A systematic review on Anatomic variants of the hepatic artery in the whipple procedure

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Abstract : Pancreatic cancer continues to pose significant health challenges, affecting 10,000 number of individuals each year in the UK alone. The Whipple procedure, a complex surgical intervention, remains a primary treatment option for these malignancies. During this procedure, the hepatic artery, a crucial blood vessel supplying the liver and surrounding structures, plays a vital role. However, anatomical variants of the hepatic artery make surgical management of the condition complicated. This dissertation aims to conduct a comprehensive analysis of the anatomical variations of the hepatic artery encountered during the Whipple procedure and their clinical significance. Utilizing PubMed, MEDLINE, Scopus, and Google Scholar, a systematic literature review was performed on 15 studies including 6487 patients using relevant keywords such as "hepatic artery variations," "Whipple procedure," and "pancreaticoduodenectomy." Findings reveal a diverse range of hepatic artery variations, including accessory hepatic arteries, replaced hepatic arteries, and aberrant hepatic arteries. The paper reports prevalence rates of hepatic variants under Hiatt's classification system. These anatomical variations present potential challenges and complications during surgical planning and execution of the Whipple procedure. The clinical significance of identifying hepatic artery variations lies in the necessity for precise preoperative imaging and surgical mapping. Understanding the vascular anatomy aids in minimizing operative risks, reducing intraoperative complications, and optimizing postoperative outcomes. The paper discusses the clinical details of Whipple procedure in context of hepatic artery variants.

IndexTerms **- Hepatic Artery Variants, Whipple Procedure, Artery-First Approach, Vascular Reconstruction, Surgical Planning.**

INTRODUCTION

Pancreatic cancer is the UK's 5th leading cause of cancer death, with around 8,000 cases annually (1). Only 10–20% of tumors are resectable due to late symptom onset, which varies by tumor location. About 90% originate in the pancreatic duct, with symptoms like weight loss, jaundice, abdominal/back pain, GI issues, fatigue, and diabetes often misdiagnosed, leading to poor prognosis (2). Around 78% of pancreatic adenocarcinoma cases require a Whipple procedure (3), which involves resecting the gallbladder, distal stomach, pancreatic head, duodenum, proximal jejunum, distal common bile duct, and lymph nodes. The surgery, first described by Allen Whipple in the 1880s, requires gastrojejunostomy, pancreatojejunostomy, and choledochojejunostomy anastomoses (4). The procedure's complexity increases with hepatic artery variations, which can cause necrosis, bile leaks, bleeding, ischemia, and postoperative morbidity (5). Understanding these variations—their origin and branching—is essential for surgical planning. This thesis reviews hepatic artery variations to support optimal management during the Whipple procedure.

MATERIALS AND METHODS:

A comprehensive literature review was conducted across databases including PubMed, Embase, Google Scholar, Ethos, Medline, and LinkSpringer. Search terms incorporated combinations of "anatomical variants," "hepatic artery," "pancreatoduodenectomy," and "Whipple procedure." The review aimed to gather data on the incidence, prevalence, historical classifications, clinical relevance, and surgical implications of hepatic artery variants in the context of the Whipple procedure. A total of approximately 200 studies from 1917 to 2023 were initially screened, including five non-English articles with translated versions.

A systematic approach was used to identify studies explicitly reporting Hiatt's classification types (I–VI) along with their occurrence rates. Eligible studies detailed their classification methodology and, in some cases, cross-referenced alternative systems like Michel's. Data from 15 qualifying studies—encompassing 6,287 cases, including both cadaveric and clinical human studies—were pooled for meta-analysis. A random-effects model was applied to estimate overall prevalence for each classification type, offering insights into anatomical variation frequencies and their implications during hepatopancreatic surgeries (Figure 1).

RESULTS:

1. ANATOMICAL OVERVIEW

The pancreas, a retroperitoneal gland at L1–L2, supports digestion and hormone regulation. It comprises the head, neck, body, tail, and uncinate process. The head lies in the duodenal C-loop near the superior mesenteric artery, portal vein, and inferior vena cava. The posterior surface is embedded in retroperitoneal fascia; the anterior is covered by the lesser sac. The common bile duct traverses the pancreatic head, joining the main pancreatic duct at the ampulla of Vater to release secretions into the duodenum. These structures are key in Whipple procedures (Figure 2; Table-1) (6–10).

i. Arteries, Veins, and Lymphatics

The head is supplied by superior and inferior pancreaticoduodenal arteries from the gastroduodenal and superior mesenteric arteries. The gastroduodenal artery also branches into right gastroepiploic and superior pancreaticoduodenal arteries, forming an arcade (13). The tail is vascularized by splenic artery branches—caudal, dorsal, and great pancreatic arteries (14). The dorsal artery divides into right and left branches, contributing to arterial anastomoses (15, 16). The gallbladder lies below liver segments IV and V, within Calot's triangle—bounded by the cystic duct, bile duct, and liver margin—key for locating the cystic artery (17–19) (Figure 3).

Pancreatic lymphatics include intrapancreatic capillaries and peripancreatic vessels, draining into celiac, superior mesenteric, and pancreaticoduodenal nodes, then into the thoracic or right lymphatic duct (23–26) (Figure 4).

ii. ANS Fibres

The pancreas receives sympathetic input from T5–L2 splanchnic nerves, synapsing in celiac and mesenteric ganglia, forming the pancreatic plexus (27–31). Parasympathetic innervation via the vagus nerve originates in the dorsal motor nucleus, promoting secretion and vasodilation (32, 33). Sympathetic fibers release norepinephrine; parasympathetic release acetylcholine and VIP (34), balancing homeostasis (35).

iii. Arterial Embryology

During development, four ventral roots arise from the dorsal aorta. The first forms the coeliac artery (hepatic, gastric, splenic branches), and the fourth forms the superior mesenteric artery. The liver initially receives blood from middle, left, and right hepatic arteries, with the middle persisting as dominant (36–38).

2. ANATOMY OF THE HEPATIC ARTERY

The hepatic artery typically arises from the coeliac trunk at T12–L1, branching into the common hepatic, splenic, and left gastric arteries. Near the pancreas, it gives off the gastroduodenal and right gastric arteries, then becomes the proper hepatic artery (39, 40), which divides into right and left hepatic arteries. This classic pattern occurs in 55–75% of people (41–43).

i. Anatomical Variations

Michel's and Hiatt's classifications (Table 2, Figure 6) describe common hepatic artery variants but omit rare forms (e.g. from GDA or splenic artery). Koops (n=604) and Kobayashi (n=1,200) proposed updated systems using angiography (Figure 7). Wu et al. (48) reported a rare case of dual accessory LHAs—from the common hepatic and left inferior phrenic arteries—prompting the "ex-CRL classification" using 3DCT.

ii. Variations in Cholecystectomy

Blecha et al. (49) described an aberrant RHA running anterior to the gallbladder, increasing hemorrhage risk. Katagiri et al. (50) found an RHA from the celiac trunk, altering cystic artery location. Polguj et al. (51) noted an accessory RHA from the GDA with dual cystic arteries. Sitarz et al. (52) emphasized that imaging may miss such anomalies.

iii. Variations in Liver Transplantation

Hepatic artery variants can impact graft success. Tzakis (53) and Heffron (54) highlighted the need for early detection. Gruttadauria (55) found variants in 42.2% of 701 transplants:

- RHA from SMA (14.98%)
- LHA from left gastric (11.55%)
- CHA from SMA (0.86%)
- Rare aortic variants (0.71%)

Chaib et al. (56) found RHA from SMA in 25% and LHA from left gastric in 3.3% of cadavers. Erbay et al. (58) observed variants in 65% of 107 donors. Kamel et al. (59) stressed mapping near the hepatectomy line in <30% liver remnants (60). Caruso et al. (61) reported a rare "four-clover leaf" variant seen only 3 times in 11,000 cases (62).

