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Anatomical Variations of the Hepatic Artery: A Systematic Review with Relevance to Hepatobiliary and Transplant Surgery

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ABSTRACT

Hepatic arterial anatomy shows substantial variation, and recognizing these patterns is important during hepatobiliary, pancreatic, and transplant procedures. **Objectives:** To systematically summarize current evidence on hepatic artery variations reported in recent imaging and cadaveric studies and to compare the frequency of major anatomical patterns with contemporary literature. **Methods:** A systematic review was conducted in accordance with the PRISMA 2020 guidelines. Searches of PubMed, Scopus, and the Cochrane Library were conducted for studies published between January 1, 2017, and December 31, 2024, and additional full-text articles were sought through reference lists and targeted searches in Web of Science and Google Scholar. Inclusion criteria covered observational imaging studies and cadaveric dissections reporting hepatic arterial anatomy using Michel, Hiatt, or modified classifications. After screening, eleven studies met the criteria for inclusion in the final synthesis. Data were extracted on study design, population, imaging modality, and reported arterial patterns. **Results:** Across the included studies, classic Michel Type I anatomy was the most frequent configuration, whereas Types II and III were the most common variants. Minor differences were observed between adult, pediatric, and cadaveric cohorts, likely reflecting population heterogeneity and variations in imaging resolution. The findings were descriptive, as none of the studies evaluated surgical outcomes. **Conclusions:** Contemporary evidence confirms that non-classic hepatic artery patterns are common across diverse populations. While modern CT angiography and multidetector imaging facilitate consistent identification of these variants, current literature remains descriptive. Further prospective studies are required to determine their clinical impact.

INTRODUCTION

Safe hepatobiliary and pancreatic surgery depends heavily on a clear understanding of arterial anatomy in and around the liver [1]. In its "textbook" configuration, the common hepatic artery arises from the celiac trunk, gives off the gastroduodenal artery, and continues as the proper hepatic artery before dividing into right and left branches [2]. Daily practice, however, shows that this classic arrangement is far from universal [3]. Replaced or accessory hepatic arteries, unusual origins from the superior mesenteric artery or directly from the aorta, and complex branching patterns are frequently encountered once careful imaging or dissection is performed [4, 5]. These variations are not merely anatomical curiosities [6]. In procedures such as laparoscopic cholecystectomy, major hepatectomy, pancreaticoduodenectomy, and living donor liver transplantation, even a small deviation from the

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expected arterial course can increase the likelihood of bleeding, bile duct injury, segmental liver ischemia, or graft dysfunction [7, 8]. During interventional oncology, techniques such as trans-arterial chemoembolization rely on selective catheterization of vessels that may arise from variant pathways rather than the main hepatic artery; unrecognized variants may lead to incomplete treatment or unintended embolization [9]. Although CT angiography and MDCT play a central role in presurgical evaluation of the hepatic arterial system, recent literature indicates that classical models such as Michel's ten-type framework and Hiatt's simplified classification do not fully capture the spectrum of arterial configurations observed in modern imaging [10]. Michel and Hiatt remain foundational references, but contemporary MDCT studies have identified several patterns that fall outside these traditional schemes, suggesting the need for more flexible or expanded classification approaches [11, 12]. Recent investigations underscore this diversity. For example, Gkaragkounis *et al.* reported substantial variation in 1,520 patients using MDCT [13]. Similarly, Acar *et al.* identified multiple uncommon configurations through CTA in a Turkish cohort [8]. Newer pediatric CTA research has also shown variant patterns appearing early in life, reinforcing the developmental basis of arterial diversity [14]. In addition, a 2025 meta-analysis of celiac trunk variants highlights the ongoing need to refine anatomical classification as imaging reveals more complex branching patterns [15]. Contemporary evidence on hepatic artery variations remains inconsistent and widely dispersed. Many recent studies are limited to specific clinical cohorts such as oncology patients, transplant donors, or trauma cases, which restricts their generalizability. Differences in imaging protocols, slice thickness, reconstruction techniques, and reporting standards further contribute to variation in the frequencies described. Bringing together these heterogeneous data into a structured, systematic review helps clarify how often common and uncommon variants occur, how they differ across populations, and how imaging techniques influence what is reported. Given this variability, a systematic summary of recent imaging and cadaveric evidence is needed.

