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The Anatomical Landscape of Living Donor Livers: A 101-Case Retrospective Single-Center Study in Indonesia From 2010 to 2025

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ABCDEF 1,2 Arnetta Naomi Louise Lalisang
CD 1,2 Toar Jean Maurice Lalisang
CDE 1,2 Yarman Mazni
CDE 1,2 Ridho Ardhi Syaiful
CDE 1,2 Lam Sihardo
CDE 1,2 Vania Myralda Giamour Marbun
BCDEF 2 Anisa Ayu Maharani
CDE 2 Nathaniel Jason Zacharia
CDE 2 Afid Brilliana Putra
B 2,3 Taufik Agung Wibowo

1 Division of Digestive Surgery, Department of Surgery, Cipto Mangunkusumo Hospital, Jakarta Pusat, Indonesia
2 Faculty of Medicine, Universitas Indonesia, Jakarta Pusat, Indonesia
3 Department of Radiology, Cipto Mangunkusumo Hospital, Jakarta Pusat, Indonesia

Corresponding Author: Arnetta Naomi Louise Lalisang, e-mail: arnetta.naomi01@ui.ac.id
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Background: Anatomical variations of the hepatic vasculature and bile ducts are critical considerations in living donor liver transplantation (LDLT), yet population-specific data remain limited. This retrospective study aimed to evaluate hepatic artery, portal vein, hepatic vein, and intrahepatic bile duct anatomy in 101 living liver donors at a single center in Indonesia from 2010 to 2025, and to identify donor characteristics associated with these variations.

Material/Methods: A retrospective review was performed on 101 living liver donors at Cipto Mangunkusumo Hospital, Indonesia (2010-2025). Hepatic artery and portal/hepatic vein anatomy were assessed using computed tomography angiography (CTA), and biliary anatomy using magnetic resonance cholangiopancreatography (MRCP). Variations were classified according to the Michel, Nakamura, and Huang systems. Logistic and multinomial regression analyses evaluated demographic predictors, and linear regression assessed operative time.

Results: Donors (mean age 31.8±6.2 years; body mass index [BMI] 22.6 kg/m^2; 62.5% female) were predominantly Javanese and Sumatran. Canonical anatomy predominated (Michel I 70.8%; Nakamura I 71.9%; Huang A1 59.7%). Sumatran donors demonstrated higher frequencies of hepatic artery and portal vein variants. Increasing age predicted hepatic artery variation (aOR 1.08/year, *P*=0.046), while BMI influenced portal vein subtypes (*P*=0.006). No factors affected operative time.

Conclusions: Canonical anatomy predominated, with ethnic variations seen in Sumatran donors. Age and BMI predicted vascular variations, while biliary anatomy remained stable. Anatomical variations did not affect operative time, highlighting the importance of preoperative imaging and planning.

Keywords: **Hepatic Artery • Portal Vein • Bile Ducts**

Full-text PDF: https://www.annalsoftransplantation.com/abstract/index/idArt/952031

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Introduction

Liver transplantation is a life-saving therapy for end-stage liver disease and selected hepatic malignancies, offering not only improved survival and quality of life but also renewed hope for patients [1]. While deceased donor liver transplantation (DDLT) is widely implemented in many countries, Indonesia continues to face significant barriers, including underdeveloped donation systems, limited infrastructure, and persistent sociocultural resistance to post-mortem organ donation [2,3]. Consequently, living donor liver transplantation (LDLT) has emerged as the predominant modality, addressing the growing demand amidst a shortage of deceased donors.

In LDLT, a comprehensive evaluation of hepatobiliary and hepatic vascular anatomy is essential for surgical safety and success. These anatomical structures exhibit substantial variability, which can complicate donor hepatectomy, affect vascular and biliary reconstruction, and increase the risk of intraoperative and postoperative complications [4,5]. As such, precise preoperative planning is vital for anticipating technical challenges and tailoring operative strategies [6-8]. Several widely recognized classification systems are used to describe these anatomical variations. The Michel classification system categorizes hepatic arterial variations into 10 types, crucial for arterial reconstruction in liver transplantation [9]. The Nakamura classification system describes 4 main types of portal vein branching, aiding in portal vein reconstruction during surgery [10]. The Huang classification system classifies intrahepatic bile duct patterns into 3 types and is important for preventing biliary complications [11].

Despite the growing number of LDLT procedures in Indonesia, population-specific anatomical data remain limited [3]. In many cases, anatomical challenges are encountered intraoperatively, limiting the ability to anticipate and mitigate surgical risks [4,5]. A clearer understanding of local anatomical patterns is essential to improve preoperative assessment and enhance donor and recipient outcomes.