3. WHIPPLE PROCEDURE:

The Whipple procedure, also known as pancreaticoduodenectomy, is a complex surgical procedure used for the treatment of pancreatic and periampullary cancers (63). First described by Dr. Allen O. Whipple in 1935, the procedure has since undergone refinements (64) and become the gold standard surgical treatment for selected cases of these malignancies (65). The Whipple procedure involves the removal of the head of the pancreas, the duodenum, a portion of the common bile duct, and the gallbladder (66) (Table 3).

Thorough preoperative evaluation is important to determine the suitability of patients for the Whipple procedure. This includes a comprehensive medical history assessment, physical examination, laboratory tests, and imaging studies such as computed tomography (CT) scans and magnetic resonance imaging (MRI). Figure 4 shows how 3-D visualisation and evaluation help in identification and location of anatomical variants of hepatic artery. These investigations help determine the extent of the tumour, involvement of adjacent structures, and the presence of distant metastases. Some patients might have risk factors such as higher age, sex, obesity, COPD, and steroid use (66) (Figure 8).

4. IMPLICATIONS OF ANATOMICAL VARIANTS OF HEPATIC ARTERY DURING THE WHIPPLE PROCEDURE

Anatomical variations in the hepatic artery have profound clinical implications, particularly during complex hepatobiliary procedures such as the Whipple procedure (pancreaticoduodenectomy). As described by **Sahani et al. (84)**, these variations can significantly complicate the surgical approach, requiring meticulous preoperative planning and intraoperative vigilance. Aberrant or accessory hepatic arteries often necessitate modified dissection techniques to avoid compromising hepatic perfusion, which, if mismanaged, may lead to liver ischemia or necrosis.

Hepatic artery variations affect more than surgical complexity. Chamberlain et al. (85) observed that variant origins impact perfusion to specific liver segments, influencing intraoperative decisions. Accurate identification is essential to preserve hepatic function during resections for malignancy or inflammation.

López-Andujar et al. (86) reported that unrecognized variants increase vascular injury risk, leading to extended operative time, more transfusions, and possible vascular reconstruction. Malviya and Verma (87) noted that variants near bile ducts complicate dissection and raise the risk of biliary injury. Resulting complications—leaks, strictures, peritonitis—may require reoperation or drainage (Martin and Rossi, 88).

Xu et al. (89) warned that ligating a variant artery supplying a large liver region can cause necrosis, especially in patients with compromised liver function. Choi et al. (90) showed that variants may distort tumor–structure relationships, complicating margin assessment and resection in oncological surgeries.

Preoperative imaging, particularly CT and MR angiography (Sahani et al., 84), is critical for identifying arterial variants. These tools improve surgical planning, reduce surprises, and enhance outcomes.

Surgical Considerations:
Hepatic artery variants during the Whipple procedure can cause ischemia, liver failure, and biliary issues. Tailored surgical strategies are recommended based on the specific variant encountered (Table 4).

5. ARTERY FIRST' APPROACHES

The "artery-first" approach in the Whipple procedure has advanced surgical planning, especially for managing vascular variations and minimizing complications. Ielpo et al. (101) define it as the early identification of major arteries—mainly the SMA or GDA—prior to pancreatic and biliary dissection, contrasting with the traditional mobilization-first method.

A major benefit is early assessment of tumor resectability. Ban and Tanabe (102) noted that early arterial control clarifies tumor involvement of vessels, reducing incomplete resections. Jiang et al. (103) found that preserving arterial supply minimizes ischemia to the remaining pancreas and duodenum, improving perfusion and lowering risks of complications like delayed gastric emptying or pancreatic fistulas.

This method also provides better dissection planes, improving visibility and reducing tissue edema. Younan et al. (104) reported that maintaining blood flow in the presence of arterial anomalies or tumor adherence helps avoid vascular damage, reduces bleeding, and ensures hemodynamic stability.

Sanjay et al. (105), in a review of artery-first techniques in pancreatoduodenectomy (PD), found this strategy enhances margin clearance and assists in evaluating borderline tumor resectability. They outlined six distinct artery-first techniques used to improve outcomes and prognosis.

1. Posterior Approach: In this approach, Kocherization of the duodenum is performed. Kocherization is a surgical maneuver used in the Whipple procedure to mobilize the duodenum and pancreatic head, facilitating access and resection of affected tissues. It allows for careful management of hepatic artery variants and is critical for optimizing surgical outcomes and patient care. The pancreatic head is retracted to the left to expose the origin of the superior mesenteric artery (SMA) in front of the left renal vein, just in front of the abdominal aorta. Dissection of the SMA starts from its origin and continues caudally along the SMA, posterior to the pancreatic head, until it crosses the duodenum. Attachments between the SMA and uncinate process are divided to expose the lateral border of the portal vein - superior mesenteric vein (PV-SMV) (106).

    a. Medial Uncinate Approach: This approach involves division of the ligament of Treitz and translocation of the proximal jejunum with its intact mesentery into the supracolic compartment, passing it to the right under the superior mesenteric vessels. The dissection begins by incising the perivascular connective tissue around the SMA, and dissection is continued in a caudal direction along the SMA, posterior to the pancreatic head, to where it crosses the duodenum. The uncinate process is mobilized, and the proximal jejunum is transected and transposed to the right abdomen, allowing further exposure of the SMA and superior mesenteric vein (SMV) (107).

    b. Inferior Infracolic Approach (Mesenteric Approach): This approach involves dissection of the SMA from the infracolic compartment at the base of the transverse mesocolon. The peritoneum is divided over the palpable SMA,

and this dissection is aided by first mobilizing the duodenojejunal (DJ) flexure and dividing the inferior mesenteric vein. The SMA is exposed, and dissection is continued along its anterior and right medial aspect to its origin, under the neck of the pancreas and splenic vein (108).

c. Left Posterior Approach: In this approach, the origins of the SMA are identified by Kocherizing the duodenum and pulling the proximal jejunum to the left, dividing the first and second jejunal arteries. Further traction on the proximal jejunum causes a counterclockwise rotation of the SMA, allowing identification and division of the inferior pancreatoduodenal artery (IPDA) arising from the posterior surface of the SMA (109).

d. Inferior Supracolic Approach (Anterior Approach): This approach involves dividing the gastric antrum and exposing the pancreatic neck by cephalad retraction of the stomach after division of the gastrocolic ligament. The origin of the SMA is exposed, and a 'hanging maneuver' is performed to expose the peripancreatic retroperitoneal margin with neural plexi and lymphatics, facilitating their division (110).

e. Superior Approach: The hepatoduodenal ligament is dissected first to expose the common hepatic artery (CHA) and gastroduodenal artery, followed by dissection down the coeliac trunk inside the perineural and lymphatic tissue on to the aorta and origin of the SMA (105).

Clinical Implications and Outcomes: The *artery-first approach* in pancreatoduodenectomy has emerged as a significant advancement in hepatopancreatobiliary surgery. Unlike the traditional resection-first method, this technique prioritizes the early identification and preservation of major arterial structures such as the superior mesenteric artery (SMA) or the gastroduodenal artery (GDA). This preemptive strategy is designed to minimize ischemic injury, reduce intraoperative blood loss, and maintain optimal tissue perfusion throughout the procedure (101, 102).

