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St. Paul's Hospital Millennium Medical College

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Department of Radiology and Medical Radiology Technology

Prevalence and anatomical characteristics of biliary duct variants on Magnetic Resonance Cholangiopancreatography (MRCP): a retrospective study at St. Paul's Millennium Medical College (2025–2026)

By Dr Hanna.Tesfaye (MD, Clinical Radiology Resident)

A research proposal to be submitted to the Department of Radiology and Medical Radiology Technology, Saint Paul's Hospital Millennium Medical College for the partial fulfillment of the requirements for certificate of specialty in Clinical Radiology

Affiliation: Department of Clinical Radiology, Saint Paul's Hospital Millennium Medical College, Addis Ababa, Ethiopia

August, 2026

Addis Ababa, Ethiopia

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Academic Research Proposal Submission Guide

Name of investigator	Dr. Hanna. Tesfaye
Full title of the research project:	Prevalence and anatomical characteristics of biliary duct variants on Magnetic Resonance Cholangiopancreatography (MRCP): a retrospective study at St. Paul's Millennium Medical College (2025–2026)
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Advisor's Approval Sheet

This is to certify that thesis proposal prepared by Dr. Hanna Tesfaye entitled as "Prevalence and anatomical characteristics of biliary duct variants on MRCP: a retrospective study at St. Paul's Millennium Medical College" submitted in partial fulfilments of the requirements of specialty clinical radiology and as a thesis advisor, I hereby, certify that I have read and evaluated this thesis proposal prepared under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby, the student can submit the thesis proposal to the department.

Approval of the Clinical Advisor, Dr. Nebyu Samuel (MD, Radiologist, Body imaging fellow)
Signature _____
Date

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Abbreviations

CBD	Common Bile Duct
CHD	Common Hepatic Duct
CI	Confidence Interval
CT	Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
EMR	Electronic Medical Record
FMOH	Federal Ministry of Health
HR	Hazard Ratio
IOC	Intraoperative Cholangiography
IRB	Institutional Review Board
LHD	Left Hepatic Duct
MRCP	Magnetic Resonance Cholangiopancreatography
MRI	Magnetic Resonance Imaging
OR	Odds Ratio
PACS	Picture Archiving and Communication System
RASD	Right Anterior Sectoral Duct
RHD	Right Hepatic Duct
RPSD	Right Posterior Sectoral Duct
SPHMMC	St. Paul's Hospital Millennium Medical College
SPSS	Statistical Package for the Social Sciences
US	Ultrasound

Abstract

Background: Biliary anatomical variations are relatively common and are clinically important because failure to recognize them may increase the risk of bile duct injury and other complications during hepatobiliary surgery and interventional procedures. Magnetic resonance cholangiopancreatography (MRCP) provides a non-invasive method for delineating biliary anatomy. However, data on the prevalence and patterns of biliary anatomical variants among patients undergoing MRCP in Ethiopia are limited.

Objectives: To determine the prevalence and patterns of biliary anatomical variants and to assess their association with selected demographic and clinical characteristics among patients undergoing MRCP at St. Paul's Hospital Millennium Medical College (SPHMMC), Addis Ababa, Ethiopia.

Methods: A retrospective cross-sectional study (chart review) was conducted among adult patients who underwent MRCP at Saint Paul's Hospital Millennium Medical College (SPHMMC) between July 1, 2025 and June 30 , 2026. All eligible MRCP examinations which were acquired using 1.5-Tesla MRI machine and standard MRCP protocols and performed during the study period were included using total enumeration. A total of 152 eligible MRCP examinations were analyzed. The MRCP images were independently reviewed by two radiologists. Intrahepatic biliary duct variations were classified according to the Huang classification system, while extrahepatic duct variations were categorized using established anatomical criteria. The collected data entered into and analyzed using SPSS version 26. Descriptive statistics was used to summarize demographic, clinical and biliary anatomical characteristics. Associations between biliary anatomical variation and selected demographic and clinical factors were assessed using appropriate inferential statistical tests and crude odds ratios with 95% confidence intervals were calculated.

Results: Biliary anatomical variants were identified in 30 patients, giving an overall prevalence of 19.7%. Intrahepatic variants alone were identified in 10 patients (6.58%), extrahepatic variants alone in 21 patients (13.82%), and both intrahepatic and extrahepatic variants in 1 patient (0.7%). A statistically significant association was observed between biliary anatomical variation and cholecystitis (OR 5.85, 95% CI: 1.65–20.74;

p=0.008). Interobserver agreement between the two radiologists for the overall classification was almost perfect, with 99.3% observed agreement and Cohen's κ=0.979.

Conclusion: Biliary anatomical variants were identified in approximately one in five patients undergoing MRCP at SPHMMC. The high interobserver agreement indicates excellent reproducibility of the overall anatomical classification. These findings provide institution-level data on biliary anatomical variation and highlight the importance of careful assessment of biliary anatomy on preoperative imaging to support safe hepatobiliary interventions.

