

# Surgical Biliary Anatomy and Safety Strategies in Laparoscopic Cholecystectomy

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## Abstract

**Background:** Anatomical variations of the extrahepatic biliary tree are common and represent one of the leading causes of bile duct injuries during laparoscopic cholecystectomy and other hepatobiliary procedures. A comprehensive understanding of these variations is therefore fundamental for safe dissection.

**Objective:** To review the surgical anatomy and anatomical variations of the biliary tree and the operative strategies used to minimize bile duct injury during laparoscopic cholecystectomy.

**Conclusion:** Detailed recognition of biliary anatomy, achievement of the Critical View of Safety, use of reliable anatomical landmarks, and timely adoption of bailout procedures are central to reducing bile duct injury during laparoscopic cholecystectomy.

**Keywords:** Biliary anatomy; Anatomical variations; Laparoscopic cholecystectomy; Bile duct injury; Critical View of Safety

## Introduction

A comprehensive understanding of the extrahepatic biliary anatomy is fundamental because anatomical variations are common and represent one of the leading causes of bile duct injuries during laparoscopic cholecystectomy and other hepatobiliary procedures [1, 2] The gallbladder is a thin-walled, pear-shaped sac measuring approximately 7–10 cm in length and 3–5 cm in diameter. It has an average capacity of 30–50 mL. It is located on the visceral surface of the liver in a shallow fossa between segments IV and V [1]

Laparoscopic cholecystectomy has replaced open cholecystectomy as the first choice of treatment for gallstones and inflammation of the gallbladder unless there are contraindications to the laparoscopic approach[3] Early recognition of hazardous operative conditions, strict adherence to the principles of the Critical View of Safety, and timely implementation of an appropriate bailout strategy are fundamental to improving surgical safety and patient outcomes [2, 4, 5]

## Surgical Aspect of Biliary Anatomy

A comprehensive understanding of the extrahepatic biliary anatomy is fundamental because anatomical variations are common and represent one of the leading causes of bile duct injuries during laparoscopic cholecystectomy and other hepatobiliary procedures. Preoperative identification of these variations by cholangiogram is useful [1, 2]

## Gallbladder anatomy

The gallbladder is a pear-shaped muscular sac situated in the gallbladder fossa between hepatic segments IVB and V. It consists of the fundus, body, infundibulum and neck. Its main function is to store and concentrate bile before releasing it into the duodenum after stimulation by cholecystokinin (CCK). Hartmann's pouch is a common site for gallstone impaction [6]

The antihaptic surface is covered with the peritoneum. Normally, there is no peritoneum between the gallbladder and the liver fossa making the cystic plate [7].

### The Cystic Duct (CD)

The cystic duct measures approximately 2–4 cm in length and contains the valves of Heister. It joins the common hepatic duct to form the common bile duct. Variations in its length, course, and insertion are among the most clinically significant biliary anomalies and should be identified preoperatively using MRCP whenever possible [2]

### Hepatic Ducts

The **right and left hepatic ducts** course within the hilar plate before joining to form the **common hepatic duct**. The left hepatic duct generally has a longer extrahepatic course than the right hepatic duct, which is shorter and exhibits greater anatomical variability. Knowledge of these anatomical relationships is essential for safe hepatic resection, biliary reconstruction, liver transplantation, and laparoscopic cholecystectomy to minimize the risk of bile duct injury [8, 9]

The hilar plate is a dense fibrous condensation of Glisson's capsule located at the porta hepatis. It encloses the extrahepatic biliary confluence together with the accompanying branches of the portal vein and hepatic artery, providing structural support to these structures. The hilar plate serves as an important anatomical landmark in hepatobiliary surgery because it defines the relationship between the hepatic ducts and the vascular structures at the liver hilum [8]