The artery-first approach in pancreatoduodenectomy prioritizes early identification of key arteries like the SMA or GDA to minimize ischemia, reduce blood loss, and maintain perfusion (101, 102). Unlike the traditional resection-first method, this technique improves intraoperative control and tissue preservation.

Clinical studies associate this approach with lower rates of complications such as pancreatic fistula, delayed gastric emptying, and reduced overall morbidity (111). It also yields higher R0 resection rates and fewer transfusion needs (112). However, it has not significantly lowered surgical mortality (105).

Oncologically, preserving arterial flow to the remnant pancreas and duodenum may support liver function recovery and reduce ischemic risks. Yet, the approach is technically demanding, requiring detailed anatomical knowledge and skill, especially when vessels are encased by tumors (105).

Technological advancements aid implementation. Intraoperative ICG fluorescence angiography provides real-time perfusion visualization, while the FLER system overlays ICG signal data to create virtual perfusion maps for precise vascular assessment during resections and anastomoses (113) (Table 5).

In summary, the artery-first technique offers clear perioperative benefits but demands surgical expertise and advanced imaging. Further research is needed to confirm its impact on survival and recurrence (113).

6. MANAGEMENT OF DISORDERS RELATED TO HEPATIC ARTERY VARIATIONS

Hepatic artery variations can lead to issues from mild dysfunction to life-threatening complications (Table 6). Early diagnosis and effective management rely on understanding these anatomical differences. Advances in imaging and surgical techniques have improved care, with ongoing research enhancing outcomes.

Management requires a personalized approach. Accurate imaging—CT, MRA, DSA, Doppler, CBCT—is essential for identifying variants and planning treatment (Table 7). Minimally invasive methods like endovascular procedures and transarterial chemoembolization are useful in high-risk cases. Medical therapy with vasodilators, antiplatelets, and anticoagulants complements surgical and interventional options. Multidisciplinary collaboration ensures tailored care.

Treatment depends on severity. Mild cases may respond to medication; severe ones may need angioplasty, stenting, or surgery for aneurysm repair or abscess drainage (129) (Table 8). Future innovations will further refine management.

7. CHRONIC PANCREATITIS

The pancreas regulates digestion and blood sugar via enzyme and hormone production. In chronic pancreatitis, persistent inflammation causes tissue damage, fibrosis, and functional decline—especially in the pancreatic head. Inflammatory masses may compress the bile duct or duodenum, prompting procedures like the Whipple or duodenum-preserving resections (139) (Table 9). Causes include alcohol use, gallstones, autoimmune disease, and genetic mutations. Structural changes—ductal obstruction, ectasia, fibrosis, islet dysfunction, calcifications, pseudocysts, and atrophy—impair both digestive and endocrine functions. Diagnosis is based on symptoms, imaging, and endoscopy. Treatment includes medical therapy (pain control, enzymes, lifestyle changes) and surgery (drainage or resection) in advanced cases. Personalized plans aim to preserve function and reduce complications.

DISCUSSION

The hepatic artery supplies oxygenated blood to the liver, but its anatomy varies. Accessory, replaced, or aberrant arteries can complicate surgeries like the Whipple procedure (Lupascu et al., 2011[106]).

Hiatt's 1994 classification remains widely used, yet large-scale prevalence data are limited. To address this, a systematic review and meta-analysis of 15 studies (6,287 cases) was conducted. Eligible studies were identified via PubMed, Scopus, and Google Scholar, including those reporting Hiatt's Types I–VI or comparing to Michel's classification.

Data were analyzed using a random-effects model. The meta-analysis confirmed Type I as most common (76.3%). Types II (10.0%) and III (7.2%) are key surgical considerations. Types IV (2.1%), V (1.9%), and VI (1.4%) are rarer but present significant challenges. An additional 1.1% were unclassified, showing variation beyond standard typologies and underscoring the need for updated classification systems.

These findings stress the importance of preoperative vascular mapping to avoid complications like ischemia, vascular injury, and biliary leaks—especially during pancreatoduodenectomy (Table-10). While Type I remains the norm, Types II–VI represent diverse configurations with different surgical implications. Unclassified patterns highlight current system limitations and the need for further research.

The Whipple procedure is the standard treatment for diseases of the pancreatic head, duodenum, and biliary tract, especially periampullary cancers. Its success hinges on understanding vascular anatomy, particularly hepatic artery variants. As Yan et al. (126) note, detailed anatomical knowledge improves safety and outcomes by anticipating complications.

Retrospective studies, some with 1,000+ cases, confirm the clinical relevance of hepatic artery variations. These require detailed preoperative imaging (CTA/MRI), careful intraoperative identification, and flexible surgical strategies. Early detection allows for alternative revascularization and improves outcomes.

CONCLUSION:

Hepatic artery variations are key anatomical factors influencing safety and outcomes in the Whipple procedure. Preoperative imaging (e.g. CT angiography/MRI) is essential to identify these variants, guide surgical strategy, and minimize risks like ischemia or vascular injury.

Type I is most common, while Types II–VI and unclassified forms require tailored approaches. Advanced techniques—artery-first dissection, 3D reconstruction, and ICG fluorescence angiography—enhance vascular visualization and improve perfusion. Surgeons familiar with variant anatomy report reduced blood loss, fewer complications, and improved R0 resection rates, though survival benefits remain unclear.

Optimal outcomes depend on multidisciplinary collaboration, continuous training, and integration of modern imaging tools. Future research should refine classification systems (e.g. Hiatt's), define risk profiles, and validate minimally invasive/hybrid techniques. In conclusion, managing hepatic artery variants requires technical precision and proactive planning, essential for success in complex procedures like the Whipple.

I. ACKNOWLEDGMENT

Thepreferredspellingoftheword "acknowledgment" inAmericaiswithoutan "e" afterthe "g".Avoidthestiltedexpression, "Oneofus(R.B.G.)thanks..."
Instead,try"R.B.G.thanks".Putapplicablesponsoracknowledgmentshere;DONOTplacethemonthefirstpageofyourpaperorasafootnote.

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TABLE-1: ANATOMY OF THE PANCREAS AND RELATED STRUCTURES

Structure	Description	Author
Pancreas	Retroperitoneal glandular organ at L1-L2 vertebral level; consists of head, neck, body, tail, and uncinate process. Head lies in the duodenal C-loop.	Russell et al., 2022 (6)
Anterior Surface	Covered by peritoneum at the posterior wall of the lesser sac.	Kitagawa et al., 2013 (7)
Posterior Surface	Covered by retroperitoneal fascia; related to SMA, abdominal aorta, left kidney, and renal vein.	Zambirinis et al., 2018 (8)
Pancreatic Head and IVC	Overlies IVC; drains into left and right renal veins.	Mahadevan et al., 2019 (9)
Pancreatic Neck	Lies in front of the portal vein, formed by union of SMV and splenic vein.	Mahadevan et al., 2019 (9)
Splenic Vein	Runs along the posterior surface of the pancreas; joins IMV and SMV.	Mahadevan et al., 2019 (9)
Common Bile Duct	Tubular structure running along the pancreatic head; carries bile to the liver.	Hawes et al., 2010 (11)
Bile Duct Segments	Divides duodenum into supraduodenal, infraduodenal, retroduodenal, and intramural parts; ends at ampulla of Vater.	Hameed et al., 2019 (12)