Therefore, this retrospective study aimed to evaluate hepatic artery, portal vein, hepatic vein, and intrahepatic bile duct anatomy in 101 living liver donors at a single center in Indonesia from 2010 to 2025. Specifically, we sought to identify the predominant anatomical variations and assess their implications for liver transplantation. By characterizing these variations, this study aims to support safer surgical planning and contribute valuable insights to the global anatomical database.

Material and Methods

Ethics Statement

All procedures in this study were performed in accordance with the ethics standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and the Declaration of Istanbul on Organ Trafficking and Transplant Tourism, as amended. The study protocol was reviewed and approved by the Ethics Committee of the Faculty of Medicine, Universitas Indonesia, Dr. Cipto Mangunkusumo National General Hospital (Approval No. KET-/76/UNZ.F1/ETIK/PPM.00.02/2024). Written informed consent was obtained from all participants prior to inclusion.

Study Population

This study included 72 subjects from a total of 101 liver donors who underwent donor evaluation at Dr. Cipto Mangunkusumo National General Hospital (CMNGH) between December 2010 and July 2025. All subjects had undergone computed tomography angiography (CTA), but only 96 had complete CTA records. In contrast, magnetic resonance imaging (MRI) data were available for 72 subjects, as incomplete documentation was present in the other cases. Demographic and clinical data, including age, sex, body mass index (BMI), and operative time, were obtained from medical records. Donors with incomplete imaging were excluded from analyses specific to the missing modality.

Anatomical Classifications

Anatomical variations were categorized using established classification systems. The hepatic arteries were classified according to the Michel classification system, which classifies variations in the origin and branching patterns of the hepatic arteries into 10 distinct types. The portal vein branching was described using the Nakamura classification system, which categorizes the portal venous anatomy into 4 main types based on the number and branching patterns of the portal vein. This classification system was applied to evaluate the variations in portal vein anatomy, which is crucial for portal vein reconstruction during liver transplantation.

The intrahepatic bile duct patterns were assessed according to the Huang classification system, which classifies bile duct anatomy into 3 types based on the number and configuration of bile ducts within the liver to identify variations in the biliary system that can reduce the risk of biliary complications during surgery.

Statistical Analysis

The baseline characteristics of donors were summarised and analyzed using descriptive statistics. Logistic regression analysis was used to estimate the adjusted odds ratios (aOR) with

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95% confidence interval (CI) of having any form of variant anatomy as opposed to canonical anatomy while controlling for age, BMI, and sex. To the extent permitted by sample size, multinomial regression analysis was performed to assess possible relationships with anatomical classes. Predictors of operative time, such as age, BMI, sex, and anatomical variation, were assessed using linear regression. The Hosmer–Lemeshow test (logistic models) and residual plots (linear models) were used to evaluate model fit. To prevent quasi-complete separation, rare categories with an incidence of fewer than 5 were collapsed. All analyses were performed using IBM SPSS Statistics, version 29.0.2.0 (IBM Corp., Armonk, NY, USA), with a 2-tailed *P* value of less than 0.05 regarded as statistically significant.

Results

A total of 101 living liver donor candidates were included in the study. The mean donor age was 31.8±6.2 years, and the mean BMI was 22.6 kg/m^2. There was a greater proportion of females (n=63, 62.5%). The average operative time for donor hepatectomy was 444.6±124.8 minutes. CTA was performed in 96 donors for evaluation of hepatic artery and portal/hepatic venous anatomy, while MRCP was performed in 72 donors for intrahepatic bile duct assessment.

Anatomical Variations

Hepatic Artery Variations

Among 96 donors with complete computed tomography angiography (CTA), Michel Type I (normal anatomy) predominated (70.8%). Variants were present in 29.2% of donors, most frequently Type II (12.5%) and Type IX (4.2%). No Type VII or X variants were observed. The overall distribution is illustrated in **Table 1**, with representative CTA images of selected variants shown in **Figure 1**.

Portal Vein Variations

Nakamura Type I (standard bifurcation) was the predominant pattern (71.9%). Variants were observed in 28.1% of donors, most commonly Type III (13.5%) and Type II trifurcation (10.4%), with rare forms including Types IV, III+IV, and V (<3% each). The overall distribution is presented in **Table 2**, and representative CTA images of a Type II trifurcation are shown in **Figure 2**.

Hepatic Vein Anatomy

Regarding hepatic venous drainage, the right hepatic vein (RHV) was the main drainage channel in all donors. In 58 donors (71.6%), a single dominant RHV drained directly into the inferior vena cava (IVC). An accessory inferior right hepatic vein (accessory IRHV) was identified in 22 donors (27.2%), resulting in a double-vein configuration (dominant RHV with accessory IRHV). Only 1 donor (1.2%) exhibited an additional small inferior RHV, producing a triple-drainage pattern (**Table 3**). For the left hepatic system, a common trunk of the left and middle hepatic veins draining together into the IVC was observed in 53 donors (65.4%), whereas separate drainage of the left and middle hepatic veins occurred in 28 donors (34.6%).