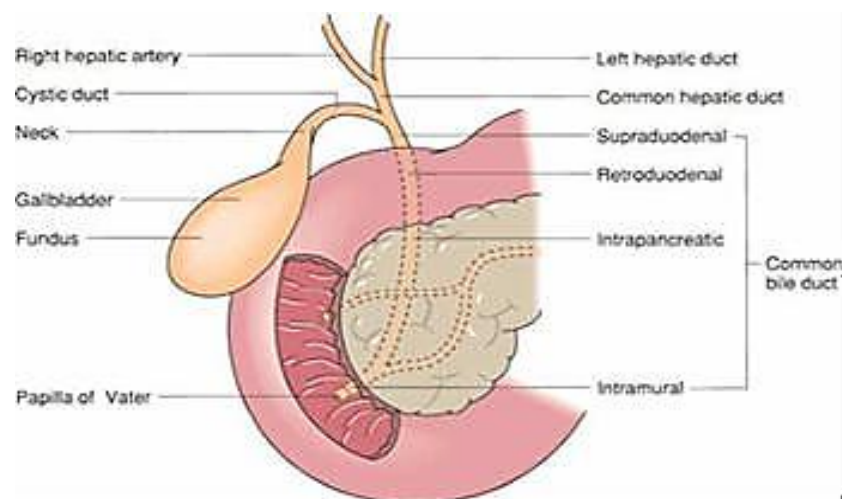
### The Common Hepatic Duct

The common hepatic duct is about 1.5 inch (4 cm) long and descends within the free margin of the lesser omentum. It is joined on the right side by the cystic duct from the gallbladder to form the bile duct [10]

### Common bile duct (CBD)

The length of the CBD varies from 5 to 15 cm depending upon the position of the entrance of the cystic duct. The duct is divided arbitrarily into 4 parts (**figure 1**):

- 1) **Supraduodenal** - average length of 2 cm
- 2) **Retroduodenal** – average length of 1.5 cm
- 3) **Pancreatic** – average length of 3 cm
- 4) **Intraduodenal** – average length of 1.1 cm [11]



**Figure (1):** The four portions of the common bile duct [12]

The CBD diameter is usually around 6 mm in adults [13]

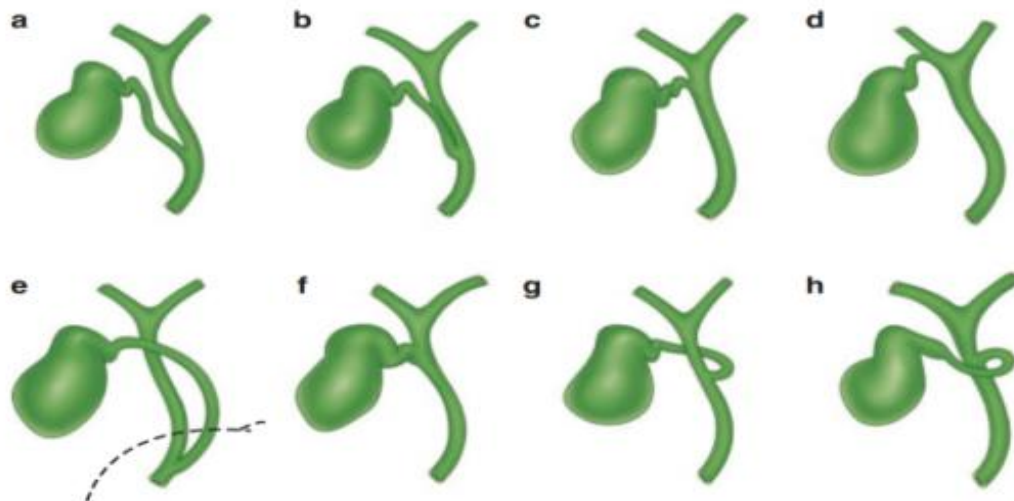
### Variations of biliary anatomy

#### Abnormalities of the cystic duct:

The most common anatomical variation is short cystic duct [14]

#### Variations in the Relation of the Cystic Duct to the Common Bile Duct (Figure 2)

1. Low insertion into common hepatic duct.
2. Parallel cystic and common hepatic duct.
3. High insertion into common hepatic duct
4. Cystic duct drains into right hepatic duct.
5. Long cystic duct that joins common hepatic duct behind the duodenum.
6. Absence of cystic duct.
7. Cystic duct crosses posterior to common hepatic duct and joins it anteriorly.
8. Cystic duct crosses anterior to common hepatic duct and joins it posteriorly [15]