Keywords: Biliary duct variants; Magnetic resonance cholangiopancreatography (MRCP); Hepatobiliary anatomy; Ethiopia

1. Introduction

1.1 Background of the Study

The biliary system represents one of the most anatomically variable regions of the human body(1). Embryological development of intrahepatic and extrahepatic bile ducts involves complex recanalization and segmental proliferation, often resulting in structural deviations from classic anatomy(2). Global data indicate that anatomical variants occur in 20–55% of individuals, with variations reflecting population-specific developmental patterns.(3).

Preoperative mapping of biliary anatomy using magnetic resonance cholangiopancreatography (MRCP) enhances surgical planning across multiple procedures, including living donor liver transplantation, partial hepatectomy, and complex biliary reconstruction(4). In this context, MRCP has demonstrated a good sensitivity and specificity for detecting anatomically significant variant patterns, though accessory ducts and minor branches may occasionally escape detection on non-enhanced imaging protocols (5,6). The spectrum of anatomical variants encompasses multiple classification schemes, each developed to systematize the observed variations and facilitate communication among clinicians. The Huang classification system, widely adopted for characterizing right hepatic duct branching patterns, identifies five major types based on the route of the right posterior sectoral duct (RPSD) and the presence of trifurcation or aberrant drainage patterns (7). Similarly, cystic duct insertion patterns, characterized by their point of origin on the extrahepatic biliary tree and their course through the hepatocytic triangle, have been extensively documented with reported prevalence variations across populations(8).

1.2 Statement of the Problem

Clinical and Diagnostic Challenges

Despite the widespread availability of advanced imaging modalities, the preoperative diagnosis and characterization of biliary anatomical variants present ongoing clinical challenges. The complexity of the biliary tree anatomy, combined with the variability of anatomical presentations, frequently results in inadequate preoperative assessment,

leading to intraoperative recognition of previously undetected variants (3). This situation is exacerbated in resource-limited settings, where imaging access may be constrained and radiological expertise in advanced biliary imaging may be concentrated at few specialized centers (9).

The critical view of safety, a well-established intraoperative technique for identifying the cystic artery-cystic duct-common bile duct triangle, remains the foundation of safe laparoscopic cholecystectomy. However, this technique provides no preoperative information and may prove impossible to achieve intraoperatively in cases of inflammation, anatomical distortion, or unexpected variants(10). Early recognition of anatomical complexity through preoperative imaging can guide decisions regarding operative approach (open versus laparoscopic), operative timing, and need for intraoperative imaging or alternative surgical strategies.

Accurate preoperative identification of biliary variants is crucial in hepatobiliary surgery to prevent iatrogenic complications. Studies from multiple geographic regions have consistently demonstrated that inadequate preoperative imaging assessment and subsequent misidentification of normal anatomy or anatomical variants during surgical procedure contribute substantially to biliary duct injury rates(11).

These injuries result in prolonged postoperative morbidity, increased healthcare costs, and in severe cases, long-term sequelae including secondary biliary strictures and cholangitis(12).Laparoscopic cholecystectomy, despite its widespread adoption and generally favorable safety profile, remains associated with bile duct injury rates of 0.3–0.7%, approximately two to threefold higher than open cholecystectomy. Many of these injuries occur in the setting of unrecognized anatomical variants, highlighting the necessity for preoperative imaging assessment in challenging cases (13,14) .

A comprehensive search of medical literature reveals substantial international variation in reported prevalence of biliary anatomical variants, ranging from 20% to 55% depending on the population studied, imaging modality employed, and classification system applied (3). However, systematic regional data from African healthcare settings, and specifically from Ethiopia, remain scarce. This represents a significant gap in the global understanding of biliary anatomical variation across diverse populations.

The absence of locally derived prevalence data creates practical challenges for clinicians in African settings. When prevalence estimates are extrapolated from geographically distant populations, potential population-specific variations may be overlooked, leading to diagnostic bias in clinical practice. Furthermore, the lack of institutional data

prevents the establishment of quality benchmarks for imaging interpretation and surgical outcomes assessment at local healthcare facilities.

1.3 Significance of the Study

This retrospective study will generate institutional data on the prevalence and characteristics of biliary duct anatomical variants within the patient population served by St. Paul's Hospital. These data will serve multiple important functions for local and regional surgical practice. First, establishment of locally derived prevalence estimates will enable more accurate preoperative risk stratification and identification of patients who would benefit from detailed preoperative imaging assessment. Second, documentation of the spectrum of anatomical variants encountered within this population will enhance surgical training and increase awareness among trainees and practicing surgeons regarding the range of potential anatomical configurations. Third, comparison of locally derived data with international literature may identify population-specific patterns in anatomical variant distribution, contributing to the growing body of evidence regarding global anatomical variation. Finally, these data will support quality improvement initiatives at St. Paul's Hospital by providing institutional baseline metrics for imaging quality assessment and outcomes monitoring in hepatobiliary surgical patients

2. Literature review

2.1 Global Prevalence and Classification of Biliary Duct Variants

Systematic documentation of biliary anatomical variation dates to the early twentieth century, with classical anatomical descriptions based on cadaveric dissection studies. However, the advent of advanced cross-sectional imaging, particularly MRCP, has enabled detailed in vivo characterization of biliary anatomy across large patient populations. Contemporary studies consistently report that anatomically standard intrahepatic bile duct branching patterns, characterized by separate right hepatic duct (RHD) and left hepatic duct (LHD) arising from a distinct common hepatic duct, occur in only 50–72% of the general population(7,15).

