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Original Article

Radiology Section

Biliary and Pancreatic Ductal Anatomical Variations in a South Indian Population: An MRCP Based Analysis and its Clinical Applications

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ABSTRACT

Introduction: The biliary and pancreatic ductal systems exhibit considerable anatomical variability, which holds significant surgical and clinical relevance. Accurate preoperative delineation of these variations helps prevent inadvertent injuries during hepatobiliary or pancreatic procedures. Magnetic Resonance Cholangiopancreatography (MRCP) serves as a safe, non-invasive modality for evaluating ductal anatomy with high diagnostic accuracy.

Aim: To determine the prevalence of anatomical variations in the biliary tree, cystic duct, and pancreatic duct in a South Indian population using MRCP.

Materials and Methods: A cross-sectional study was conducted at a Chettinad Hospital and Research Institute, Kelambakkam, Chennai, Tamil Nadu, India from January 2023 to July 2025. A total of 345 MRCP studies were reviewed retrospectively, of which 45 were excluded due to poor image quality. The remaining 300 studies were analysed independently by two senior radiologists, with discrepancies resolved by consensus. Variations of the right and Left Hepatic Ducts (LHD) were classified according to Lyu SY et al., while cystic duct and pancreatic duct morphology were evaluated based on their course and insertion patterns. Data were analysed using Statistical Package for Social Sciences (SPSS) version 23.

Results: Among 300 patients (mean age 44.3 years), the most common Right Hepatic Duct (RHD) variant was Type A1 (48%), followed by A2 (30%). LHD anatomy was predominantly Type B1 (82%). Right lateral insertion of the cystic duct was the most frequent variant (62%), while low insertion was noted in 15% of cases. The mean CBD diameter was 6.5±3.2 mm, and the mean Main Pancreatic Duct (MPD) diameter was 2.1±1.2 mm. The descending type of pancreatic duct was observed in 78% of patients, and pancreatic divisum was identified in two cases. No statistically significant association was found between ductal variations and gender (p-value >0.05, using chi-square test).

Conclusion: MRCP effectively characterises hepatobiliary and pancreatic ductal variations, many of which bear important surgical and endoscopic implications. Understanding these variants is essential for safe operative planning, particularly in donor hepatectomy, laparoscopic cholecystectomy, and Endoscopic Retrograde Cholangiopancreatography (ERCP). Further multicentric studies across India are recommended to improve demographic representation.

Keywords: Anatomical variations, Biliary tract anatomy, Cystic duct, Hepatic ducts, Magnetic resonance cholangiopancreatography

INTRODUCTION

The biliary and pancreatic ductal systems exhibit a wide spectrum of anatomical variations, many of which have important clinical and surgical implications. Detailed knowledge of these variations is crucial for safe hepatobiliary and pancreatic surgery, as well as for interventional procedures, to minimise inadvertent iatrogenic injuries [1-3]. These variants are particularly relevant for hepatobiliary surgeons and surgical gastroenterologists during procedures such as laparoscopic cholecystectomy, partial liver resections, donor hepatectomies in liver transplantation, and advanced endoscopic interventions. Although many anatomical variations remain asymptomatic, unrecognised variants may significantly increase the risk of complications, thereby contributing to avoidable morbidity and mortality.

The MRCP is considered a safe, non-invasive imaging modality for evaluating biliary and pancreatic ductal anatomy, offering a diagnostic accuracy between 90-95% and providing excellent anatomical detail compared with ERCP and intraoperative cholangiography [1,4,5]. In contrast, ERCP and intraoperative techniques carry inherent risks such as haemorrhage, bowel perforation, and post procedural pancreatitis, whereas MRCP avoids these complications entirely due to its non-invasive nature [5].

Several classification systems exist for describing biliary ductal anatomy, with the system proposed by Lyu SY et al. being among the most widely accepted [6]. According to this classification, the RHD is typically formed by the confluence of the Right Anterior Segmental Duct (RASD) and Right Posterior Segmental Duct (RPSD), while the LHD forms from segments II, III, and IV. Reported frequencies of classical patterns vary, with 57% and 82% prevalence for the right and left-sided systems, respectively, in earlier studies [6]. Cystic duct variations, mainly characterised by differences in their course and site of insertion into the Common Hepatic Duct (CHD), also hold considerable surgical significance [7].