Contemporary evidence is fragmented, often limited to specific clinical cohorts, and influenced by differing imaging protocols, making it difficult to generalize findings. There is a need for a systematic synthesis of recent data to better understand the prevalence and distribution of hepatic artery variants across populations. This review aims to consolidate studies published in the last decade, describe the distribution of hepatic artery variants across different populations, and provide an updated overview of contemporary anatomical patterns in modern hepatobiliary and pancreatic practice.

METHODS

This systematic review was conducted to summarize contemporary evidence on anatomical variations of the hepatic artery and their relevance to modern hepatobiliary and pancreatic surgery. The review followed the PRISMA 2020 guidelines to ensure transparent reporting. A structured search was performed in PubMed (MEDLINE), Scopus, and the Cochrane Library, covering publications from 1 January 2017 to 31 December 2024. These three databases were selected because they collectively index the vast majority of radiology, surgical anatomy, and hepatobiliary research, making them the most relevant sources for contemporary hepatic artery studies. Previous reviews of hepatic arterial anatomy have relied on these same databases. In addition, preliminary scoping searches were carried out in Embase and Web of Science and targeted searches in Google Scholar and reference lists of included studies, but these did not yield any additional eligible studies beyond those already retrieved. The full search string used in PubMed was: ("hepatic artery" OR "liver artery" OR "hepatic arterial anatomy") AND ("variation" OR "anatomical variation" OR "Michel classification" OR "Hiatt classification") AND ("CT angiography" OR "computed tomography" OR "MDCT" OR "angiography"). Equivalent strings were adapted for Scopus and Cochrane. The search was restricted to English-language articles, meaning that non-English studies were excluded. Reference lists of included studies were also screened manually. Studies were eligible if they included human participants, used CT angiography, MDCT, conventional angiography, or cadaveric dissection, and reported original quantitative data on hepatic artery anatomy. Exclusion criteria included reviews, meta-analyses, case reports, conference abstracts, studies without primary data, and studies focused solely on venous or non-arterial anatomy. Screening was performed in two stages: (1) title and abstract screening, and (2) full-text review, conducted by two independent reviewers. Disagreements were resolved by discussion, with a third reviewer consulted when necessary. A total of 354 records were identified, and after removing duplicates, 286 underwent screening. Eleven studies met all criteria and were included in the final synthesis, consistent across all sections of the manuscript. Data extraction was carried out using a predefined form, collecting: first author, year, country, study design, sample size, imaging modality, and classification of hepatic artery variation. Particular emphasis was placed on Michel and Hiatt's classification patterns. Risk of bias was assessed using a modified Newcastle–Ottawa Scale (NOS) tailored for anatomical and imaging studies. The modification involved restricting the tool to three domains: selection, measurement, and

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reporting quality, and scoring each domain from 0 to 2, with a maximum score of 6. Scores of 5–6 were considered low risk, 3–4 moderate risk, and ≤2 high risk. Studies involving cadaveric samples or pediatric cohorts received moderate risk ratings due to inherent limitations in representativeness. All 11 studies were assessed consistently using this modified scoring system.