Intrahepatic Bile Duct Variations

In 72 donors evaluated with MRCP, Huang Type A1 was most frequent (59.7%). More complex variants accounted for 40.3% of donors, with A2 and A3 each observed in 13.8%, A4 in 11.1%, and A5 in 1.4% (**Table 4**).

Sex and Anatomical Variations

In most structures, anatomical variations were more prevalent across both male and female donors; however, females were more likely to have anatomical variations in the vascular and biliary systems.

Michel Hepatic Artery

Type I was the most common pattern present across both sexes; however, it was more common in males, at 78.4% for males and 66.1%for females. Females had more variants, with 33.9% as opposed to males at 21.6%. Type II, "replaced LHA from LGA", was more common in females.

Nakamura Portal Vein

Type I bifurcation was more common in males (75.7% for males and 69.5% for females. However, the variant forms such as trifurcation and early right posterior were more common in females (30.5% for females and 24.3% for males.

Huang Intrahepatic Bile Ducts

Type A1 was the most common of all configurations and was present in both males and females. Males had more A1 and A3, and females had A1, A2, A3, and A4, which means females had a more biliary configurations. Taken together, although females had a greater frequency of both vascular and biliary variants, the overall distribution patterns were similar, and canonical anatomy predominated.

Ethnicity and Anatomical Variations

Analysis of ethnic subgroups showed differences in the vascular and biliary anatomy of Indonesian living liver donors among subgroups.

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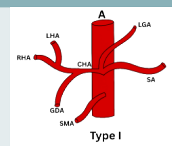
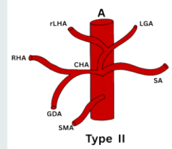
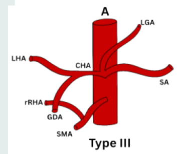
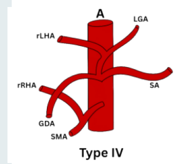
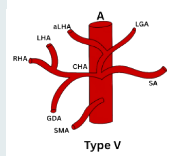
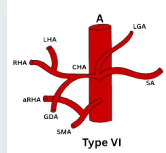
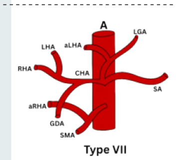
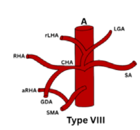
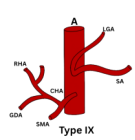
Table 1. Hepatic artery variations according to the Michel classification (N=96).

Michel type	Description		n	%
I	Normal anatomy		68	70.83%
II	Replaced LHA with LGA		12	12.50%
III	Replaced RHA with SMA		4	4.20%
IV	Replaced RHA and LHA		2	2.10%
V	Accessory LHA		3	3.10%
VI	Accessory RHA		1	1.10%
VII	Accessory LHA and RHA		1	1.10%
VIII	Accessory LHA and RHA		1	1.10%
IX	Common hepatic artery from the SMA		4	4.20%

Percentages are calculated from donors with complete CTA data (N=96). LHA – left hepatic artery; RHA – right hepatic artery; LGA – left gastric artery; CHA – common hepatic artery; SMA – superior mesenteric artery. *Illustration by Anisa Ayu Maharani, MD, MRes.*