Within the pancreatic ductal system, pancreatic divisum represents the most frequently encountered congenital variant, with an estimated prevalence of 4-10% in prior investigations [8]. This anomaly arises due to failure of fusion of the dorsal and ventral ducts during embryogenesis and may be associated with recurrent pancreatitis or technical challenges during ERCP [8,9]. Variations in ductal configuration, including differences in course and insertion patterns, further contribute to diagnostic complexity.

Approximately, 42% of the general population is expected to demonstrate some form of anatomical variation within the hepatobiliary or pancreatic ductal systems [9]. These variations may

be influenced by demographic factors such as ethnicity, geography, and gender. While multiple studies have documented such variations in Western populations, literature from India-particularly from the southern regions remains relatively sparse. Given the increasing prevalence of hepatobiliary and pancreatic surgeries in India, there is a growing need for region-specific anatomical data to support safer surgical planning and patient selection, especially in living-donor liver transplantation where certain ductal variants, such as the RPSD draining into the LHD, may serve as relative contraindications [4].

In view of these gaps, the present study aims to assess the prevalence and distribution of anatomical variations in the biliary tree, cystic duct, and pancreatic duct using MRCP in a South Indian population, and to evaluate their clinical relevance in contemporary surgical and interventional practice.

MATERIALS AND METHODS

A cross-sectional study was conducted to evaluate MRCP examinations performed at Chettinad Hospital and Research Institute, Kelambakkam, Chennai, Tamil Nadu, India, from January 2023 to July 2025. Ethical approval (ref no- CARE IHEC-II/0927/25) was obtained from the Institutional Review Board prior to commencement of the study.

Sample size calculation: The minimum required sample size was calculated based on the study by Abdelkareem H et al., on anatomical variations of the pancreatico-biliary system in Palestine [10], which reported that 78% of images demonstrated normal intrahepatic duct anatomy. Using the formula $n=4pq/d^2$, with p=78, q=22, and d=5, the calculated minimum sample size was 275.

Study Procedure

A total of 345 MRCP examinations were retrieved from the hospital's medical information system. Of these, 45 scans were excluded due to inadequate image quality. The remaining 300 MRCP studies were reviewed retrospectively by two senior radiologists, each with over 10 years of experience in abdominal imaging. Interobserver agreement was assessed by comparing the independent reports from both radiologists. Any discrepancy in interpretation was resolved through consensus. Demographic and clinical details including age and sex were obtained from electronic medical records.

The anatomy of the right and LHDs was classified using the system proposed by Lyu SY et al., [6]. For the RHD, five types were identified based on the drainage pattern of the RPSD:

- **Type A1:** RPSD draining into the RASD (most common pattern);
- **Type A2:** Trifurcation of RASD, RPSD, and LHD;
- **Type A3:** RPSD draining into the LHD;
- **Type A4:** RPSD draining into the CHD;
- **Type A5:** RPSD draining into the cystic duct.

The LHD anatomy was categorised into six types based on the drainage of the segment 4 duct:

- **Type B1:** Segment 4 duct draining into the LHD (most common);
- **Type B2:** Segment 4 duct draining into the CHD;
- **Type B3:** Segment 4 duct draining into the RASD;
- **Type B4:** Segment 4 duct draining into the CHD;
- **Type B5:** Segment 4 duct draining into the segment 2 duct;
- **Type B6:** Ducts of segments 2 and 3 join, and segment 4 duct joins to form the LHD [4,7].

Cystic duct anatomy was evaluated based on its course and insertion into the CHD. The following variants were assessed: right lateral insertion, anterior spiral insertion, posterior spiral insertion, medial insertion, high insertion, and low insertion. The diameter of the Common Bile Duct (CBD) was measured in each case.

Pancreatic duct anatomy was assessed according to its course and configuration. The presence or absence of pancreatic divisum was recorded. The diameter of the MPD was also measured.

STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS Version 23 (SPSS Inc., Chicago, Illinois, USA). Categorical variables were expressed as frequencies and percentages, while continuous variables were summarised as mean, standard deviation, and range. The prevalence of each anatomic variant was calculated for the study population, and subgroup analysis based on gender was performed.

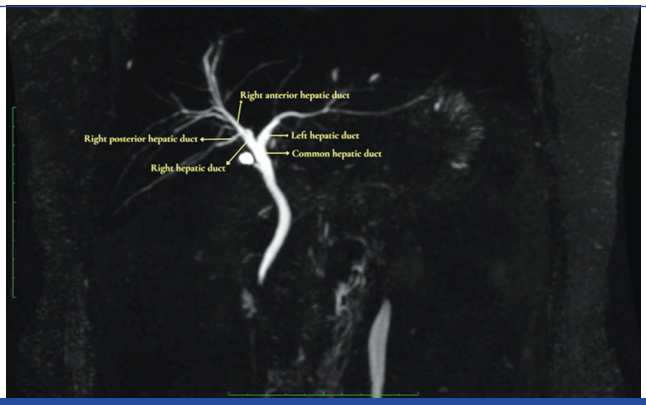
RESULTS

A total of 345 MRCP studies were initially reviewed. Forty-five examinations were excluded due to inadequate image quality, leaving 300 studies for final analysis. The mean age of the study population was 44.3 years (range: 3-82 years). Of the 300 patients, 178 were males and 122 were females.

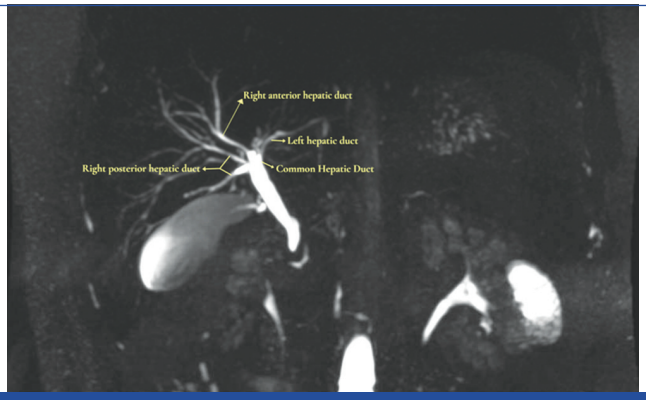
Type A1 was the most frequently observed RHD variant, identified in 144 patients (48%). This was followed by Type A2 in 90 patients (30%), Type A3 in 54 patients (18%), and Type A4 in 12 patients (4%). Type A5 was not encountered in the present study. The distribution of RHD variants is summarised in [Table/Fig-1], with representative images shown in [Table/Fig-2-5].

Type	Number (n)	Percentage (%)
A1	144	48
A2	90	30
A3	54	18
A4	12	4
A5	-	-

[Table/Fig-1]: Number of Right Hepatic Duct (RHD) variants.

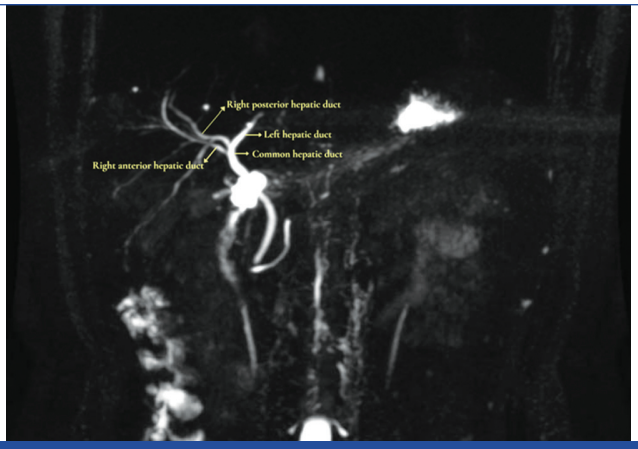


[Table/Fig-2]: MRCP coronal MIP image showing type A1 biliary anatomy- Common Hepatic Duct (CHD) was seen to divide in to right and Left Hepatic Ducts (LHD). Right Hepatic Duct (RHD) was seen to divide in to right anterior and right posterior ducts.

