector [2]. Controlling this type of injury is limited to being expert in case reports or small series. Moreover, therapeutic management options differ from case to case. Severity of the symptoms, volume of bile drainage, and presentation with leak or stenosis lead to difficulties in appropriate management and treatment [25]. Önder et al. [15] recorded type A3b in 12.1% of patients. Types A3a and A3b combined were recorded by Choi et al. [6] in 17% of cases, by Karakas et al. [12] in 21%, and by Tawab and Ali [19] in 17% as the most frequent RHD variation. Al-Jiffry [1] recorded type-A3b RHD in only 4% and type-A3a RHD in 2.2% of patients using IOC. In the present study, we detected no cases of A3a RHD.

In 0.7% of cases in this study, the RPHD opened directly into the cystic duct (type A5 RHD). It is evident that the least reported variation was A5 RHD in this study. This is close to the figure recorded by Al-Jiffry [1] of 1.1% (Table 4, Fig. 1). Herein, our sample emphasizes the likelihood of RPHD to drain into the LHD (Type A3b) rather than directly into the cystic duct.

The previous results reported by Haung et al. concerning types B1 and B2 were similar to the findings of the present study [11] (Table 3). Type B1 LHD, in which segment IV opens into the LHD, was seen in 82.7% of patients in this study, representing the prevalent anatomical variant for the LHD. Followed by type B2-LHD, in which segment IV opens into the CHD separately to segments II and III; the rate was 11.3%. In general, the available literature regarding the anatomical variations of the LHD is scarce, warranting further study.

Cystic duct anatomical variants are relatively rare. The identifications of actual anatomical trajectory variants of the cystic duct is important due to the recent emerging types such as the perivesical cystic duct [10] or double CBD [5, 12] reflecting the fact that cystic duct types may be present more commonly but are underdiagnosed. Some types are even difficult to detect on imaging explorations. [5, 10, 12] The present findings show that the most common type of cystic duct insertion variant is type A (angular) in which the cystic duct joins the CHD at its distal third, near the ampulla of Vater. This variant was present in 72% of cases, which is comparable to the value of 74.6% reported by Al-Jiffry [1]. The incidences of other variations are shown in Table 4.

Anatomic variations in the biliary system are highly prevalent and might be seen in more than 30% of cases. This value is supported by the present and previous studies. Ethnicity and gender do not play a significant role in producing these variations. Thus, further investigations should be performed to identify factors that might influence the type of these variations. It has been reported by Deka et al. [8] that there are six different classification systems that can be used to study biliary anatomical variations. These classifications have been described by Couinaud [7], Champetier [4], Huang et al. [11], Choi et al. [6], Ohkubo et al. [18], and Karakas et al. [14]. This diversity in classification systems could be one explanation for the discrepant results observed in previous reports.

Moreover, this is not the only study performed in an Asian country. Another recent study was conducted at Chiba University Hospital, Japan. This study addressed the importance of imaging techniques (including MRCP and ERCP) for the evaluation of biliary tract anatomy while focusing on variations among the pediatric population [3]. However, the present study included a larger sample and did not restrict enrollment to a particular age group. Our study revealed no significant associations between anatomical variants and different age groups. Furthermore, we did not confine our investigation to choledochal cystic dilatation of the biliary tree and instead investigated all anatomical variants encountered during the study period.

The present study had some limitations that should be discussed. First, the retrospective nature of this study introduced the risk of selection bias. As such, essential missing findings due to incomplete files and images cannot be ruled out. Second, the number of ERCP and MRCP procedures was insufficient, meaning that more critical radiological findings could have been missed.

In conclusion, the findings of this study correlated with the findings of other studies in some respects, suggesting that the normal biliary tree anatomy is similar among the Saudi population and in other different ethnic groups. However, there were many encountered differences in few of the variations observed. Type A1 and type-A3b were the two most common variations in the RHD, whereas the two most common variations in the LHD were variants B1 (segment