Table 2. Hiatt's Classification of Hepatic Artery Variants Based on Arterial Anatomy and Origin

Type	Arterial anatomy	Origin
I	Normal	Left gastic artery
II	Replaced LHA and RHA	SMA
III	Accessory LHA and RHA	Double replaced pattern
IV	Replaced/Accessory LHA and Replaced/Accessory RHA	
V	Aberrant CHA rising from SMA	
VI	Aberrant CHA rising from aorta	

TABLE 3: Comprehensive Overview of the Whipple Procedure: Preoperative, Intraoperative, and Postoperative Considerations

Whipple Procedure:		
Category	Component/Step	Details
Preoperative Evaluation	Preoperative Considerations	Thorough preoperative evaluation is important to determine the suitability of patients for the Whipple procedure. This includes a comprehensive medical history assessment, physical examination, laboratory tests, and imaging studies such as computed tomography (CT) scans and magnetic resonance imaging (MRI). Figure 4 shows how 3-D visualisation and evaluation help in identification and location of anatomical variants of hepatic artery. These investigations help determine the extent of the tumour, involvement of adjacent structures, and the presence of distant metastases. Some patients might have risk factors such as higher age, sex, obesity, COPD, and steroid use (Greenblatt et al., 2011).
Multidisciplinary Care	Multidisciplinary Team	Includes surgeons, oncologists, radiologists, gastroenterologists, anesthesiologists. Ensures collaborative decision-making.
	Comorbidities Optimization	Manage diabetes, cardiovascular/pulmonary conditions, provide nutritional support pre-surgery.
	Lifestyle Interventions	Smoking cessation (Sadr-Azodi et al., 2012), weight loss (Hendifar et al., 2019) improve surgical outcomes.
	Predictive Limitations	Preoperative body composition reflects cancer stage but doesn't predict post-op outcomes. (Aslani et al., 2010)
Surgical Technique	Patient Positioning and Incision	Supine position with midline/subcostal incision for abdominal access. Minimally invasive options possible. (MacKenzie et al., 2011)
	Mobilization and Exposure	Expose pancreas, duodenum, bile duct. Dissect and preserve SMA/SMV. (Zeh et al., 2011)
	Pancreatic Head Resection	Resect head of pancreas; preserve duct; improve pain and outcomes. Portal vein reconstruction if needed. (Witzigmann et al., 2003; Weitz et al., 2007)
	Duodenal Resection and Reconstruction	Duodenum divided distal to pylorus; reconstructed using Billroth II, Roux-en-Y, etc. (Morris and Ford, 1993)

	Bile Duct Resection and Reconstruction	Dissect and divide CBD; lymphadenectomy; stents may be placed. Watch for stent migration risks. (Rezvani and Aroori, 2022)
	Reconstruction of GI Continuity	Join jejunum with pancreatic duct and bile duct; drainage of digestive fluids. (Madiba and Tomson, 1995; You et al., 2009)
	Lymphadenectomy	Lymph node removal around pancreas, CHA, SMA. Important for staging. (Pavlidis et al., 2011; Colussi et al., 2015)
Postoperative Care	Monitoring & Support	Patients are monitored in ICU/HDU. Support includes fluids, pain control, antibiotics, and physiotherapy. (Yeung et al., 2013)
	Recovery Period	Recovery is prolonged; hospital stay averages 1–2 weeks. (Koerner et al., 2023)
	Postoperative Complications	Potential issues: pancreatic fistula, bile leak, delayed gastric emptying, infections, bowel obstruction.
	Long-Term Outcomes	Outcomes depend on tumour stage, patient age, health status, and postoperative weight gain. (van Berge Henegouwen et al., 1998)
	Overall Efficacy	Despite complexity, the Whipple procedure improves survival. Outcomes benefit from surgical and therapeutic advances. (van Dijk et al., 2018)

Table 4: Stage-specific Surgical Strategies for Hepatic Artery Variants in the Whipple Procedure

Stage	Consideration	Author(s)
Preoperative Planning	Preoperative imaging helps identify hepatic artery variants for tailored planning and to avoid complications. Variants should be classified (e.g., Hiatt's) and the surgical team should anticipate changes in anatomy.	Gagner and Palermo et al. (91)
Intraoperative Techniques	Midline or right-sided incision made under general anaesthesia. Liver, gallbladder, duodenum, pancreas visualized and mobilized. Surrounding tissues dissected to expose target anatomy.	Longmire Jr and Traverso et al. (92)
	Resection adjusted if an accessory hepatic artery (e.g., from celiac or SMA) is present. Must be identified, dissected, and preserved to ensure hepatic perfusion.	Mann and Izbicki et al. (93)
	Replaced arteries (e.g., hepatic artery from SMA/splenic) require early identification and protection. May need reattachment or careful routing.	Malviya and Verma et al. (94)
	Aberrant courses crossing surgical field call for tailored incisions and dissection paths. Preserving aberrant vessels reduces bleeding and ischemia.	Chamberlain et al. (95)
	Use of intraoperative Doppler ultrasound or indocyanine green fluorescence angiography ensures real-time arterial perfusion assessment.	Raabe et al. (96)
Post-Resection	Gastrointestinal reconstruction includes reattaching remaining bile duct, pancreas, and intestine. Anastomoses are monitored with placed drains for leakage.	Allan et al. (97)
Vascular Reconstruction	Revascularization via grafts or autologous vessels (e.g., splenic, gastric arteries) when preservation is not feasible.	Strasberg et al. (98)
	Arterial anastomosis may link the variant artery to another hepatic or regional artery. Ligation considered when sufficient perfusion exists.	Portolani et al. (99)
	Ligation used if arterial redundancy ensures hepatic perfusion. Reduces complications such as pump-pocket, catheter, vascular, or biliary issues.	Sharib et al. (100)

Table 5: Key Surgical Steps in the Artery-First Whipple Procedure and Supporting Literature

Step	Description	Authors
1. Early Identification and Preservation of Arterial Supply	Initial step involves identifying and preserving the SMA or GDA by careful dissection. Arterial branches to the pancreatic head are ligated, ensuring preservation. If SMA is involved, reconstruction such as vein graft interposition may be required.	Negoi et al., 2018 (113)
2. Pancreatic and Biliary Dissection	Proceed with pancreatic head and biliary structure dissection. This includes separation from the portal vein, dissection and ligation of the bile duct, and preservation of the main pancreatic duct.	Le Bian et al., 2015 (114)
3. Duodenal Resection and Reconstruction	Duodenum is divided distal to the pylorus. The distal segment is closed; proximal end is either closed or connected to the jejunum or stomach depending on the clinical scenario.	Grace et al., 1990 (115)
4. Reconstruction of Gastrointestinal Continuity	Jejunum is mobilized and anastomosed with the pancreatic duct, bile duct, and stomach/jejunum. Ensures restoration of digestive continuity and reduces postoperative complications.	Negoi et al., 2018 (113)

Table 6: Common disorders associated with hepatic artery variations and their clinical implications