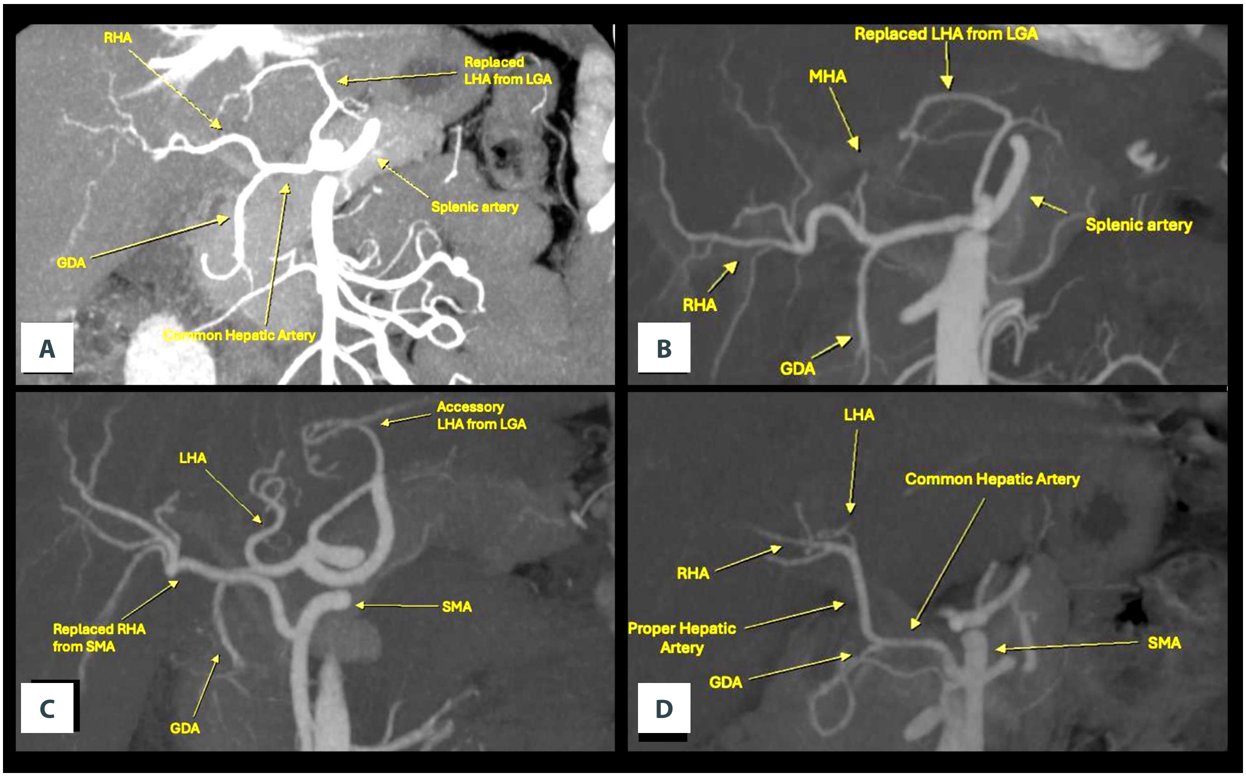


Figure 1. Computed tomography angiography (CTA) images illustrating hepatic arterial variations according to Michel's classification. (**A, B**) Type II variant showing the left hepatic artery (LHA) arising from the left gastric artery (LGA). (**C**) Type VIII variant showing replaced right hepatic artery (RHA) from the superior mesenteric artery (SMA) and accessory LHA from the LGA. (**D**) Type IX variant where the common hepatic artery (CHA) originates from the SMA. LHA – left hepatic artery; RHA – right hepatic artery; CHA – common hepatic artery; LGA – left gastric artery; SMA – superior mesenteric artery; GDA – gastroduodenal artery.

Hepatic Artery (Michel)

Among Javanese donors (N=32), Michel Type I (canonical anatomy) predominated, observed in 90.6% (n=29), with variants identified in 9.4% (n=3). In contrast, Sumatran donors (N=13) demonstrated a lower prevalence of Type I anatomy (53.3%, n=7) and a higher frequency of variants (46.7%, n=6), most commonly Michel Type II (26.7%, n=4). Donors from Sulawesi (N=4) exhibited mixed patterns, with both Type I and Type III anatomies observed. Kalimantan donors (N=2) showed both Type I and Type III variants. All donors from Maluku (N=1) and Chinese Indonesian donors (N=1) exhibited Michel Type I anatomy exclusively. Interpretations for these smaller subgroups should be made cautiously due to the limited sample size.

Portal Vein (Nakamura)

Nakamura Type I was the most common portal vein configuration across ethnic groups, occurring in 84.4% of Javanese donors (n=27/32) and 60.0% of Sumatran donors (n=6/10). Among Sumatran donors, portal vein variants – including Type II trifurcation and Type III early right posterior branching – were more frequently observed than in Javanese donors. In Sulawesi donors (N=3 with evaluable CTA), Type III anatomy predominated (66.7%, n=2), whereas Kalimantan (N=2), Maluku (N=1), and Chinese Indonesian (N=1) donors primarily had Type I anatomy. The small number of donors in these subgroups limits definitive conclusions.

Intrahepatic Bile Ducts (Huang)

Huang Type A1 was the most common biliary pattern overall. Among Javanese donors (N=24 with MRCP), Type A1 was observed in 75.0% (n=18). All Kalimantan donors (N=2) demonstrated Type A1 anatomy. In contrast, all Sumatran donors who underwent MRCP (N=5) exhibited Huang Type A3 anatomy (100%), suggesting greater biliary complexity in this subgroup. However, this finding should be interpreted with caution given the limited sample size. Overall, anatomical variants – particularly of the hepatic artery, portal vein, and bile ducts – were more frequently observed among Sumatran donors compared with Javanese and Kalimantan donors, reflecting the anatomical diversity within Indonesia's multiethnic population.

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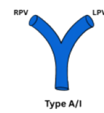
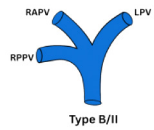
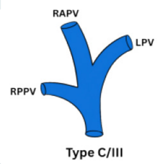
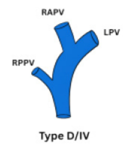
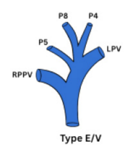
Table 2. Portal vein anatomy according to the Nakamura classification among 96 living liver donor candidates.