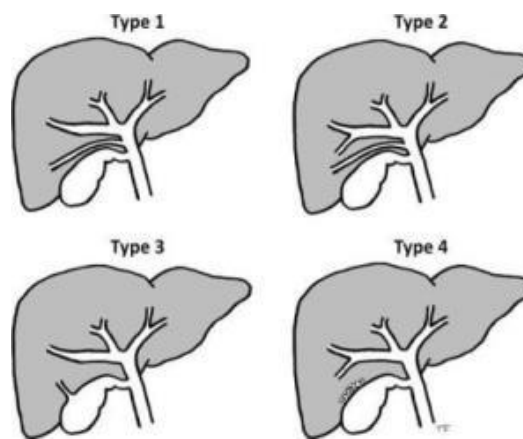
**Figure (2):** Variations in the relation of the Cystic Duct to the Common Bile Duct [15]

Among all the variations of extrahepatic biliary tree the cystic duct variations are most significant from a surgical point of view. Cystic duct entering the right hepatic duct is a rare condition which is prone to injury. Sectorial Right hepatic duct can be mistaken for cystic duct, ligated and divided [7].\*\*

#### Accessory bile ducts:

Accessory hepatic ducts are anomalous ducts that drain individual segments of liver. They usually drain from the right hepatic lobe to the biliary tree anywhere from the hepatic hilum to the cystic duct and occur in between 1–31% of patients. These ducts may be truly ‘accessory’ or ‘aberrant’. If the duct is the sole drainage to that segment, the duct is ‘aberrant’. If, however, that segment has drainage via the right hepatic duct in addition to the accessory duct, the duct is ‘accessory’ [16]

Bile ducts near the gallbladder fossa are comprised of four types (**Figure 3**), (1) segmental or sectorial subvesical bile ducts, (2) accessory subvesical bile ducts, (3) hepaticocholecystic bile ducts, and (4) aberrant subvesical bile ducts.



**Figure (3):** Types of subvesical bile ducts [17]

### Huang Classification of Biliary tree

The Huang classification describes anatomical variations of the right posterior sectoral duct and their surgical significance. These variants are important in laparoscopic cholecystectomy, liver resection, and liver transplantation [2, 7]

**This classification focuses on the branching patterns of the Right Posterior Hepatic Duct (RPHD) on a cholangiogram**

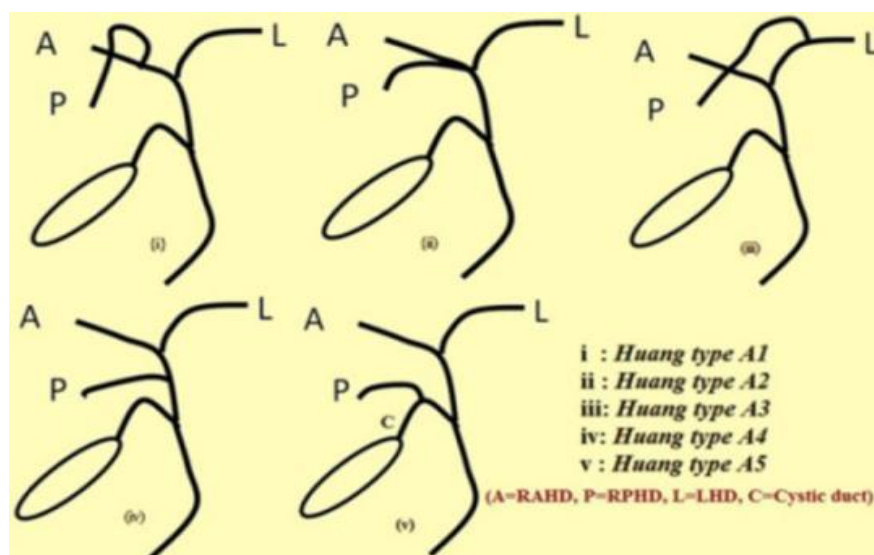
**Type A1 (Normal/Dominant):** The right anterior hepatic duct and right posterior hepatic duct join to form the standard right hepatic duct before it merges with the left hepatic duct. This is the classic, most prevalent anatomy (found in roughly 60% to 65% of the population).