Disorder	Description	Author(s), Year
Anomalous Origin of the Hepatic Artery	The hepatic artery may arise from sources like the superior mesenteric artery or the aorta, leading to compromised blood flow, ischemia, and hepatic necrosis.	Bhardwaj, 2010 (116)
Hepatic Artery Aneurysm	Variations in branching patterns may predispose to aneurysm formation, which can rupture and cause life-threatening hemorrhage.	Berceli, 2005 (117)
Hepatic Artery Stenosis	Narrowing of the hepatic artery due to atherosclerosis or compression; variants can increase susceptibility to this condition.	Bommena et al., 2022 (118)
Hepatic Artery Thrombosis	Formation of blood clots due to anatomical variants, risking ischemia and graft failure post-transplant.	Fouzas et al., 2019 (119)
Hepatic Ischemia	Caused by stenosis or occlusion of the artery due to variants; leads to liver dysfunction or failure.	Traverso and Freeny, 1989 (120)
Liver Abscesses	Compromised blood flow weakens liver defenses, encouraging abscess formation due to infection.	Ishigami et al., 2004 (121)
Liver Transplant Complications	Variants complicate arterial anastomosis and perfusion during transplant, affecting graft function.	Ishigami et al., 2004 (121)
Hepatobiliary Malignancies	Associated with cancers like hepatocellular carcinoma; variants complicate surgical planning and vascular integrity.	Winston et al., 2007 (122)

Table -7: Investigations for Locating Hepatic Artery Variations:

Imaging Modality	Description	Reference (Author et al.)
Computed Tomography (CT) Scan with Contrast	Provides detailed images of arterial anatomy, including course, branching, and anomalies; contrast enhances detection aiding surgical planning.	Coskun et al., 2005 (123)
Magnetic Resonance Angiography (MRA)	Non-invasive, uses magnetic fields to visualize vessels; avoids radiation and contrast agents, ideal for patients with contraindications.	Stafford-Johnson et al., 1998 (124)
Digital Subtraction Angiography (DSA)	Invasive procedure with contrast injection and real-time X-ray; valuable for identifying complex anomalies and guiding interventions.	Covey et al., 2012 (125)
Three-dimensional (3D) CT Angiography	Specialized 3D reconstruction of hepatic artery anatomy; enhances spatial understanding for surgical planning.	Yan et al., 2020 (126)
Doppler Ultrasound	Assesses blood flow within hepatic artery; useful intraoperatively and for identifying stenosis or variations.	Barnes and Garrett, 1978 (127)
Cone-beam CT (CBCT)	Emerging modality with real-time, high-resolution 3D imaging; valuable for accurate endovascular intervention guidance.	Wallace et al., 2008 (128)

Table-8: Management Strategies for Hepatic Artery Variations:

Category	Subcategory	Description	Author(s)
Surgical Management	Variant-Specific Approaches	Tailored approaches based on anatomy; careful dissection and reconstruction to restore blood flow and minimize complications.	Sitarz et al., 2018 ()130
	Vascular Reconstruction	Use of autologous vessels or synthetic grafts to restore blood supply in complex anomalies or disease.	Stauffer et al., 2009 (131)
	Microsurgical Techniques	High-precision microvascular anastomosis requiring advanced surgical skill and magnification tools.	Balci and Ahn, 2019 (132)
	Hybrid Surgical Approaches	Combines open surgery with endovascular methods for tailored, minimally invasive solutions in complex cases.	Cebrián et al., 2017 (133)
Minimally Invasive Interventions	Endovascular Techniques	Includes angioplasty, stent placement, or embolization for high-risk or unfit patients.	Chen et al., 2014 (134)
	Transarterial Chemoembolization (TACE)	Delivers chemotherapy followed by embolization directly into hepatic artery; requires variant knowledge.	Glantzounis et al., 2017 (135)
Medical Management	Vasodilators	Used to improve blood flow and relieve ischemic symptoms; includes nitroglycerin or calcium channel blockers.	Karam et al., 2000 (136)
	Antiplatelet and Anticoagulant Therapy	Prevents thrombotic events and ensures graft patency post-reconstruction.	Pawlicki et al., 2022 (137)
	Immunosuppressive Therapy	Used in liver transplantation to prevent rejection and manage complications from artery variations.	Chan et al., 1998 (138)

Table 9: pathological and clinical features of chronic pancreatitis

Category	Item	Description	Author(s)
Cause	Heavy alcohol consumption and smoking	Prolonged alcohol use causes inflammation and damage to pancreatic tissue, potentially through toxic metabolites, oxidative stress, and altered blood flow.	Yadav and Whitcomb, 2010 (140)
	Gallstones	Gallstones may block the pancreatic duct, causing enzyme build-up and inflammation, resulting in tissue damage.	Yan et al., 2006 (141)
	Autoimmune disorders	The immune system attacks the pancreas, leading to chronic inflammation. Often associated with other autoimmune conditions.	Yoshida et al., 1995 (141)
	Genetic factors	Mutations in PRSS1, SPINK1, and CFTR genes can predispose individuals to chronic pancreatitis, though not all carriers develop the disease.	Sobczynska-Tomaszewska et al., 2006; Witt et al., 2001; Rosendahl et al., 2013 (143, 144, 145)
Structure	Pancreatic Ducts	Inflammation leads to narrowing and scarring, causing obstruction and accumulation of digestive enzymes. Characterized by ductal ectasia, contributing to pain.	Mann and Izbicki, 2005; Sakorafas et al., 2007 (146, 147)
	Parenchyma and Fibrosis	Exocrine tissue replaced with fibrous scar tissue due to inflammation. Fibrosis increases pressure and pain, may cause duct and biliary/duodenal obstruction.	Kleef et al., 2017; Grace et al., 1993 (148, 149)
	Islet Cells	Affected by inflammation and fibrosis, impairing hormone production and potentially leading to diabetes mellitus.	Roy et al., 2020; Unger and Orci, 2010 (150, 151)
	Pancreatic Calcifications	Calcium deposits form in pancreatic tissue due to inflammation, indicating long-standing disease. More severe in smokers.	Ammann et al., 1988; Imoto and DiMagno, 2000 (152, 153)
	Pancreatic Pseudocysts	Fluid-filled sacs without epithelial lining form from ductal disruptions. Can cause pressure and major complications.	Aghdassi et al., 2008; Rosso et al., 2003; Stanley et al., 1976 (154, 155, 156)
	Pancreatic Atrophy	Pancreas shrinks due to fibrosis, compromising function and enzyme/hormone production. Often seen in diabetic patients.	Olesen et al., 2021 (157)

Aspect	Symptoms	Persistent upper abdominal pain, diarrhoea, oily stools (steatorrhea), weight loss, nausea, vomiting, development of diabetes, and malnutrition.	Duggan et al., 2010 (158)
	Diagnosis	Combination of medical history, physical examination, blood tests, imaging (ultrasound, CT, MRI), and endoscopic procedures.	Banks et al., 2010 (159)
	Medical Treatment	Includes lifestyle changes (e.g., cessation of alcohol), pain management with analgesics, enzyme supplements, diabetes management, and endoscopic procedures to relieve obstructions or fluid buildup.	Giger et al., 2004 (160)
	Importance of Early Intervention	Crucial to avoid complications such as pancreatic cancer, malnutrition, and organ failure.	General Clinical Consensus
	Surgical Indications	Intractable pain, complications involving adjacent organs, pseudocysts, ductal abnormalities, or unresolved suspicion of cancer.	Cunha et al., 2004; Anderson, 1972 (161)
	Surgical Approach	Customized based on patient needs; may include drainage (e.g., pancreaticojejunostomy) or resection based on disease morphology.	Bradley, 1987; Gourgiotis et al., 2007 (163, 164)
	Cancer Differentiation	Distinguishing chronic pancreatitis from cancer is essential. Requires imaging and FNA to rule out malignancy.	Fritscher-Ravens et al., 2002 (165)

Table 10: Prevalence of Hepatic Artery Variants According to Hiatt's Classification (Meta-Analysis Results)