Nakamura type	Description		n	%
I	Standard bifurcation		69	71.88%
II	Trifurcation		10	10.42%
III	Early branching of RPV		13	13.50%
IV	Separate segmental origin		2	2.10%
V	Other variation		1	1.10%
III+IV	Combination of III and IV		1	1.10%

Data derived from donors with complete portal venous imaging (CTA, N=96). MPV – main portal vein; RPV – right portal vein; LPV – left portal vein. *Illustration by Anisa Ayu Maharani, MD, MRes.*

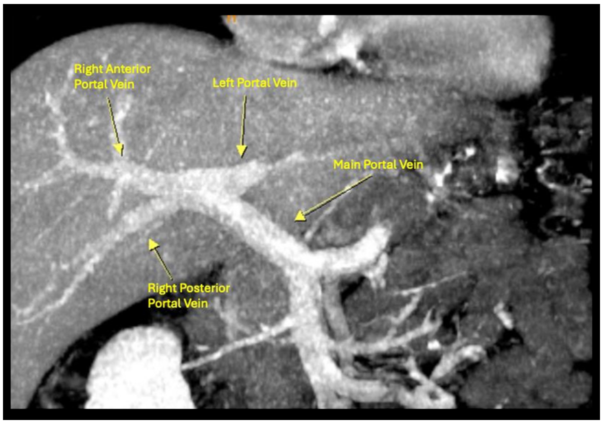


Figure 2. Computed tomography angiography image demonstrating a portal vein variation according to Nakamura Type II. Trifurcation of the main portal vein into right anterior, right posterior, and left portal veins is visualized. MPV – main portal vein; RPV – right portal vein; LPV – left portal vein.

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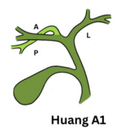
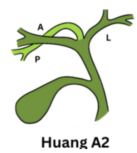
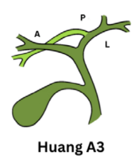
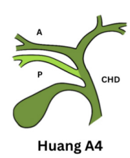
Table 3. Hepatic vein drainage patterns among 96 donors.

Pattern	Description	n	%
Single RHV	The dominant right hepatic vein drains directly to the IVC	58	71.6%
RHV + accessory IRHV	Main RHV plus 1 inferior accessory RHV	22	27.2%
RHV + two accessory IRHVS	Main RHV plus 2 inferior accessory RHV	1	1.2%

Percentages reflect donors with complete venographic evaluation (N=81). RHV – right hepatic vein; IRHV – inferior right hepatic vein; IVC – inferior vena cava.

Table 4. Intrahepatic bile duct anatomy according to the Huang classification among 72 living liver donor candidates.

Huang type	Description		n	%
A1	RPHD drains into RAHD		43	59.7%
A2	RPHD drains into the hepatic confluence		10	13.8%
A3	RPHD drains into LHD		10	13.8%
A4	RPHD drains into CHD		8	11.1%
A5	RPHD drains into the cystic duct		1	1.4%

Data based on donors with available MRCP studies (N=72). RAHD – right anterior hepatic duct; RPHD – right posterior hepatic duct; LHD – left hepatic duct; CHD – common hepatic duct. *Illustration by Anisa Ayu Maharani, MD, MRes.*

Regression Analysis: Predictors of Anatomical Variation

Hepatic Artery (Michels)

Age was significantly associated with the presence of arterial variation (aOR per year=1.08, 95% CI 1.00-1.16, *P*=0.046). BMI (aOR=0.99, *p*=0.897) and sex (aOR male vs female=1.74, *P*=0.256) were not significant predictors.

Portal Vein (Nakamura)

The multinomial logistic regression model was significant overall (χ^2=28.06, *P*=0.021). BMI showed an effect across subtypes (*P*=0.006), with higher BMI tending to increase the likelihood of certain variants (eg, Type IV: B=1.30, *P*=0.053). However, estimates were unstable due to small numbers in rare subgroups, and results should be interpreted cautiously. Age (*P*=0.178) and sex (*P*=0.185) were not significant.

Intrahepatic Bile Duct (Huang)

None of the predictors was associated with biliary variation. Age (aOR=0.98, *P*=0.795), BMI (aOR=1.16, *P*=0.349), and sex (aOR=1.43, *P*=0.698) were all non-significant.

Operative Time Predictors

Linear regression analysis showed that age (B=0.01, *P*=0.999), BMI (B=-15.6, *P*=0.319), and sex (B=-136.7 minutes for males vs females, *P*=0.122) were not significant predictors of operative time. Likewise, the presence of anatomical variation in the hepatic artery (*P*=0.947), portal vein (*P*=0.401), or bile duct (*P*=0.666) did not significantly influence operative time. The overall model was not statistically significant (*P*=0.763, R^2=0.16).