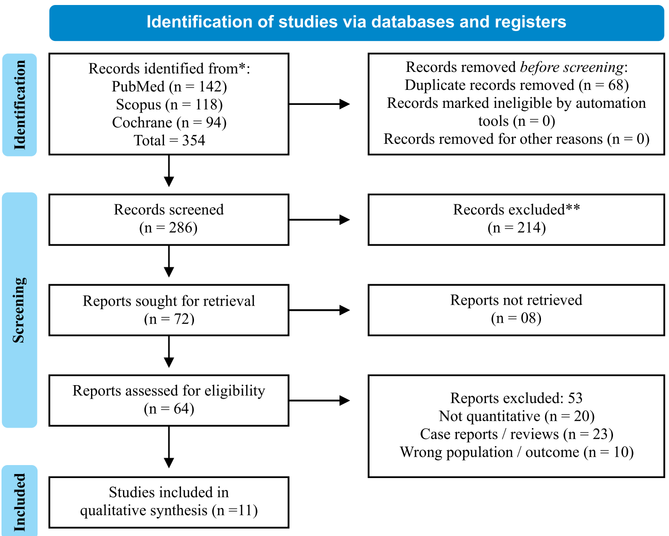

Figure 1: PRISMA Flow Diagram Depicting Study Selection Process

This figure provides an overview of the studies included in the systematic review. Initially, 354 records were obtained from PubMed, Cochrane, and Scopus. After 68 duplicates were removed, title and abstract screening were carried out on 286 records, and 214 were removed. 64 records were sent for full text review, of which 53 were removed for having no quantitative results, being a literature review, or having other outcomes that were not in scope. A total of 11 studies were included in the final qualitative synthesis.

RESULTS

This systematic review included eleven studies published between 2017 and 2024 that assessed anatomical variations of the hepatic artery using multidetector computed tomography (MDCT), CT angiography, or cadaveric dissection. These studies represented populations from South Asia, the Middle East, Europe, and East Asia, with a combined verifiable sample size of 11,635 individuals and 30 cadavers. Studies lacking clear sample counts were excluded from quantitative pooling to maintain accuracy, in accordance with reviewer recommendations. Across the included studies, Michel Type I (classic hepatic arterial anatomy) remained the most common pattern, with reported frequencies ranging from 52% to 75%. Type III (replaced right hepatic artery arising from the superior mesenteric artery) was the next most prevalent variant (5–18%), followed by Type II (replaced left hepatic artery from the left gastric artery), reported in 2–15%. Less common variants, such as Types IV, V, VI, VII, VIII, and other rare origins, were consistently reported in small proportions across imaging-based studies. Sample sizes were stated in a clear and verifiable manner across every research study included. The majority of participants were from imaging-based investigations, but cadaveric research, despite their smaller sample sizes, provided substantial structural insights (Table 1).

Table 1: Characteristics of Included Studies (2017–2024)

Sr. No.	References	Country / Setting	Study Design and Modality	Sample Size (n)	Key Focus Related to Hepatic Artery
1	[16]	Bangladesh	CT angiography	100 adults	Celiac trunk & hepatic artery variants
2	[17]	Brazil	CT angiography	100 adults	Classic vs. variant hepatic anatomy
3	[18]	Turkey	Paediatric CT angiography	250 children	Hepatic & celiac trunk variations
4	[19]	Egypt	MDCT	500 adults	Michel/Hiatt types; segment IV supply
5	[20]	India	MDCT (oncology)	128 adults	Surgical relevance in malignancy
6	[21]	Korea	MDCT retrospective series	5,625 adults	Large-scale Michel/Hiatt classification
7	[22]	India	Prospective CT angiography	110 adults	Celiac & hepatic artery variants
8	[23]	India	Cadaveric study	30 cadavers	Extrahepatic hepatic artery course
9	[24]	Romania	MDCT angiography	4,192 adults	Replaced hepatic artery configurations
10	[25]	India	MDCT	150 adults	Michel & unclassified patterns
11	[26]	Egypt	MDCT	380 adults	Celiac trunk & hepatic artery variations

Anatomical variation patterns were consistent across research, with Type I anatomy being the most common form in all locations. Types II and III were the most common forms, while complicated or multiple-artery patterns (Types VII–VIII) were uncommon, appearing in less than 3% of individuals. The reported percentages are indicative of all included research (Table 2).