The Huang classification system, which categorizes intrahepatic and hilar ductal anatomy into five major types based on the drainage pattern of the RPSD and presence of trifurcation or other variations, has achieved widespread adoption in surgical literature and institutional protocols. Type A1 anatomy, representing the classic bifurcation pattern, occurs in approximately 60% of patients; Type A2, characterized by RPSD drainage into the LHD, occurs in 12%; Type A3, with trifurcation pattern, occurs in 12%; while less common variants (Types A4, A5, and Type B) account for the remaining cases. These prevalence estimates, derived from large multicenter MRCP studies, demonstrate relative consistency across geographic regions, though minor variations attributable to population differences have been documented (16,17).

Extrahepatic bile duct variations, encompassing aberrant ductal configurations, accessory ducts, and anomalies of cystic duct insertion, demonstrate greater geographic variation and population-specific patterns(3).Systematic review of 70 studies with 17,207 subjects indicates that prevalence of extrahepatic biliary system variations includes low insertion (11.2%), medial insertion (9.8%), and parallel course of the cystic duct (7.4%), with Hartmann's pouch present in 12.2% and the cystic artery arising from the right hepatic artery in 83.6%(3).

Cross sectional study from Iran indicates that cystic duct insertion into the biliary tree follows multiple patterns: the most common lateral insertion into the middle third of the common hepatic duct occurs in 70–77% of patients, while medial insertions, low insertions, high insertions, parallel courses, and short cystic ducts each occur with frequencies ranging from 1% to 7%(18) . A large MRCP-based study in Turkey found that among 1,011 patients, 36.5% exhibited variant intrahepatic biliary drainage, with the

most common being the right posterior duct draining directly into the left hepatic duct or common hepatic duct(19). Another study from Saudi Arabia reported a 34.7% prevalence of variant biliary anatomy among living liver donors, highlighting the importance of preoperative mapping(20).

Uncommon variants, including cystic duct insertion into the right hepatic duct, left hepatic duct, or duodenum, have been documented in case reports and small series, though their population prevalence remains uncertain(12,21).

2.2. African and Ethiopian Imaging Studies

The medical literature reveals a substantial paucity of systematic imaging studies documenting biliary anatomy and anatomical variants in African populations. While epidemiological surveys of hepatobiliary disease burden and surgical outcomes have been conducted in various African settings, detailed morphological characterization of biliary ductal anatomy utilizing contemporary imaging modalities has not been systematically documented in published African literature. This represents a notable gap in the global understanding of biliary anatomical variation and raises important questions regarding potential population-specific variations in the distribution and prevalence of anatomical variants (3).

In a retrospective cross-sectional study conducted at the Kampala MRI Centre in Uganda, MRCP images from 231 patients were reviewed to document biliary anatomical variations. The study found that 53.2% of patients had typical cystic duct anatomy, while the remainder exhibited a variety of anatomical variants, including intrahepatic and extrahepatic duct patterns(22). Similarly, a Sudanese MRCP cohort found that between 57.6% and 75% exhibited normal biliary anatomy, indicating a wide range of variant patterns such as low cystic duct insertion and parallel courses, reinforcing the need for detailed preoperative MRCP assessment in diverse patient populations(23).

In the Ethiopian context specifically, the research literature addressing hepatobiliary imaging findings remains limited. This retrospective study addresses this significant gap by providing the first systematic institutional characterization of biliary ductal anatomy and anatomical variants in an Ethiopian population.

2.3. Clinical Diagnostic Value of MRCP

Magnetic resonance cholangiopancreatography (MRCP) is non-invasive imaging modality of choice for detailed visualization of biliary and pancreatic ductal anatomy. Numerous comparative studies have established its high diagnostic accuracy for detecting and characterizing biliary ductal variations and pathology when compared with other imaging modalities. In patients with obstructive jaundice, MRCP demonstrated superior sensitivity and specificity for benign and malignant disease compared with both ultrasound and CT imaging, and in direct MRCP vs ultrasound comparisons MRCP showed significantly higher diagnostic performance for bile duct dilatation and associated abnormalities, supporting its utility in preoperative and clinical evaluation(24).

Recent studies comparing MRCP with intraoperative cholangiography, considered the gold standard for real-time biliary anatomy assessment, have demonstrated excellent concordance for detecting anatomically significant variants. In a large retrospective series of living donor candidates, MRCP achieved 100% sensitivity and 94.5% specificity for identifying variant biliary anatomy when compared with intraoperative findings, with an overall accuracy of 96.9% (4). These findings underscore the reliability of MRCP for preoperative surgical planning and highlight its utility in reducing the need for intraoperative imaging procedures that may prolong operative time and increase procedural morbidity.