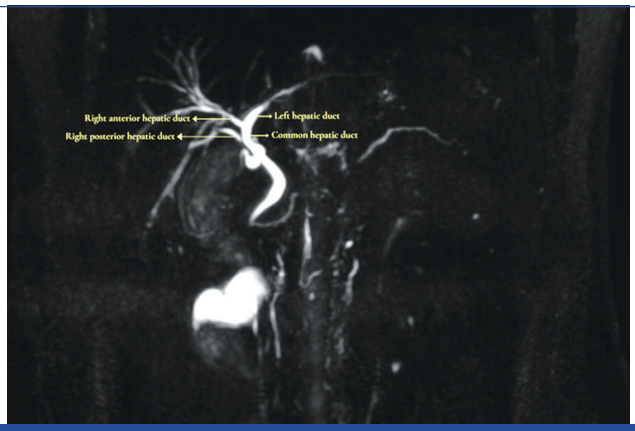


[Table/Fig-3]: MRCP coronal MIP image showing type A2 biliary anatomy- Common Hepatic Duct (CHD) was seen to trifurcate in to right anterior, right posterior and Left Hepatic Ducts (LHD).

Type B1 was the predominant LHD variant, observed in 246 patients (82%). Type B2 was identified in 24 patients (8%), while Types B3 and B6 were seen in three patients (1%) each. Types B4 and B5 were not encountered. The LHD anatomy could not be assessed in 24 cases (8%). Findings are summarised in [Table/Fig-6].



[Table/Fig-4]: MRCP coronal MIP image showing type A3 biliary anatomy- Common Hepatic Duct (CHD) was seen to divide in to right anterior and Left Hepatic Ducts (LHD). Right posterior duct was seen to drain in to Left Hepatic Duct (LHD).



[Table/Fig-5]: MRCP coronal MIP image showing type A4 biliary anatomy- Common Hepatic Duct (CHD) was seen to divide in to right anterior and Left Hepatic Ducts (LHD). Right posterior duct was seen to drain in to Common Hepatic Duct (CHD).

Type	Number (n)	Percentage (%)
B1	246	82
B2	24	8
B3	3	1
B4	-	-
B5	-	-
B6	3	1

[Table/Fig-6]: Number of Left Hepatic Duct (LHD) variants.

Right lateral insertion of the cystic duct was the most common pattern, seen in 186 cases (62%). Anterior spiral insertion was observed in 18 cases (6%) and posterior spiral insertion in 12 cases (4%). High insertion occurred in 15 cases (5%), while low insertion was noted in 45 cases (15%). Medial insertion was identified in 6 cases (2%). The anatomy could not be evaluated in 18 patients (6%). These findings are summarised in [Table/Fig-7].

Type	Number (n)	Percentage (%)
Right lateral insertion	186	62
Anterior spiral insertion	18	6
Posterior spiral insertion	12	4
Medial insertion	6	2
High insertion	15	5
Low insertion	45	15

[Table/Fig-7]: Number of cystic duct variants.

The mean CBD diameter was 6.5±3.2 mm, with a range of 2.1-32 mm. One case of choledochal cyst was identified. The mean diameter of the MPD was 2.1±1.2 mm, ranging from 0.6-11 mm. The most common pancreatic duct configuration was the descending type, observed in 78% of cases. Two cases of pancreatic divisum were also identified. No statistically significant association was found between gender and any of the hepatobiliary or pancreatic ductal anatomical variations. The p value was >0.05, varying between 0.25 and 0.74 when evaluated using chi square tests.

DISCUSSION

Advances in hepatobiliary and pancreatic surgery including laparoscopic, robotic, and endoscopic techniques have heightened the need for precise preoperative understanding of biliary and pancreatic ductal anatomy [10,11]. Procedures such as laparoscopic cholecystectomy, donor hepatectomy, focal liver resection, ERCP, and percutaneous biliary interventions require surgeons to anticipate and correctly interpret anatomical variants to avoid inadvertent injuries. Unrecognised anomalies may lead to serious complications, such as complete transection of the CBD when it is mistaken for the cystic duct during cholecystectomy [7,12]. Similarly, detailed anatomical mapping of segmental duct drainage, particularly the right posterior duct and segment i.v. duct, is crucial when assessing suitability for living donor liver transplantation, as certain drainage patterns such as the RPSD draining into the LHD- are considered relative contraindications [4].