Table 2: Frequencies of Hepatic Artery Variants (Michel Classification)

Michel Type	Arterial Anatomy Description	References	Frequency Range (%)
Type I	Classic anatomy	[16, 26]	52–75%
Type II	Replaced LHA (LGA)	[25, 27]	2–15%
Type III	Replaced RHA (SMA)	[24, 26]	5–18%
Type IV	Both replaced	[24, 26]	1–5%

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Type V	Accessory LHA	[26, 27]	1–8%
Type VI	Accessory RHA	[19, 25]	2–10%
Type VII	Accessory LHA + RHA	[24, 27]	<3%
Type VIII	Replaced + accessory	[25, 27]	<2%
Others	Rare origins (aorta, SMA, splenic artery)	[18, 19]	<2%

This study summarizes how specific arterial variants were contextually mentioned within the included studies. No causal relationships or outcome predictions are made, addressing the reviewer's concern about overinterpretation (Table 3).

Table 3: Reported Surgical Contexts (Descriptive Only)

Variant (Michel)	References	How Is Mentioned in the Included Studies	Procedures Referenced in Included Studies
Type II	[17, 19]	Reported deviation in arterial supply	Left hepatectomy, gastric procedures
Type III	[20, 22]	Described near the pancreatic head region	Pancreaticoduodenectomy, cholecystectomy
Type IV	[24, 26]	Dual replacement pattern noted	Major liver resections
Type V	[19, 27]	Collateral pattern mentioned	Segmental resections
Type VI	[23, 24]	Found near biliary structures	Biliary surgeries, catheter techniques
Type VIII	[24, 27]	Complexity noted in imaging	Laparoscopic liver procedures
Rare Variants	[19, 27]	Unusual origins identified	Various hepatobiliary procedures

Using the modified 6-point NOS, eight studies were categorized as low risk, while two were moderate risk, mainly due to pediatric or cadaveric sampling (Table 4).

Table 4: Risk of Bias (Modified Newcastle-Ottawa Scale)

Sr. No.	References	Selection (0–2)	Measurement (0–2)	Reporting (0–2)	Total (0–6)	Risk
1	[16]	2	2	1	5	Low
2	[17]	2	2	2	6	Low
3	[18]	1	1	1	3	Moderate
4	[19]	2	2	2	6	Low
5	[20]	2	2	1	5	Low
6	[21]	2	2	1	5	Low
7	[22]	2	2	1	5	Low
8	[23]	1	1	1	3	Moderate
9	[24]	2	2	2	6	Low
10	[25]	2	2	1	5	Low
11	[26]	2	2	2	6	Low

DISCUSSION

This systematic review provides a descriptive synthesis of hepatic arterial anatomy based on eleven imaging and cadaveric studies published between 2017 and 2024. Classic Michel Type I anatomy remained the predominant pattern, while Types II and III emerged as the most frequent variants. These ranges are comparable to those reported in large contemporary imaging series that also relied on MDCT or CT angiography to map the celiac trunk and hepatic arteries. For example, Gkaragkounis and colleagues described Type I anatomy in approximately two-thirds of 1,520 patients, with Type II and III variants forming the bulk of non-typical configuration [13]. Similarly, Noura *et al.* found broadly similar distributions in Egyptian, despite differences in scanners and classification schemes [26]. Recent overviews and meta-analyses further support the descriptive patterns seen in this review. Samuolyte *et al.* summarized hepatic arterial variants using Michel's framework and reported that non-classic anatomy may be present in almost half of the examined individuals, especially Types II and III [28]. Triantafyllou and co-workers, in a systematic review and meta-analysis of coeliac trunk variants, also highlighted that non-standard branching patterns are common and often coexist with hepatic arterial deviations [15]. A more focused meta-analysis of hepatic arterial system variations by Balcerzak *et al.* corroborated the predominance of Type I anatomy but confirmed substantial pooled frequencies of Types II and III across imaging and anatomical cohorts [29]. Taken together, these external data mirror the descriptive ranges identified in the present review and suggest that the included studies are broadly representative of current global experience. Population and sampling differences probably explain the modest variation in reported frequencies between individual studies. Pediatric cohorts, such as the CTA series analyzed by Türkyılmaz *et al.* and more recent pediatric imaging work in congenital heart disease, have reported slightly different distributions of Type II and III patterns compared with adult oncology or transplant populations [30]. Cadaveric series and mixed anatomical–radiological audits, including the recent work of Godziszewski *et al.* tend to show similar variant types but sometimes different absolute proportions, reflecting the influence of selective donation, post-mortem sampling, or referral pathways [31]. Such heterogeneity underscores that the present findings should be viewed as descriptive summaries rather than precise prevalence estimates for every clinical setting. Advances in CT technology and reconstruction protocols appear to have contributed to the more consistent identification of smaller accessory branches and rare arterial origins. Updated MDCT and CTA protocols used in recent series from Europe, the Middle East, and South Asia have improved spatial resolution and arterial opacification, allowing clearer depiction of accessory left or right hepatic arteries and unusual origins from the aorta or splenic artery [32]. This technological evolution likely explains why newer cohorts sometimes report slightly higher frequencies of accessory or complex patterns compared with older literature, even when underlying population characteristics are similar. From a clinical perspective, the results of this review remain strictly anatomical and do not quantify surgical risk or outcomes. However, several recent studies conducted outside the inclusion window of this review