2.4. Conceptual framework

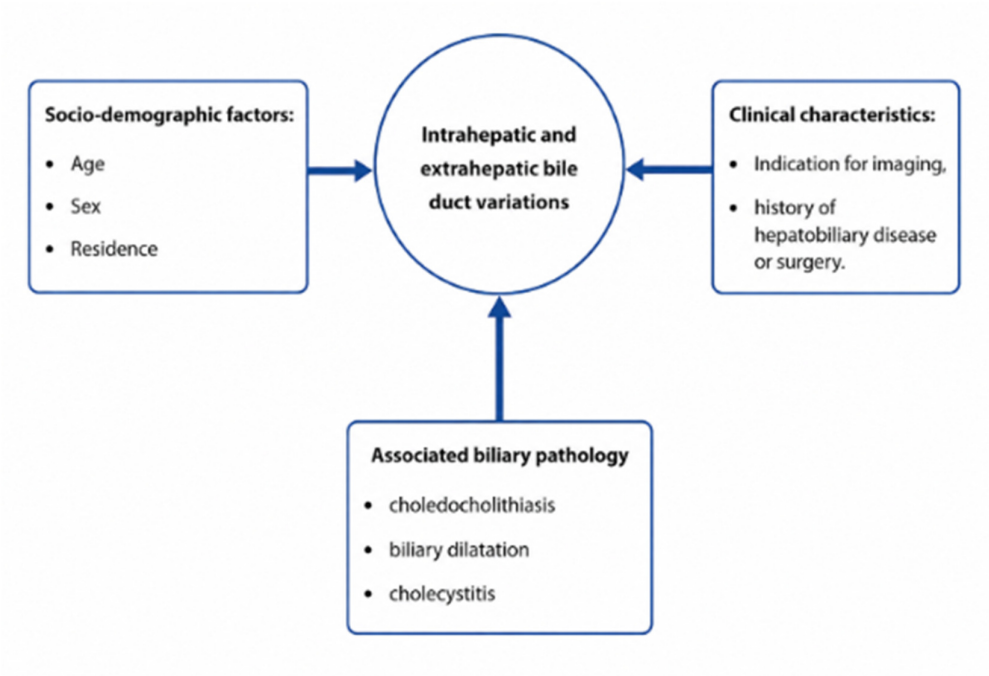


Figure 1: Conceptual framework illustrating factors associated with biliary duct anatomical variants and the role of MRCP in their identification.

3. Objective

3.1 General objective

- To determine the prevalence and anatomical characteristics of biliary duct variants and to assess their association with socio-demographic and clinical factors among patients undergoing MRCP at St. Paul's Hospital Millennium Medical College from July 1 ,2025 to June 30 2026.

3.2. Specific Objectives

- To classify and document intrahepatic biliary ductal anatomy using the Huang classification system and identify the prevalence of each anatomical type within the study population.
- To characterize extrahepatic biliary duct variations, including cystic duct insertion patterns, aberrant bile ducts, and accessory ducts, and calculate their prevalence within the study population.

- To identify the prevalence of biliary anatomical variants according to demographic variables (age, sex, patient presentation category)
- To assess the association between biliary duct anatomical variants and selected socio-demographic and clinical factors

4. Methodology

4.1. Study Area

This study was conducted at St. Paul's Hospital Millennium Medical College, a tertiary referral and teaching hospital located in Addis Ababa, Ethiopia. The Department of Radiology maintains advanced imaging infrastructure including 1.5-Tesla magnetic resonance imaging systems equipped with standard MRCP capability. The hospital serves as a referral center for patients with complex hepatobiliary and surgical conditions from throughout the city and surrounding regions, resulting in a geographically diverse patient population. The hospital maintains comprehensive electronic and paper medical records, providing the necessary data sources for retrospective review.

In addition to providing the clinical services, SPHMMC is also a well-known academic and research institution under which the school of medicine provides specialty and subspecialty training in clinical radiology.

4.2. Study design and period

A retrospective cross-sectional record review were conducted of all MRCP examinations performed at St. Paul's Hospital Millennium Medical College from July 1, 2025 to June 30, 2026 . Retrospective data collection and analysis of existing imaging data and electronic medical records were conducted from July 1 to July 30, 2026. All MRCP examinations that met the predefined inclusion criteria were included in the final analysis.

4.3. Population

4.3.1. Source population

All patients who underwent MRCP examination at St. Paul's Hospital Millennium Medical College. This includes patients presenting with suspected biliary pathology, patients undergoing preoperative evaluation prior to hepatobiliary surgical procedures, patients referred for evaluation of abdominal pain or jaundice, patients undergoing

screening prior to liver transplantation evaluation, and patients undergoing imaging for other clinical indications.

4.3.2. Study Population

The study population consists of patients meeting inclusion criteria from among all MRCP examinations performed during the study period.

4.4. Exclusion/Inclusion Criteria

4.4.1. Inclusion criteria:

- All patients aged ≥18 years who underwent diagnostic MRCP examination
- MRCP examinations with adequate image quality permitting complete visualization of intrahepatic and extrahepatic biliary ductal anatomy
- Complete demographic and clinical data available in electronic medical records

4.4.2. Exclusion criteria:

- Patients with severe biliary obstruction or dilation that precludes accurate identification of anatomical variants
- Patients with prior biliary-enteric anastomosis or surgical alteration of biliary anatomy

4.5. Sampling and sample size

A whole-population (total enumeration) approach was employed. All eligible MRCP examinations performed during the predefined study period that met the study inclusion criteria were included in the analysis. Therefore, no sampling procedure was applied and no participants were selected through random or systematic sampling. The final sample comprised 152 eligible MRCP examinations, representing the complete set of eligible studies available during the study period.