Discussion

This study provides the first comprehensive characterization of hepatic arterial, portal venous, hepatic venous, and biliary anatomy among Indonesian living liver donors over a 15-year period at a single center. Canonical anatomical patterns predominated across all systems, while a substantial proportion of donors exhibited clinically relevant vascular and biliary variants. Regression analysis identified older donor age as an independent predictor of hepatic artery variation and higher BMI as associated with certain portal vein subtypes, whereas biliary anatomy was not significantly influenced by demographic factors. Importantly, neither donor characteristics nor anatomical variation significantly prolonged operative time, underscoring the feasibility and safety of donor hepatectomy when guided by meticulous preoperative imaging. These findings are broadly consistent with previously published international series and provide important comparative data from a Southeast Asian population. Although anatomical variations did not significantly prolong operative time in our cohort, such variants have been associated with increased surgical complexity and risk of perioperative complications in hepatobiliary practice. Variants of the hepatic artery and portal vein are known to alter the usual anatomy encountered during donor hepatectomy and other liver surgeries, and can increase the likelihood of intraoperative injury, hemorrhage, ischemia, or biliary trauma if not anticipated and carefully managed. Aberrant arterial anatomy has been reported to raise the risk of unintentional injury to vascular and biliary structures, which can result in bile leaks, ischemic complications, or the need for additional vascular reconstruction during or after surgery. These potential complications could contribute to longer operative times in other settings and, importantly, may influence postoperative outcomes such as bile duct injury, vascular complications, or incidence of leaks, all of which have clinical significance in living donor and transplant surgery [26].

The inclusion of regression modeling represents a unique strength of this study. Most previous reports describe only prevalence, whereas our analysis identifies independent predictors and confirms that demographic variables are insufficient to replace imaging. This analytic approach adds novel insight to the anatomical literature and provides clinically relevant reassurance for donor selection and operative planning.

Our study demonstrates that canonical anatomy predominated across the hepatic artery, portal vein, hepatic veins, and intrahepatic bile ducts, broadly consistent with the global literature [6,12,13]. Michel Type I anatomy was present in 70.8% of donor, aligning worldwide prevalence estimates of approximately 70% [12]. Variants such as Type II and IX were also common and required meticulous dissection with potential microvascular reconstruction [6]. Similarly, Nakamura Type I portal vein branching was the most frequent (71.9%), with Type II trifurcation (10.4%) and Type III early branching (13.5%) observed at comparable rates to international reports, which may necessitate tailored reconstruction [13]. Hepatic venous drainage via single right hepatic vein was the dominant variant (71.6%), whereas other complex variants needed venous reconstruction to maintain outflow [5,11]. Intrahepatic bile duct anatomy was primarily Huang Type A1 (59.7%), though variant such as A3, A4, and A5 were more common (26.3%) in our series than in Western cohorts, which may increase the risk of biliary leakage and stricture [7,8,10,13]. This discrepancy may reflect ethnic or regional influences on biliary embryo development.

In our cohort, males tended to show a higher prevalence of canonical anatomy, with Type I hepatic artery (78.4% vs 66.1%) and Type I portal vein (75.7% vs 69.5%) more frequently observed in males, whereas females demonstrated a broader spectrum of vascular and biliary variants, including higher proportions of hepatic artery variants (33.9% vs 21.6%), portal vein variants (30.5% vs 24.3%), and multiple bile duct configurations (A1-A4). This contrasts with previous studies reporting that Type I bile duct anatomy was slightly higher in males (55.7%) than females (44.3%) and that only bile duct Type II was more common in females (52.6% vs 47.4%), although without statistical significance. Furthermore, those studies found no significant association between sex or ethnicity and the presence of anatomic variants, suggesting that while our findings highlight trends of greater variability in females, these differences may not reach statistical significance in larger or more diverse populations.

In our Indonesian series, males consistently showed higher frequencies of Type I anatomy in the hepatic artery (78.4% vs 66.1%) and portal vein (75.7% vs 69.5%), while females demonstrated greater variability, particularly in biliary anatomy where configurations extended beyond A1 to include A2-A4. In