Hiatt's type	**N**	**%**
I	4794	76.3
II	631	10
III	454	7.2
IV	130	2.1
V	120	1.9
VI	89	1.4
Not Classified	69	1.1

Figure 1: PRISMA flow Diagram of study selection

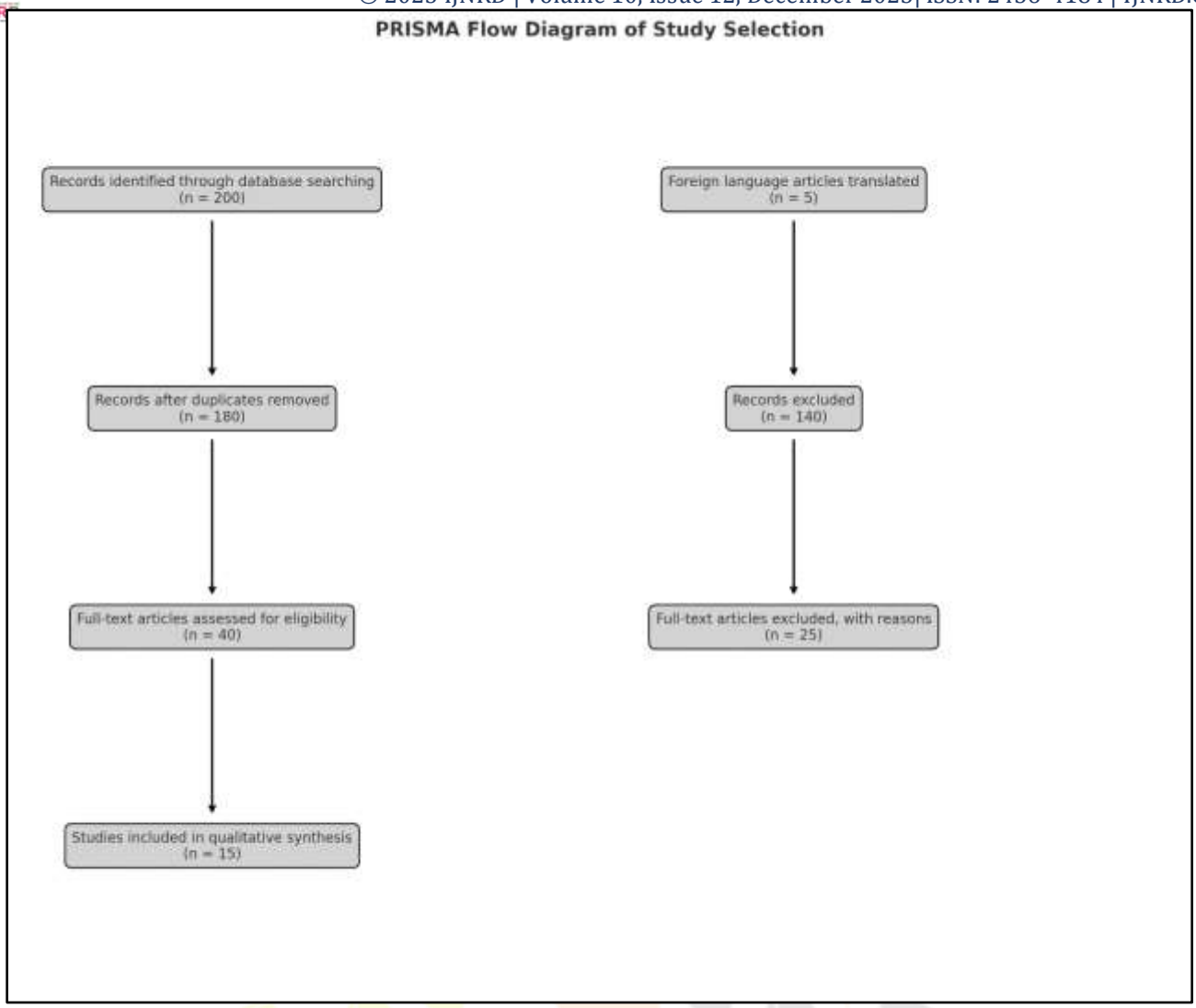


Figure 2: Principal anatomical relations of the pancreas, highlighting its proximity to key vascular and biliary structures relevant during the Whipple procedure.***(Ellis, 2007) (10)***

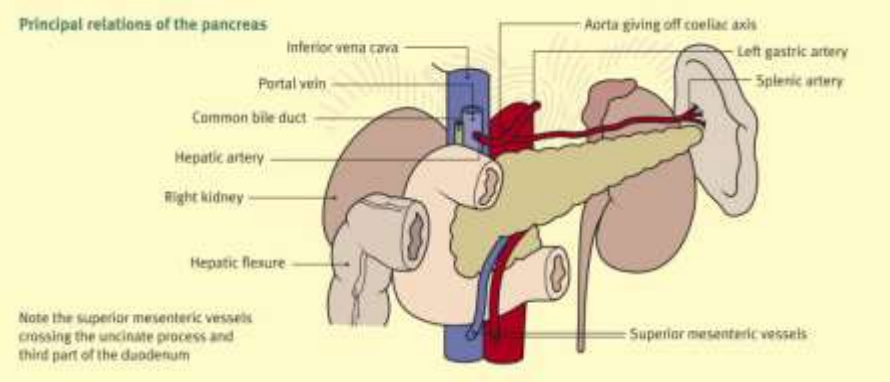
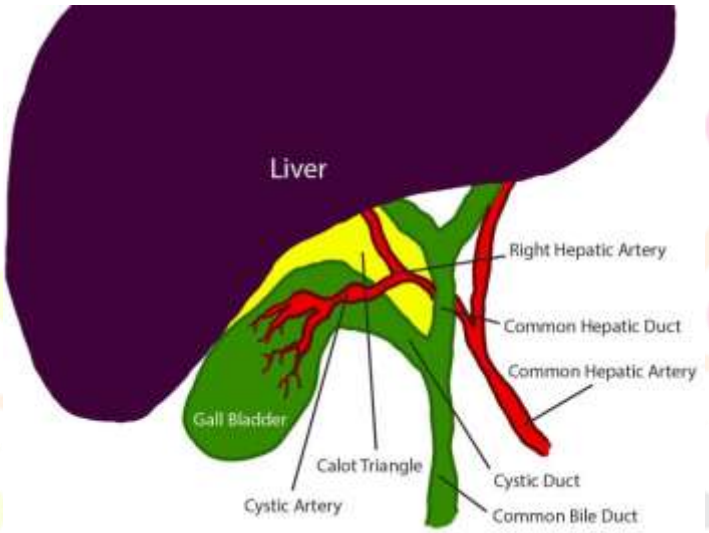


Figure 3. Anatomy of Calot's Triangle, highlighting the relationship between the cystic artery, cystic duct, and common hepatic structures, which is crucial for safe dissection during cholecystectomy. ***(Jones et al., 2017)*** *(19)*