4.6. Data collection tool and procedure

Data were abstracted from two sources: (1) institutional Picture Archiving and Communication System (PACS) containing all digital MRCP imaging studies, and (2) electronic medical records (EMR) system containing demographic and clinical information. Imaging Review Protocol: Two senior radiologists, blinded to all patient clinical information and each other's assessments during initial review, independently evaluated all

MRCP studies for anatomical classification. All imaging evaluations were performed on dedicated radiology workstations with standard DICOM viewing software enabling multiplanar reconstruction and three-dimensional visualization.

A standardized data collection form were recorded: (1) patient demographic data (age, sex, location/district), (2) clinical indication for MRCP, (3) date of examination, (4) anatomical classification data using Huang system and extrahepatic classification, (5) presence of accessory ducts or other variants, (6) associated pathology (stones, obstruction, dilation), and (7) overall image quality assessment.

4.7. Data quality management

Image Quality Assessment: All MRCP studies were assessed using standardized quality criteria including visibility of cystic duct, common bile duct, left and right hepatic ducts, intrahepatic ducts, and pancreatic duct. Studies rated as suboptimal quality will be noted and excluded from analysis. The proportion of studies rated as adequate quality will be reported.

A structured data extraction sheet was used to record patient demographics, imaging parameters, and biliary anatomical variants. Two independent trained Radiologists will review the image. All extracted data were double-checked for accuracy, and discrepancies on the reading will be resolved through consensus. Cases with incomplete or unclear imaging will be excluded, and all patient identifiers will be anonymized to maintain confidentiality. Regular quality checks and audit reports were performed to check adherence to these procedures, ensuring that the dataset is reliable, and ethically managed throughout the study.

4.8. Study Variables

4.8.1. Dependent Variable

- Biliary anatomical variants: intrahepatic and extrahepatic bile duct variations
- Overall prevalence of any anatomical variant versus standard anatomy

4.8.2. Independent Variables

- Socio-demographic factors: Age, sex, residence
- Associated biliary pathology (choledocholithiasis, dilatation, cholecystitis, other)

- Clinical characteristics: Indication for imaging, history of hepatobiliary disease or surgery.
- Surgical or procedural factors (if available): Planned procedure type (e.g., laparoscopic cholecystectomy, hepatic resection, liver transplantation) and intraoperative findings.

4.8.3. Operational Definition

- Anatomical Variant: Any biliary ductal configuration that deviates from the standard anatomy
- Standard Anatomy: Right hepatic duct and left hepatic duct arising separately and joining to form a common hepatic duct; cystic duct joining common hepatic duct at the lateral aspect of the middle third; no accessory ducts or other anomalies.
- Adequate Image Quality: MRCP study permitting clear visualization and classification of all major biliary ductal segments and reliable identification of anatomical variants.
- Prevalence: Proportion of patients with documented anatomical variants among total study population, expressed as percentage with 95% confidence intervals. It is based on the presence of ≥1 predefined intrahepatic or extrahepatic variant

Anatomical Classification System:

Intrahepatic Biliary Anatomy(17,25): All intrahepatic biliary ductal patterns were classified according to the Huang classification system, which categorizes anatomy based on the course and drainage of the right posterior sectoral duct (RPSD):

Type A1: RPSD joins right anterior sectoral duct (RASD) to form right hepatic duct (RHD), which then joins LHD to form common hepatic duct

Type A2: RPSD drains into LHD

Type A3: Trifurcation pattern with separate drainage of RPSD, RASD, and LHD into confluence

Type A4: RPSD drains into common hepatic duct

Type A5: RPSD drains into cystic duct

Type B: Other anatomical variants not fitting Type A categories

Extrahepatic Biliary Anatomy(25,26): Cystic duct variations were classified based on insertion site and course:

Standard insertion: Lateral insertion into middle third of common hepatic duct

High insertion: Into upper third or right hepatic duct

Low insertion: Into lower third of common bile duct

Medial insertion: Into medial aspect of bile duct

Parallel course: Cystic duct running parallel to common bile duct before joining

Short cystic duct: Abnormally abbreviated course

Aberrant insertion: Into duodenum, liver, or other non-standard location

Accessory ducts and other anatomical variants will be documented separately.

4.8.4. Data Analysis and Processing

Data were checked for completeness, coded, and entered into EpiData version 4.6, then exported to SPSS version 26 for analysis. Descriptive statistics were used to summarize demographic, clinical, and anatomical characteristics. Continuous variables were presented as mean ± standard deviation or median (IQR), as appropriate, while categorical variables were presented as frequencies and percentages. The prevalence of biliary anatomical variants was reported with 95% confidence intervals using the exact binomial (Clopper–Pearson) method where appropriate. Associations between anatomical variation and selected demographic and clinical variables were assessed using Pearson's chi-square or Fisher's exact test for categorical variables and the Mann–Whitney U test for non-normally distributed continuous variables. Crude odds ratios (ORs) with 95% confidence intervals were calculated for selected associations. A two-sided p-value <0.05 was considered statistically significant.