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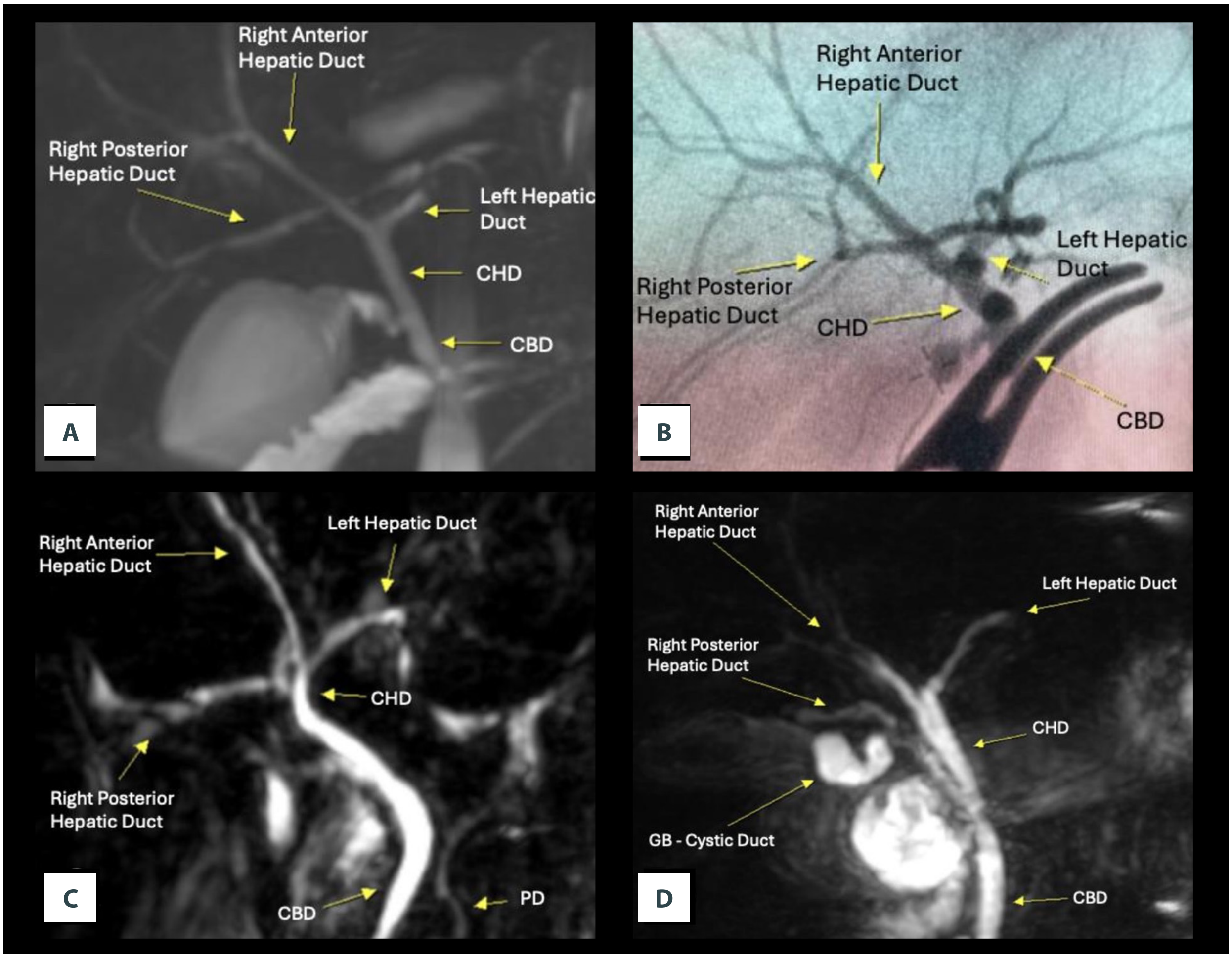

Figure 3. Magnetic resonance cholangiopancreatography (MRCP) and intraoperative cholangiography (IOC) showing intrahepatic bile duct anatomy according to the Huang classification. (**A, B**) Normal anatomy (Type I): right anterior hepatic duct (RAHD) and right posterior hepatic duct (RPHD) join to form the right hepatic duct before merging with the left hepatic duct (LHD) to form the common hepatic duct (CHD). (**C**) Type IV variant: RPHD drains into the CHD. (**D**) Type V variant: RPHD drains into the cystic duct. RAHD – right anterior hepatic duct; RPHD – right posterior hepatic duct; LHD – left hepatic duct; CHD – common hepatic duct; CBD – common bile duct; GB – gallbladder; PD – pancreatic duct.

contrast, the Indian study reported slightly lower overall rates of canonical hepatic artery anatomy in both males (69.9%) and females (67.1%), though the sex gap was narrower than in our series [14]. For portal vein anatomy, however, their cohort showed an even higher predominance of Type I in both sexes (80.2% in males, 83% in females), with relatively fewer variants compared to our data. Similar trends were seen in hepatic vein and venous variants, where differences between males and females were small and did not reach statistical significance [15]. Taken together, while both populations demonstrate that canonical anatomy is most common, our data suggest relatively greater sex differences in Indonesia, especially with respect to hepatic artery and biliary variants [16].