In addition to biliary variations, anomalies of the pancreatic duct also hold clinical significance. Pancreas divisum, for example, has been associated with episodes of acute pancreatitis and can pose technical challenges during ERCP cannulation [8,9]. MRCP serves as an excellent modality for depicting both biliary and pancreatic ductal anatomy, producing images comparable to percutaneous cholangiography while avoiding radiation exposure, contrast-related risks, and need for sedation. Its advantages make it an optimal choice for preoperative anatomical assessment in both routine and complex hepatobiliary cases [13,14].

In the present study, Type A1 was the most common RHD variant (48%), followed by Type A2 (30%). Although Aljiffry M et al., observed a lower prevalence of A1 (34%) in their Saudi population, the pattern remained the most common [15]. These findings align with earlier studies by Sarawagi R et al., (55%) and Abueldahab M and Ali T (63%), which also reported Type A1 as the predominant pattern [7,16]. Similarly, our results are consistent with the Indian study from Himachal Pradesh, where Khanduja N et al., reported Type A1 in 63% of subjects [17].

For LHD variants, Type B1 constituted 82% of cases in our cohort, closely corresponding to findings from Aljiffry M et al., who reported a prevalence of 71.4% [15]. This reinforces the predominance of classical LHD patterns across various populations.

Cystic duct variations demonstrated notable diversity. The most common variant was right lateral insertion (62%), which is similar to the 51% prevalence reported by Sarawagi R et al., [7]. Abdelkareem H et al., reported a higher proportion (89%) in their Palestinian population [10]. Low insertion was present in 15% of our cases, comparable to previous reports ranging from 9-11% [18-20]. Medial insertion, which carries surgical relevance due to the risk of inadvertent ductal injury, was identified in 2% of patients in our study, lower than the 10-18% reported in earlier literature [21,22].

Regarding pancreatic duct anatomy, the most frequent configuration was the descending type, observed in 78% of patients. These findings are comparable to Abdelkareem H et al., who documented a prevalence of 75% [10]. Adibelli ZH et al., reported descending anatomy in 62.5% of patients, slightly lower than our study [9]. We identified two cases of pancreatic divisum, a known congenital variant that may predispose individuals to pancreatitis and influence endoscopic management [8,9].

No association between gender and ductal variations was observed in our study, a result consistent with some prior reports. Adibelli ZH et al., and Abdelkareem H et al., similarly reported no significant correlation between gender and biliary variations, though the latter found some statistical associations with pancreatic ductal morphology [9,10].

The present study included 345 MRCP examinations over two years, which is comparable to sample sizes in several published studies that included 100-500 participants [10,19,23]. The present study provides valuable insights into anatomical patterns within the South Indian population, predominantly from Tamil Nadu. Despite similarities with global data, regional variation patterns emphasise the need for broader population-based mapping.

Limitation(s)

The primary limitation of this study is its single-centre design, which may limit generalisability to other regions of India. Imaging assessment was performed using MRCP alone, without correlation from surgical or ERCP findings. Additionally, 45 studies were excluded due to poor image quality, which may have influenced variant distribution. Larger, multicentric studies across diverse Indian populations are recommended to establish more comprehensive demographic data.

CONCLUSION(S)

The MRCP proved to be a highly effective, non-invasive modality for assessing biliary and pancreatic ductal anatomy in this South Indian population. The study demonstrated a wide spectrum of anatomical variations, with Type A1 and Type B1 being the most common right and LHD patterns, respectively. Right lateral cystic duct insertion and descending pancreatic duct configuration were the predominant variants. Although many of these variations may remain clinically silent, their identification is essential to guide safe surgical and endoscopic interventions, particularly in procedures such as laparoscopic cholecystectomy, donor hepatectomy, and ERCP. Recognising these patterns preoperatively can significantly reduce the risk of iatrogenic injury and improve patient outcomes. Further multicentric studies with larger and more diverse cohorts are recommended to enhance understanding of regional and demographic differences in pancreatico-biliary ductal anatomy within the Indian population.

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