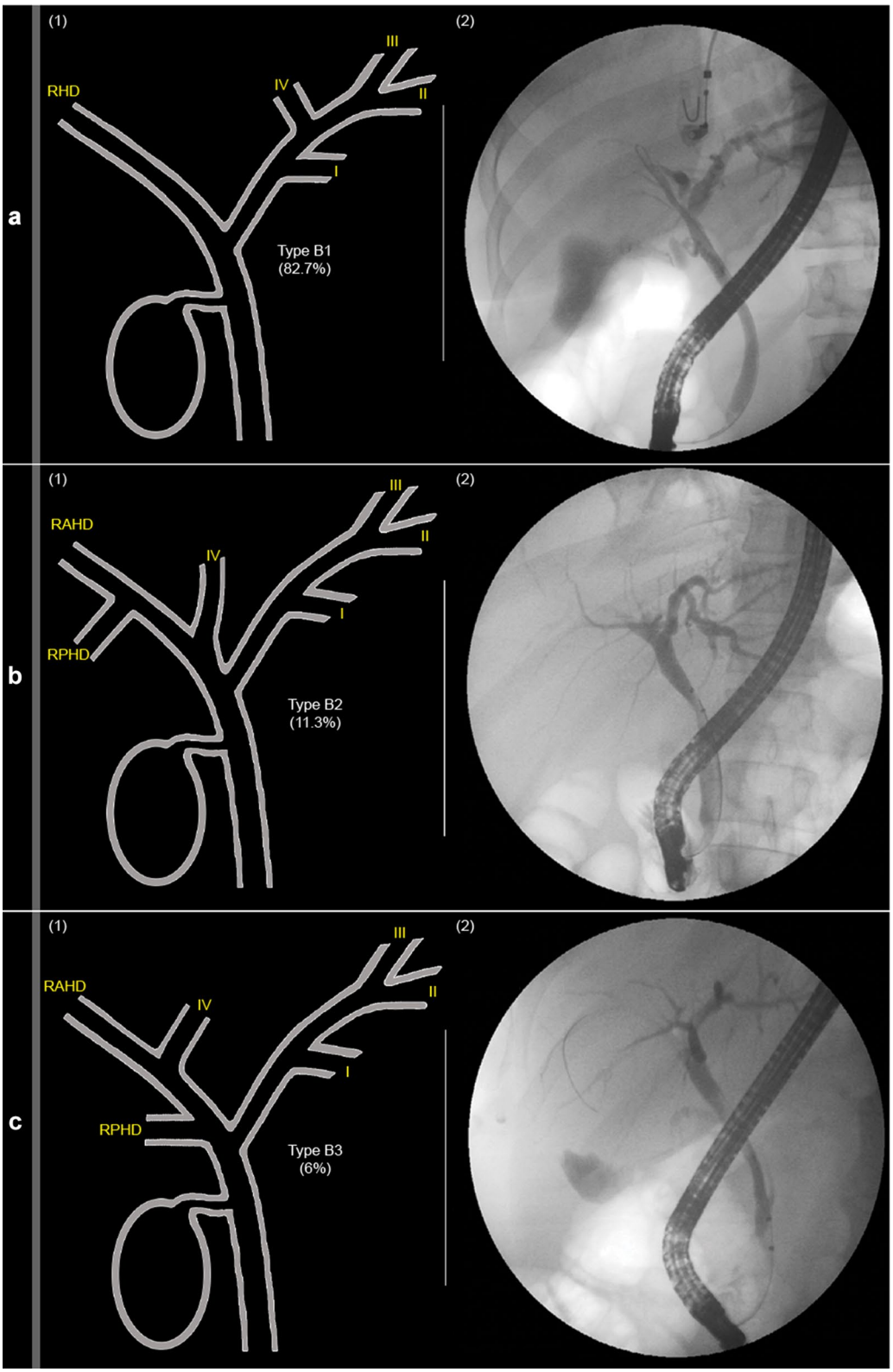


Fig. 2 Demonstration of the recorded types of LHD, according to the Huang et al. [11] classification system: **a** Type-B1 LHD: (1) illustrating typical anatomical branching of the LHD dependent on segment IV insertion. (2) Type B1 selective image of ERCP. **b** Type-B2 LHD: (1) segment II, segment III, and segment IV ducts; drainage of segments II and III into the LHD; and segment IV draining into the common hepatic duct independently of the segments II and III ducts. (2) Type B2 selective image of ERCP. **c** Type B3 LHD: (1) segment IV draining directly into the RAHD. (2) Type B3 selective image of ERCP. *LHD* left hepatic duct, *RPHD* right posterior hepatic duct, *ERCP* endoscopic retrograde cholangiopancreatography, *RHD* right hepatic duct, *RAHD* right anterior hepatic duct