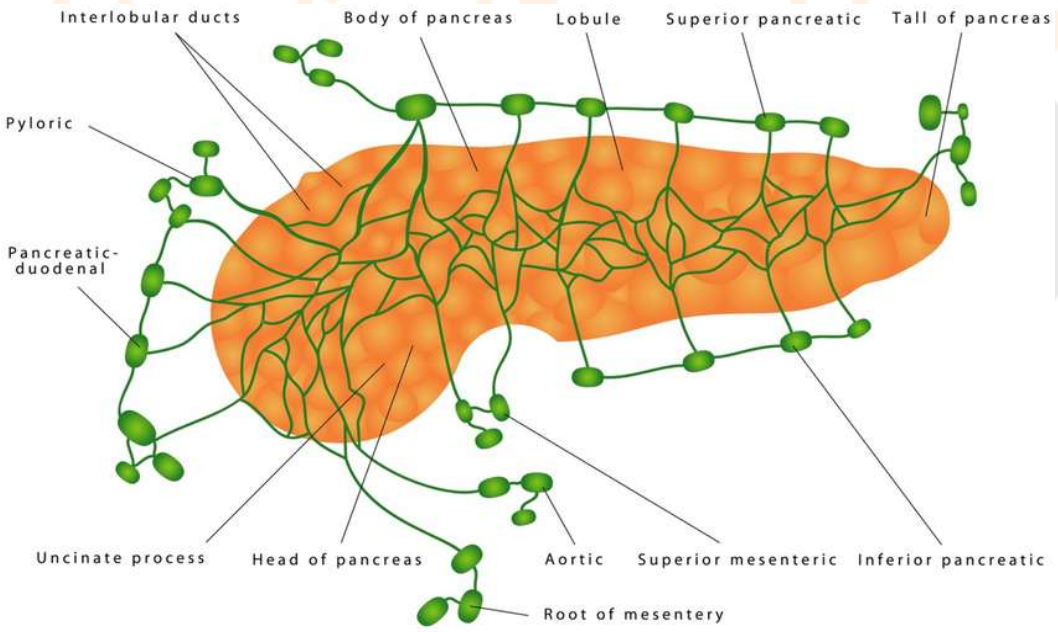


Figure 4. Lymphatic drainage of the pancreas showing intrapancreatic and peripancreatic lymph nodes and vessels. Drainage pathways include superior, inferior, pancreaticoduodenal, and mesenteric routes. *(Leong et al., 2022) (43)*

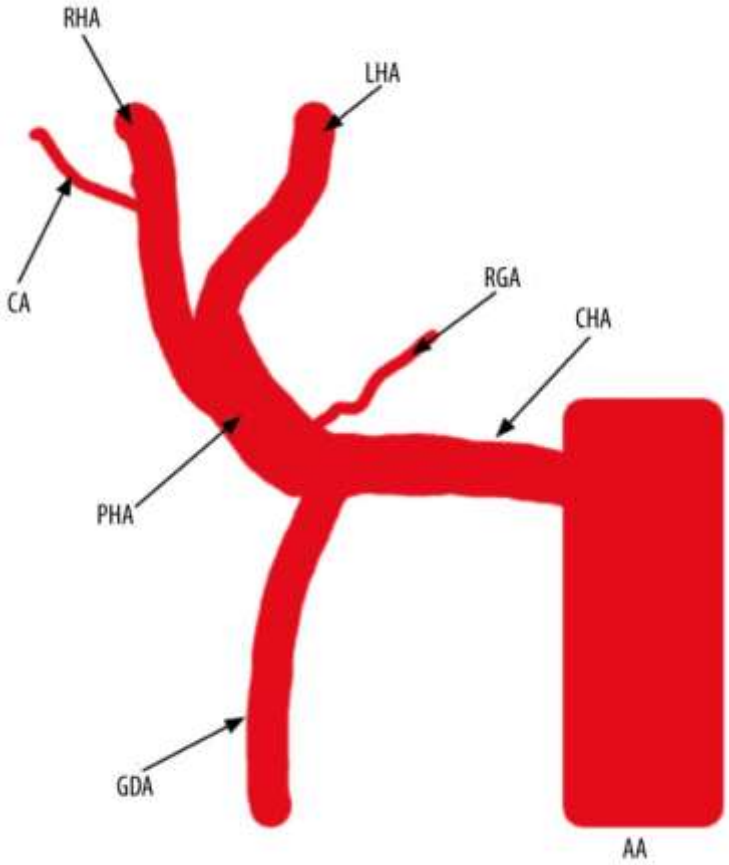


Figure 5. Typical anatomy of the hepatic artery system. AA: Abdominal Aorta, CHA: Common Hepatic Artery, RHA: Right Hepatic Artery, LHA: Left Hepatic Artery, PHA: Proper Hepatic Artery, GDA: Gastroduodenal Artery, RGA: Right Gastric Artery, CA: Cystic Artery.*(McDaniel and Frank, 2022) (82).*

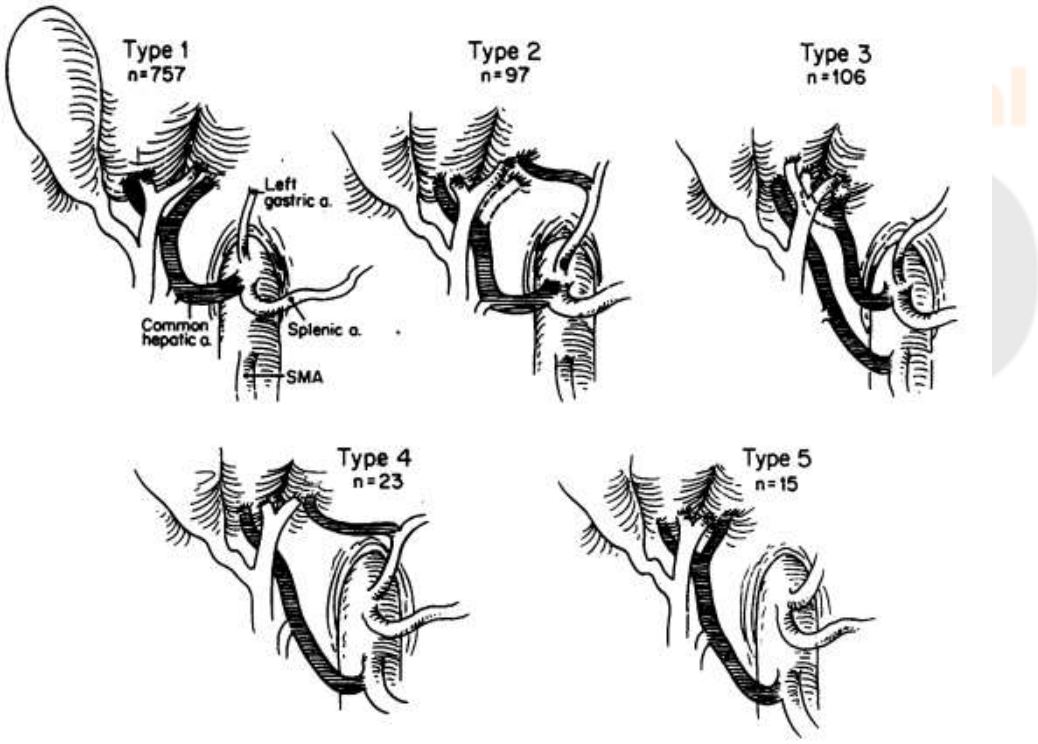


Figure 6. Type 1 = typical artery, Type 2 = replaced (accessory) left hepatic artery from left gastrc; Type 3 = replaced (accessory) right hepatic artery from SMA, Type 4 = double replaced system, Type 5 = common hepatic artery (CHA) from SMA. (91)