A unique strength of our study lies in its regression analysis. Donor age showed a statistically significant association with hepatic artery variation (aOR 1.08 per year), suggesting that subtle vascular remodeling or age-related morphological changes contribute to this trend. However, given the cross-sectional design and modest effect size, this association should be interpreted as an observation rather than a causal relationship. Higher BMI demonstrated an effect across PV subtypes, though estimates were unstable and were likely affected by the small sample size within rare variants. This pattern could reflect either genuine anatomical diversity in higher-BMI donors or limitations in imaging resolution. In contrast, biliary anatomy was unaffected by age, sex, or BMI, consistent with its embryological origin, which stabilizes early in development [17-19]. These findings suggest that demographic data are insufficient to predict complex anatomy, reinforcing the essential role of preoperative imaging.

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Comprehensive preoperative planning in LDLT is critical for minimizing morbidity and optimizing surgical outcomes for donors and recipients [20-22]. Due to the high variability in hepatic anatomy (hepatic artery, portal vein, hepatic veins, and biliary ducts), accurate anatomical assessment is essential. Variants of HA may predispose to inflow compromise or increase the risk of HA thrombosis if not carefully constructed [6]. Portal vein variants can create challenges in anastomotic planning, requiring venoplasty or interposition grafts to prevent segmental congestion [20-22]. Multiple right hepatic veins necessitate additional venous anastomoses to secure outflow and prevent graft congestion, while biliary variants increase the risk of bile leak or stricture through the need for multiple anastomoses [24,25]. Importantly, in our cohort, anatomical variation and donor demographics did not significantly affect operative time. This finding underscores that, with meticulous preoperative planning and intraoperative adaptation, complex variants can be safely managed without prolonging donor hepatectomy [8,21]. For centers in developing transplant programs, this offers reassurance that donor selection should not be limited by anatomical variation alone.

In our program, CTA reliably delineated arterial and portal venous anatomy, while MRCP provided accurate biliary mapping. Importantly, the expected results from MRCP and intraoperative cholangiography (IOC) are usually concordant, as shown in **Figure 3**, further validating preoperative imaging accuracy and minimizing the likelihood of unexpected intraoperative biliary findings, although IOC remained valuable in selected cases where biliary detail was unclear. Use of the Michel, Nakamura, and Huang standardized classification systems not only facilitated surgical planning but also ensured consistency in interdisciplinary communication and data reporting [21,26,27]. While recent studies have not definitively quantified reductions in ischemia time, optimized planning has been consistently associated with shorter operative times, fewer intraoperative surprises, and improved donor and recipient outcomes [21,22]. Together, these approaches highlight the indispensability of comprehensive imaging in modern LDLT practice.

Strengths and Limitations

Our study represents the largest single-center experience in Indonesia, encompassing 101 living liver donors evaluated over a 15-year period. Key strengths include the systematic application of validated anatomical classification systems and the use of regression modeling to explore potential demographic predictors of vascular and biliary variation.

Several limitations should be acknowledged. First, the retrospective single-center design limits generalizability to other institutions and populations. Second, incomplete availability of MRCP imaging prior to 2015 reduced the number of donors included in the biliary anatomy analysis. Third, although regression analyses were performed to assess predictors of anatomical variation, rare portal vein subtypes were represented by very small numbers, resulting in unstable coefficient estimates and wide confidence intervals. Consequently, the observed associations – particularly for infrequent Nakamura variants – should be interpreted with caution, and the regression models should be regarded as exploratory rather than confirmatory for these subgroups. The limited event-per-variable ratio further constrained statistical power and precluded robust inference for rare anatomical patterns.

Finally, postoperative outcomes were not evaluated, preventing correlation of donor anatomical variation with recipient complications or graft survival. Future directions include multicenter collaboration and the development of a national living donor registry to improve sample size, representation, and statistical robustness. Prospective studies with standardized imaging protocols could enable more stable multivariable modeling and clarify the clinical relevance of rare vascular and biliary variants. Incorporation of three-dimensional reconstruction, virtual surgical planning, and patient-specific liver modeling may further enhance operative precision, particularly in donors with complex anatomy. Participation in international anatomical variation databases would also allow Indonesian data to contribute to global reference standards and improve cross-population applicability.

Conclusions

This study provides a comprehensive analysis of hepatic vascular and biliary anatomy in Indonesian living liver donors. Canonical anatomical patterns predominated across all systems, with subtle ethnic differences observed, particularly among Sumatran donors, who showed higher rates of vascular and biliary variants. Regression analysis identified age as a predictor of hepatic artery variation and BMI as a factor influencing portal vein subtypes, while biliary anatomy remained unaffected by demographic variables. Notably, anatomical variations did not significantly prolong operative time, showing that with meticulous preoperative imaging and planning, complex anatomy can be safely managed without affecting donor hepatectomy duration. This study underscores the importance of preoperative imaging and standardized classification systems for optimal donor selection and surgical planning, while also providing valuable insights into the anatomical diversity within Indonesia's multiethnic population.

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No AI-based tools were used in generating the scientific content of this manuscript. Grammarly was used solely for English language editing to improve grammar and clarity.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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