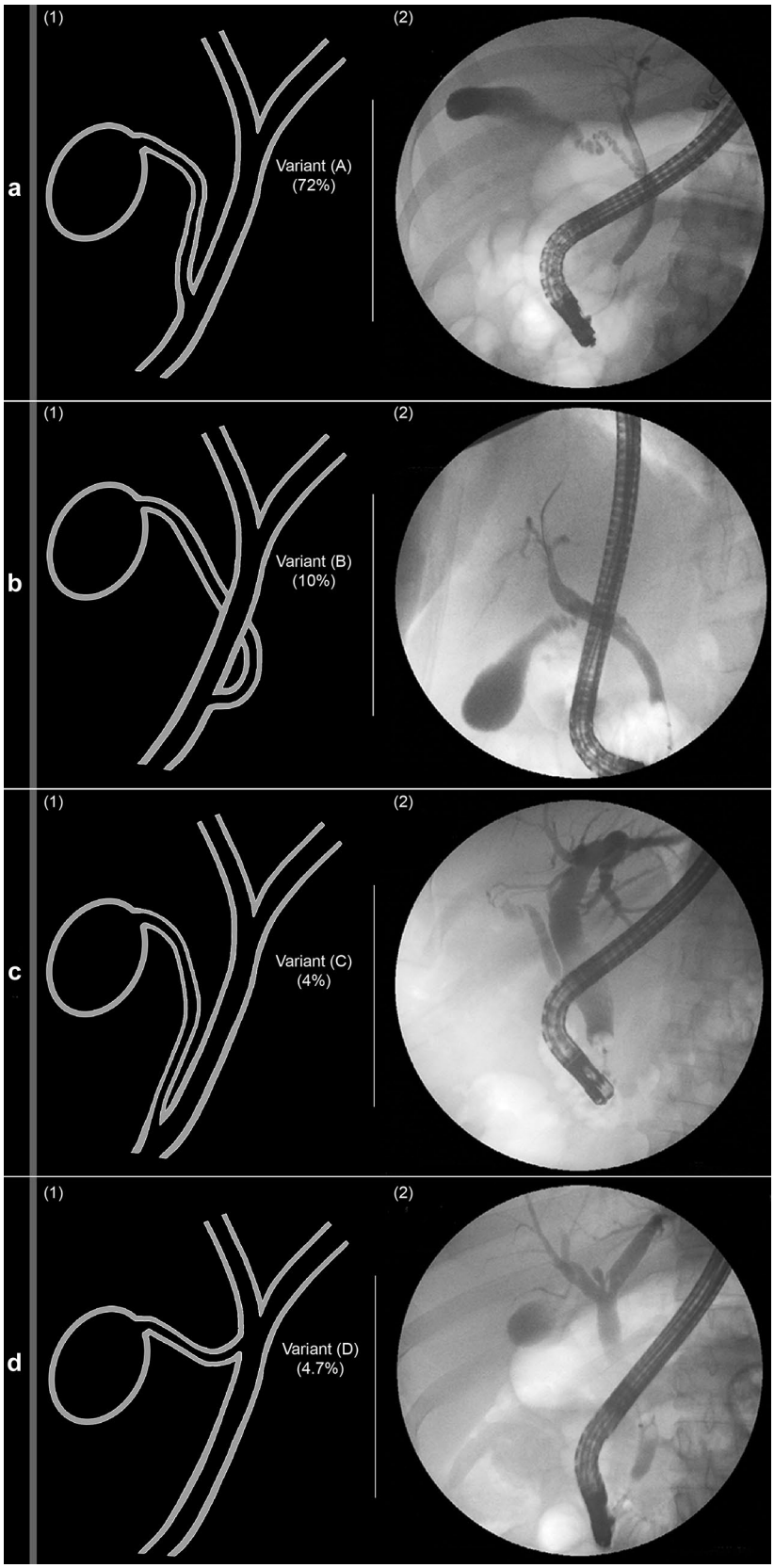


Fig. 3 Demonstration of the recorded types of cystic duct, according to the Sureka et al. [22] classification system: **a** Variant-A (angular) cystic duct: (1) demonstrating a long, tortuous angular cystic duct in which the cystic duct joining the CHD at its distal third. (2) Variant-A selective image of ERCP. **b** Variant-B (spiral) cystic duct: (1) demonstrating a cystic duct joining the distal third of the CHD medially to form the CBD. (2) Variant-B selective image of ERCP. **c** Variant-C (parallel) cystic duct: (1) demonstrating a parallel course between the cystic duct and CHD running together at least 2 cm before joining to form the CBD. (2) Variant-C selective image of ERCP. **d** Variant-D (short) cystic duct demonstrating high insertion of the short cystic duct at the level of the CHD confluence. (2) Variant-D selective image of ERCP