4.8.5. Ethical Consideration

Ethical clearance was obtained from the Institutional Review Board (IRB) of St. Paul's Hospital Millennium Medical College. Permission to access data was granted by the hospital administration. As this is a retrospective record review, informed consent was waived. All data was kept confidential, and patient identifiers will not be included in the data collection process.

4.8.6. Dissemination Plan

The finding of the study will be disseminated to St. Paul's Hospital Millennium Medical college and FMOH. The findings of this study will be published on peer reviewed journals and will also be submitted for presentations on esteemed national and international conferences.

5. Result

5.1 Socio-demographic characteristics

Sex	**N**	**%**	**Variant n**	**Variant % within group**
Male	68	44.7%	17	25.0%
Female	84	55.3%	13	15.5%
Residence	**N**	**% of nonmiss-ing**	**Variant n**	**Variant % within group**
Urban	117	77.5%	24	20.5%
Rural	34	22.5%	6	17.6%

Table 1: Socio-Demographic Characteristics and Distribution of Biliary Duct Variants ($N = 152$)

A total of 152 eligible MRCP examinations were analyzed. The mean age was 46.27±16.13 years and the median age was 45.0 years (IQR 34.0–60.0); range 18–87 years. Females comprised 84 (55.3%) participants and males 68 (44.7%).

5.2 Overall biliary anatomical variants

Overall anatomy	**N**	**%**
Standard	122	80.26%
Variant	30	19.74%

Table 2: Overall Prevalence of Biliary Duct Anatomical Variations ($N = 152$)

Overall biliary anatomical variants were identified in 30/152 participants (19.74%).

5.3. Intrahepatic biliary anatomy — Huang classification

Huang type	**N**	**% of 152**	**Exact 95% CI**
A1	142	93.4%	88.2–96.8%
A2	1	0.7%	0.0–3.6%
A3	7	4.6%	1.9–9.3%
A4	2	1.3%	0.2–4.7%

Table 3: Intrahepatic Biliary Duct Distribution According to Huang Classification ($N = 152$)

Intrahepatic anatomical variation was present in 10 participants (6.58%; 95% CI: 3.20–11.77). Huang A1 was the most common pattern (142/152, 93.4%), followed by A3 (7/152, 4.6%), A4 (2/152, 1.3%), and A2 (1/152, 0.7%). No A5 or Type B2 patterns were recorded. A3 trifurcation was the most frequent non-A1 Huang pattern.

5.4. Extrahepatic biliary anatomy

Cystic duct insertion	N	% among 151 nonmissing
Standard	122	80.3%
High	1	0.7%
Low	4	2.6%
Medial	9	6.0%
Parallel	4	2.6%
Short	0	0.0%
Aberrant	0	0.0%
Missing	1	

Table 4: Extrahepatic Cystic Duct Insertion Patterns ($n = 151$)

Extrahepatic anatomical variation was present in 21 participants (13.82%; 95% CI: 8.76–20.34). Among 151 participants with a recorded cystic duct insertion pattern, standard insertion was most frequent (122/151, 80.3%), followed by medial insertion (9/151, 6.0%), low insertion (4/151, 2.6%), parallel course (4/151, 2.6%), and high insertion (1/151, 0.7%). No short or aberrant cystic duct insertion patterns were recorded.

5.5. Accessory bile ducts & Distribution of variants

Distribution	N	% of total	% among 30 variants
Intrahepatic only	9	5.92%	30.0%
Extrahepatic only	20	13.16%	66.7%
Both	1	0.66%	3.3%

Table 5: Distribution and Anatomical Localization of Biliary Duct Variants

Accessory bile ducts were present in 3 participants (1.97%; 95% CI: 0.41–5.66).All three individual accessory-duct cases were type 2 (aberrant hepatic duct). Among the 30 participants with any anatomical variant, 9 (30.0%) had intrahepatic-only variation, 20 (66.7%) had extrahepatic-only variation, and 1 (3.3%) had both.

5.6. Clinical indications for MRCP

Indication	**N**	**% of participants**
Obstructive jaundice	40	26.3%
Abdominal pain	39	25.7%
Suspected choledocholithiasis	63	41.4%
Pre-operative evaluation	0	0.0%
Suspected malignancy	33	21.7%
Transplant evaluation	2	1.3%
Other	0	0.0%

Table 6: Clinical Indications for MRCP Examination ($N = 152$)

Indication was a multiple-response variable, so percentages do not have to sum to 100%.

Suspected choledocholithiasis was the most frequent indication for MRCP (41.4%, $n = 63$), followed by obstructive jaundice (26.3%, $n = 40$), abdominal pain (25.7%, $n = 39$), suspected malignancy (21.7%, $n = 33$), and pre-transplant evaluation (1.3%, $n = 2$).