**Type A2 (Trifurcation):** There is no true right hepatic duct. Instead, the right anterior hepatic duct, right posterior hepatic duct, and the left hepatic duct all converge at the same point (confluence).

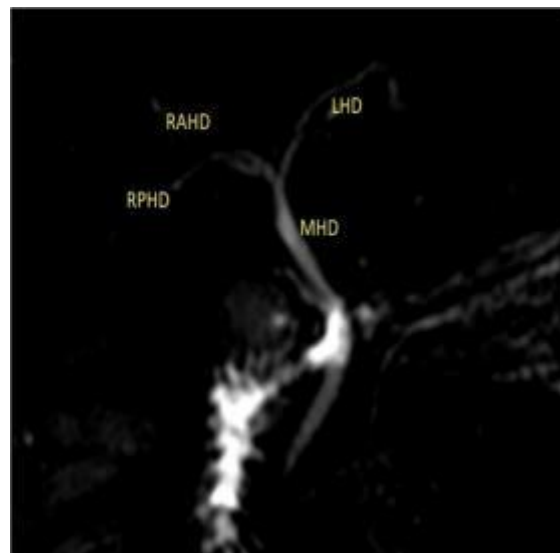
**Type A3:** The right posterior hepatic duct drains directly into the left hepatic duct.

**Type A4:** The right posterior hepatic duct drains directly into the main common hepatic duct, bypassing the main right/left confluence.

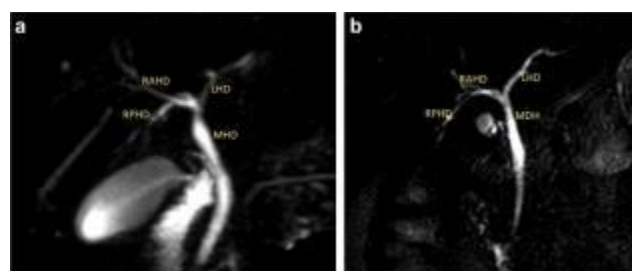
**Type A5:** The right posterior hepatic duct drains directly into the cystic duct rather than the main hepatic duct



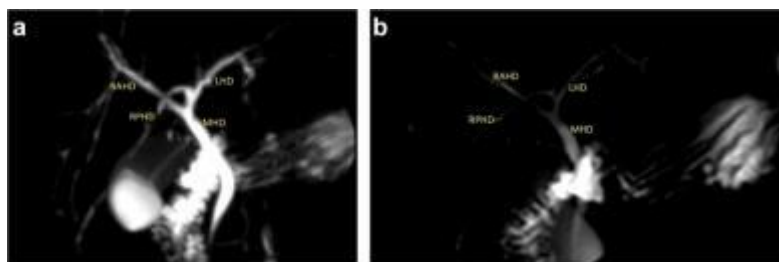
**Figure (4):** Huang classification of the biliary tract anatomy [18].\*\*



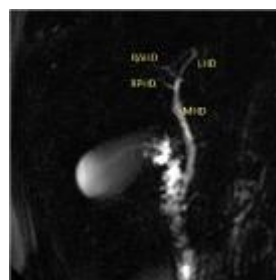
**Figure (5):** Huang type A1: RPHD drain into the RAHD (RPHD, right posterior hepatic duct; RAHD, right anterior hepatic duct; LHD, left hepatic duct; and MHD, main hepatic duct) [19]



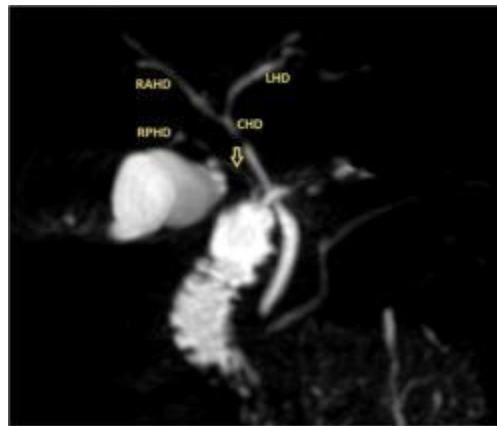
**Figure (6):** Trifurcation (Huang A2): RPHD open into the hepatic common confluence (RPHD, right posterior hepatic duct; RAHD, right anterior hepatic duct; LHD, left hepatic duct; and MHD, main hepatic duct) [19]