Table 2 Various types of RHD variation in this study and previous studies

Study information				RHD variations				
Researcher/s	Population	Method	*N*	Type A1 (%)	Type A2 (%)	Type A3 (a + b) (%)	Type A4 (a + b) (%)	Type A5 (%)
Huang et al. [11]	China	ERCP and MRCP	959	62.6	19	11	5.8	1.6
Choi et al. [6]	Korea	IOC	300	63	10	17	0	6
Karakas et al. [14]	Anatolian Caucasians	MRCP	112	55	14	21	10	0
Tawab and Ali [24]	Egypt	MRC	106	63.2	10.4	17	7.5	1.9
Mariolis-Sapsakos et al. [16]	Greece	Cadaveric dissection	73	65.75	9.59	5.48	18.44	1.37
Al-Jiffry [1]	Saudi-Taif	IOC	177	59	10.7	6.2	18	1.1
This study	Present study Saudi-Khobar	ERCP and MRCP	150	56	13.3	28.7	1.4	0.7

ERCP endoscopic retrograde cholangiopancreatography, *IOC* intraoperative cholecystography, *MRCP* magnetic resonance cholangiopancreatography, *MRC* magnetic resonance cholangiography, *N* number of cases, *A1* right anterior hepatic duct (RAHD) and right posterior hepatic duct (RPHD) join to form the right hepatic duct (RHD), *A2* RHD is absent and RAHD and RPHD join directly to the confluence with the left hepatic duct to form the common hepatic duct, *A3a* RAHD drains directly into the LHD, *A3b* RPHD drains directly into the LHD, *A4a* RAHD drains directly into the common hepatic duct, *A4b* RPHD drains directly into the common hepatic duct, *A5* RPHD drains into the cystic duct

Table 3 Various types of LHD in this study compared to Haung et al. [11]

Type of LHD variation	Haung et al. [11] *N*: 959 (%)	Present study *N*: 150 (%)
Type B1	76.1	82.7
Type B2	16	11.3
Type B3	4	6
Type B4	0.9	0
Type B5	3	0

N number of cases, *LHD* left hepatic duct, *Type B1* segment IV duct opens to the left hepatic duct, *Type B2* segment IV opens to the common hepatic duct separately to segments II and III, *Type B3* segment IV opens to the right anterior hepatic duct, *Type B4* segment IV opens to the common hepatic duct, *Type B5* segment IV opens to the segment II duct

Table 4 Various types of cystic duct insertion in this study compared to Al-Jiffry [1]

Type of cystic duct insertion	Al-Jiffry [1] *N*: 177 (%)	Present study *N*: 150 (%)
Type A	74.6	72
Type B	11.3	10
Type C	14.1	4
Type D	0	4.7

N number of cases, *Type A* long cystic duct with low insertion into the distal third of common bile duct, *Type B* medial cystic duct insertion, *Type C* parallel course of the cystic duct with common hepatic duct, *Type D* abnormally high fusion of cystic duct with the common hepatic duct

IV duct opens to the LHD), and B2 (segment IV duct opens to the CHD separately). Moreover, the angular type was the most prevalent among cystic duct variations. These results stress that all patients should be thoroughly assessed before surgical procedures, especially liver transplantation.

Author contributions All authors contributed toward data analysis, drafting, revising the paper and agree to be accountable for all aspects of the work. Prof. AA-Q has a substantial role in preparing our revised paper.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Approval was obtained from the Ethics Committee of Imam Abdulrahman Bin Faisal University, King Fahd Hospital of the University (IRB-2018-01-144).

Informed consent For this type of study formal consent is not required. For ethical reasons, patient data were omitted from the cholangiograms used in this study.

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