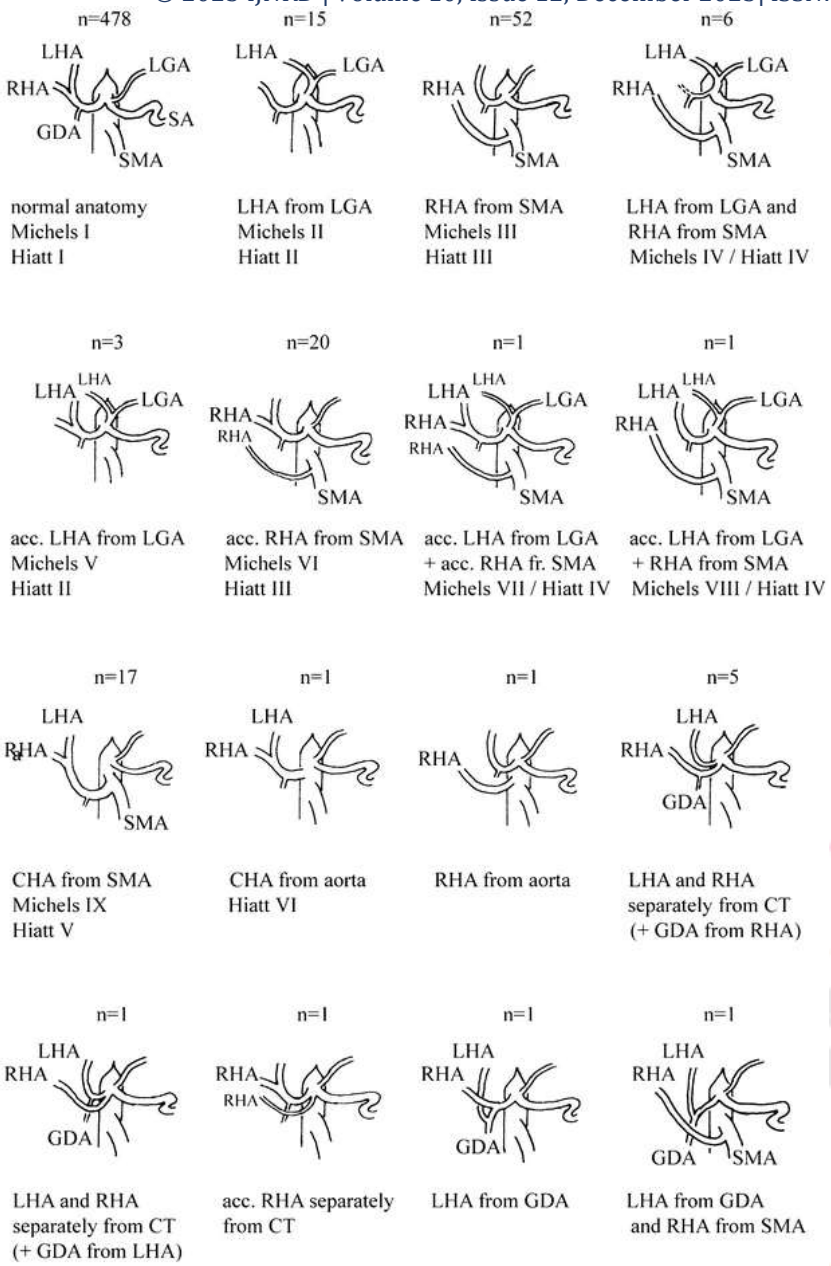


Figure 7. Comprehensive overview of hepatic artery variants based on angiographic data, incorporating Hiatt and Michels classifications and additional rare anatomical configurations. *(46) LHA = left hepatic artery; RHA = right hepatic artery; LGA = left gastric artery; SMA = superior mesenteric artery; GDA = gastroduodenal artery; SA = splenic artery; CT = celiac trunk.*

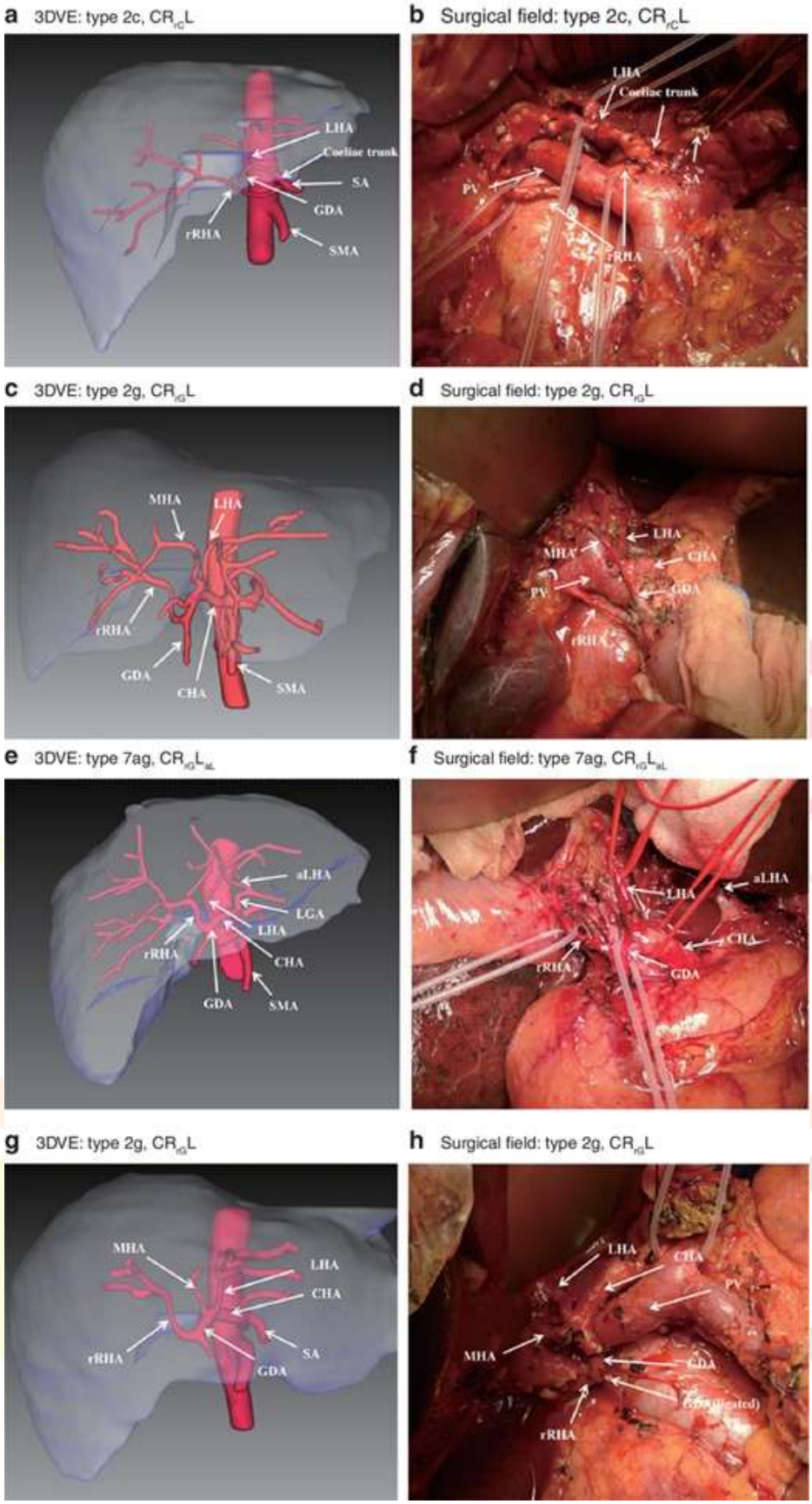


Figure 8: 3D vascular reconstructions and corresponding surgical fields showing hepatic artery variations under the CRL classification system *(Yan et al., 2020). (157)*