5.7. Associated biliary pathology

Associated pathology	**N**	**% of participants**
Stones	86	56.6%
Ductal dilatation	81	53.3%
Cholecystitis	11	7.2%
Obstruction	19	12.5%
None	30	19.7%

Table 7: Associated Biliary Pathological Findings on MRCP ($N = 152$)

Associated biliary pathology was a multiple-response variable. The separate 'History of hepatobiliary pathology' field was 141/152 (92.8%) missing and was not used in inferential modelling.

5.8. Inter-observer agreement

Interobserver agreement for the overall classification of biliary anatomy (standard vs variant) was almost perfect (Cohen's $\kappa = 0.979$), with 99.3% observed agreement (151/152 examinations).

5.9. Association with overall biliary anatomical variation

Variable	Variant group	Standard group	Test	p-value	Crude OR (95% CI)
Age, years (continuous)	Median 45.0 (IQR 33.8–60.8)	Median 44.5 (IQR 34.0–58.8)	Mann–Whitney U	0.875	—
Sex (male vs female)	17/68 (25.0%)	13/84 (15.5%)	Pearson χ^2	0.142	1.82 (0.81–4.08)
Residence (rural vs urban)	24/117 (20.5%)	6/34 (17.6%)	Pearson χ^2	0.712	1.20 (0.45–3.24)
Obstructive jaundice	10/40 (25.0%)	20/112 (17.9%)	Pearson χ^2	0.330	1.53 (0.65–3.64)
Abdominal pain	7/39 (17.9%)	23/113 (20.4%)	Pearson χ^2	0.745	0.86 (0.34–2.19)
Suspected choledocholithiasis	14/63 (22.2%)	16/89 (18.0%)	Pearson χ^2	0.517	1.30 (0.58–2.91)
Suspected malignancy	5/33 (15.2%)	25/119 (21.0%)	Pearson χ^2	0.454	0.67 (0.24–1.92)
Stones	18/86 (20.9%)	12/66 (18.2%)	Pearson χ^2	0.673	1.19 (0.53–2.69)
Ductal dilatation	19/81 (23.5%)	11/71 (15.5%)	Pearson χ^2	0.218	1.67 (0.73–3.81)
Cholecystitis	6/11 (54.5%)	24/141 (17.0%)	Fisher's exact	0.008	5.85 (1.65–20.74)
Obstruction	2/19 (10.5%)	28/133 (21.1%)	Fisher's exact	0.368	0.44 (0.10–2.02)
None	2/30 (6.7%)	28/122 (23.0%)	Pearson χ^2	0.045	0.24 (0.05–1.07)

Table 8: Bivariate Analysis of Factors Associated with Overall Biliary Variants

Bivariate analysis was performed to assess the association between participant characteristics, clinical variables, and overall biliary anatomical variation. Pearson's chi-square or Fisher's exact test was used for categorical variables, as appropriate, while the Mann–Whitney U test was used for age. In bivariate analysis, age, sex, residence, MRCP indications, and most biliary pathologies were not significantly associated with anatomical variation. Cholecystitis was significantly associated with higher odds of anatomical variation (54.5% vs. 17.0%; Fisher's exact p=0.008; crude OR=5.85, 95% CI: 1.65–20.74). Participants without associated biliary pathology had lower odds of variation (6.7% vs. 23.0%; OR=0.24, 95% CI: 0.05–1.07; p=0.045). No significant associations were observed for age, sex, residence, MRCP indications, stones, ductal dilatation, or obstruction.

6. Discussion

This study found biliary anatomical variation in 19.7% of patients undergoing MRCP, with extrahepatic variation (13.8%) more frequent than intrahepatic variation (6.6%). The observed prevalence was at the lower end of the range reported in previous MRCP-based studies. Differences in study population, imaging methodology, anatomical definitions, and classification systems may partly explain variation between reported estimates. Standard intrahepatic anatomy was predominant (93.4%), while the most frequent non-standard intrahepatic pattern in the present study was the trifurcation pattern (4.6%). Previous studies have reported substantial variation in the frequency of these patterns; a 2024 review using the Huang classification reported frequencies of 60.44% for A1, 11.76% for A2, and 11.73% for A3, while other MRCP studies have reported different distributions(16,20). The relatively small number of intrahepatic variants in the present study limits precise comparison with larger series.

Extrahepatic anatomical variation was more frequent than intrahepatic variation, with medial cystic duct insertion being the most common non-standard configuration in the present study. This finding is consistent with previous MRCP literature demonstrating

substantial variability in cystic duct anatomy, including medial, low, and parallel insertions. In a study of 198 patients undergoing MRCP, medial insertion was observed in 16.1%, low insertion in 9%, and parallel course in 7.5% of patients(8). Such variants are clinically important because unrecognized cystic duct anatomy may complicate surgical dissection and increase the risk of biliary injury, particularly when inflammation or distorted anatomical landmarks are present(3,10). The identification of accessory bile ducts in 2.0% of examinations further emphasizes the importance of systematic assessment of the biliary tree. MRCP provides non-invasive delineation of biliary anatomy and is widely used for preoperative assessment of biliary anatomy(4,16).