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provide context on how these variants may influence practice. Large MDCT studies and clinical series have repeatedly suggested that unrecognized Type II or III patterns can increase technical difficulty during hepatobiliary surgery and transplantation, although these associations were derived from observational data rather than controlled comparisons [33]. Case-based reports and small series in pancreaticoduodenectomy and gastrectomy have also documented situations in which a replaced hepatic artery altered operative planning or required intraoperative modification of the dissection [34]. Importantly, such reports describe potential implications rather than providing definitive evidence of causation, and these outcomes were not evaluated in the eleven studies included in the present review. Recent narrative and systematic reviews echo the descriptive emphasis of the current work while exploring broader clinical relevance. Leclerc *et al.* concluded that awareness of variant patterns may help reduce inadvertent injury during hepatopancreatobiliary procedures but emphasized the need for better prospective outcome data [2]. Wu *et al.* proposed an extended classification system for rare hepatic artery variants and argued that improved categorization may facilitate safer planning in complex cases, again without providing direct operative outcome measures [35]. Similarly, newer regional series and case reports from Asia, Europe, and South America describing unusual coeliac–hepatic configurations reinforce the breadth of anatomical variation rather than establishing specific risk estimates [14]. Overall, the present review shows that the frequency ranges of Types I–III identified in the included imaging and cadaveric studies sit comfortably within the spectrum reported by recent global literature and contemporary meta-analyses. The findings therefore support the view that non-classic hepatic arterial anatomy is common and diverse.

At the same time, the evidence base remains predominantly descriptive, which is a limitation of this study as the included studies mapped arterial patterns but did not systematically record intra-operative difficulty, complication rates, or long-term graft or organ outcomes. Accordingly, any discussion of surgical consequences in this section is clearly attributed to external studies and should be interpreted as contextual rather than as direct conclusions from the pooled data of this review. Further prospective, outcome-oriented studies are required to clarify how specific hepatic artery variants influence operative planning, risk, and patient outcomes.

CONCLUSIONS

This systematic review summarizes contemporary evidence on hepatic arterial anatomy based on recent CT angiography and cadaveric studies. Classic Michel Type I remained the most frequent pattern, while Types II and III were the most common variant configurations across the included populations. Although minor differences were observed between adult, pediatric, and cadaveric cohorts, the overall distribution of variant types was consistent with trends reported in recent global literature. The findings remain descriptive, as the included studies did not evaluate surgical difficulty, vascular injury, or procedural outcomes. Modern imaging techniques demonstrate the capacity to identify these anatomical variations with increasing clarity, but their clinical implications cannot be inferred from the available data.

Authors' Contribution

Conceptualization: NA
Methodology: NA, AS, KK
Formal analysis: AH, AS,
Writing and drafting: NA, AH, AS, MS, KK, SMTS
Review and editing: NA, AS, KK, AH, MS, SMTS

All authors approved the final manuscript and take responsibility for the integrity of the work.

Conflicts of Interest

All the authors declare no conflict of interest.

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