**Figure (7):** Huang type A3: RPHD opens into LHD (RPHD, right posterior hepatic duct; RAHD, right anterior hepatic duct; LHD, left hepatic duct; and MHD, main hepatic duct) [19]



**Figure (8):** Huang type A4: RPHD opens into main hepatic duct (MHD) (RPHD, right posterior hepatic duct; RAHD, right anterior hepatic duct; LHD, left hepatic duct; and MHD, main hepatic duct) [19]



**Figure (9):** Huang type A5: RPHD drains into cystic duct (arrow) (RAHD, right anterior hepatic duct; LHD, left hepatic duct; MHD, main hepatic duct) [19]

### Laparoscopic cholecystectomy

Laparoscopic cholecystectomy has now replaced open cholecystectomy as the first choice of treatment for gallstones and inflammation of the gallbladder unless there are contraindications to the laparoscopic approach [3].

Serious complications that occur with laparoscopic cholecystectomy are common bile duct injury, major vessel laceration, hemorrhage, bile leak, bowel perforation, trocar injury, liver injury and stray electrosurgical burns [20].

### Safe cholecystectomy: Strategies for Minimizing Bile duct injury (The Society of American Gastrointestinal and Endoscopic Surgeons Safe cholecystectomy program)

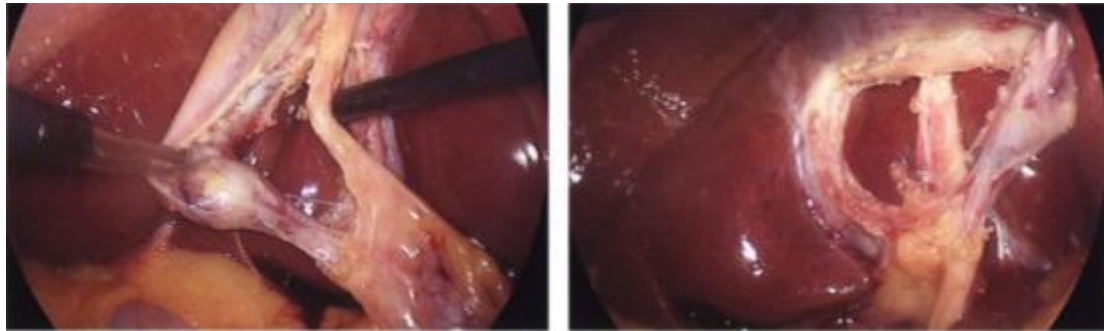
The **Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) Safe Cholecystectomy Program** was developed to reduce the incidence of bile duct injury during laparoscopic cholecystectomy by promoting a universal culture of surgical safety.

**The program emphasizes six key strategies:** (1) achieving the **Critical View of Safety (CVS)** before dividing any ductal structures, (2) recognizing aberrant biliary anatomy and anatomical landmarks, (3) using intraoperative biliary imaging, such as intraoperative cholangiography or indocyanine green fluorescence imaging, when anatomy is uncertain, (4) performing a bailout procedure, such as subtotal cholecystectomy, in difficult cases, (5) seeking assistance from an experienced surgeon when necessary, and (6) documenting the Critical View of Safety before clipping or transecting the cystic duct and artery. These recommendations aim to minimize misidentification of biliary structures, the leading cause of bile duct injury during laparoscopic cholecystectomy [21]