Most demographic and clinical characteristics were not significantly associated with overall biliary anatomical variation. Age, sex, residence, MRCP indications, stones, ductal dilatation, and obstruction showed no statistically significant associations. In contrast, cholecystitis was significantly associated with anatomical variation: 54.5% of patients with cholecystitis had a variant compared with 17.0% without cholecystitis (crude OR 5.85, 95% CI: 1.65–20.74; Fisher's exact p=0.008). This association is clinically noteworthy but should not be interpreted as causal. The small number of patients with cholecystitis and the retrospective design limit the precision and interpretation of this finding. Larger multicenter studies are needed to determine whether this association persists after accounting for potential clinical and referral-related factors.

The clinical importance of these findings lies in the recognition of biliary anatomy before hepatobiliary intervention. Detailed identification of intrahepatic branching patterns, cystic duct insertion, and accessory ducts can contribute to safer surgical planning and reduce the likelihood of unexpected biliary anatomy during procedures(4,5,10).In a setting where imaging-based data on biliary anatomical variation remain limited, these findings provide useful local evidence and reinforce the value of systematic MRCP assessment.

Limitations

This study have some limitations. First, its retrospective, single-center design limits the generalizability of the findings to other institutions and populations. Second, the relatively small number of anatomical variants, particularly individual intrahepatic and extrahepatic subtypes, resulted in imprecise estimates for uncommon patterns. Third, the assessment was based on MRCP findings without systematic surgical or intraoperative cholangiographic confirmation. Finally, the observed association between cholecystitis

and biliary anatomical variation should be interpreted cautiously because of the small number of patients with cholecystitis and the retrospective study design; therefore, causal relationships cannot be established.

Conclusion

These findings provide institution-level data on biliary anatomical variation and may support awareness of variant anatomy during hepatobiliary imaging and surgical planning. Biliary anatomical variation was identified in approximately one in five patients undergoing MRCP, with extrahepatic variants more common than intrahepatic variants. Most demographic and clinical factors were not significantly associated with anatomical variation, whereas cholecystitis showed a strong association with increased odds of variation. These findings highlight the importance of systematic evaluation of both intrahepatic and extrahepatic biliary anatomy on MRCP, particularly before hepatobiliary intervention.

Recommendations

Routine MRCP interpretation should include systematic assessment and documentation of intrahepatic branching patterns, cystic duct insertion, and accessory bile ducts, particularly in patients being considered for hepatobiliary procedures. Further multicenter prospective studies with larger samples and, where feasible, surgical or intraoperative confirmation are recommended to establish more precise population estimates and investigate the observed association between cholecystitis and biliary anatomical variation.

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8. Annexes

Data collection questionnaire/tool

Section	Variable	Response Type	Options / Coding
Patient Identification	Study ID	Text	_____
	Age	_____	Years
	Sex	Categorical	1 = Male, 2 = Female
	Residence	Categorical	1 = Urban, 2 = Rural
Clinical Information	Date of MRCP examination	Date	DD/MM/YYYY
	Indication for MRCP	Multiple choice	1 = Obstructive jaundice 2 = Abdominal pain 3 = Suspected choledocholithiasis 4 = pre-operative evaluation 5 = Suspected malignancy 6 = Transplant evaluation 7 = Other(specify): - _____
	History of hepatobiliary surgery	Categorical	0 = No, 1 = Yes
	Associated biliary pathology	Multiple choice	1 = Stones 2 = Ductal dilatation 3 = Cholecystitis 4 = Obstruction 5 = None
MRCP Image Quality	Overall image quality	Categorical	0 = Inadequate, 1 = Adequate
	Visualization of biliary ducts	Categorical	RHD (0/1): ____ LHD (0/1): ____ CHD (0/1): _____ CBD (0/1): ____ Cystic duct (0/1): _____
Intrahepatic Biliary Anatomy	Huang classification type	Categorical	1 = A1 2 = A2 3 = A3 4 = A4 5 = A5 6 = Type B

	Intrahepatic anatomical variant present	Categorical	0 = No, 1 = Yes
Extrahepatic Biliary Anatomy	Cystic duct insertion pattern	Categorical	1 = Standard 2 = High 3 = Low 4 = Medial 5 = Parallel 6 = Short 7 = Aberrant
	Extrahepatic anatomical variant present	Categorical	0 = No, 1 = Yes
Accessory Ducts	Accessory bile duct present	Categorical	0 = No, 1 = Yes
	Type of accessory duct	Multiple choice	1 = Duct of Luschka, 2 = Aberrant hepatic duct, 3 = Other
Overall Anatomical Assessment	Overall biliary anatomy	Categorical	0 = Standard, 1 = Variant
	Distribution of variant	Categorical	1 = Intrahepatic only, 2 = Extrahepatic only, 3 = Both
Image Review	Reviewer 1 assessment	Text	_____
	Reviewer 2 assessment	Text	_____
	Inter-observer agreement	Categorical	0 = Discordant, 1 = Concordant
	Final consensus classification	Text	_____
Remarks	Additional comments	Text	_____

IRB letter of proposal approval