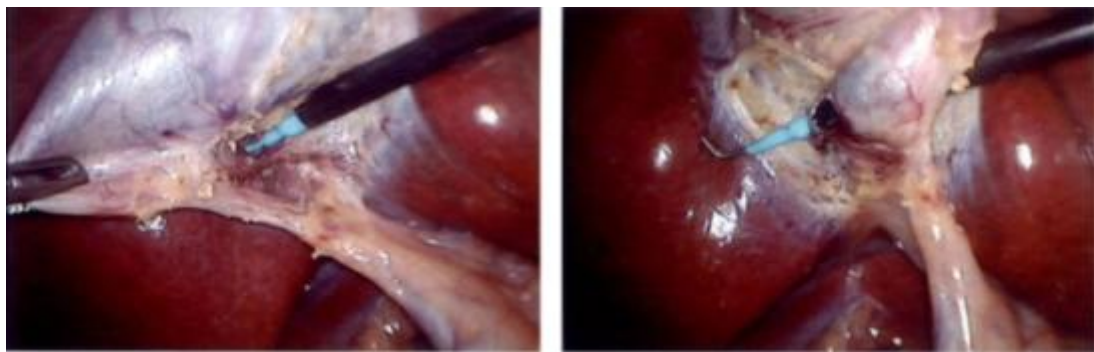
Different anatomy in laparoscopic view of the area around the gall bladder specially the Calot's triangle contributes to misidentification of structures. The limited magnified view of anatomy of Calot's triangle in laparoscopy is 2-dimensional vision as compared to 3-dimensional view in open cholecystectomy. The retraction of Hartmann's pouch during laparoscopic cholecystectomy (LC) tends to distort the Calot's triangle by actually flattening it rather than opening it out [22]

To prevent serious bile duct injuries during laparoscopic cholecystectomy, guidelines recommend that a critical view of safety (CVS) be obtained during the procedure. CVS has 3 requirements. First, the triangle of Calot must be cleared of fat and fibrous tissue, and a 360 view of the cystic duct entering the gallbladder must be attained. Second, the lowest third of the gallbladder should be dissected from the liver bed. Third, a 2-window view should be created between the cystic duct and the cystic artery and between the cystic duct and the liver.

Only when all 3 criteria are met CVS has been reached (**Figure 12**). Although CVS is an important safety feature to prevent serious bile duct injuries, the number of these injuries after LC has not decreased since the introduction of CVS. The reason may be that CVS is not actually reached [23]



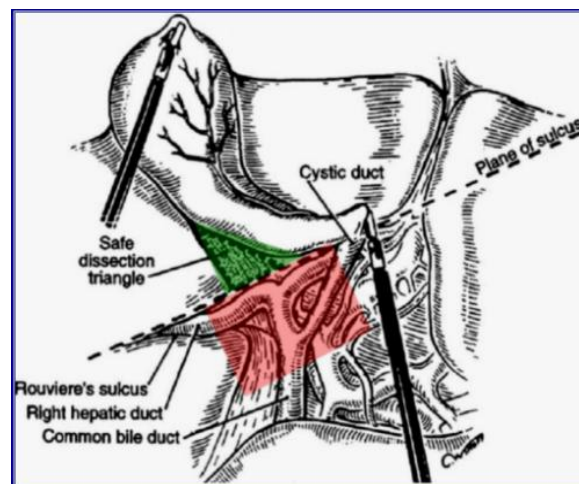
*A: Example of an 'adequate' critical view of safety photo.*



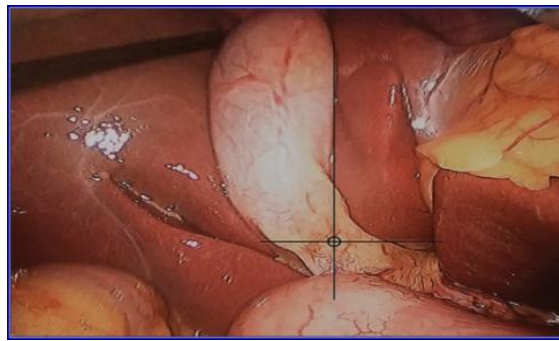
*B: Example of an 'inadequate' critical view of safety photo*

**Figure (12): CVS adequacy A & B [24]**

The Rouvière's sulcus is a fissure on the liver between right lobe and caudate process and is clearly visible during LC during posterior dissection in a majority of patients (**Figure 13**). Being an extra biliary reference point it does not get affected by distortion due to pathology (**Figure 14**) [22].



**Figure (13):** Rouvière's sulcus; imaginary line drawn between the sulcus and the base of segment IV indicates the level below which dissection should not occur (red) and level of safe initial dissection (green) [25]

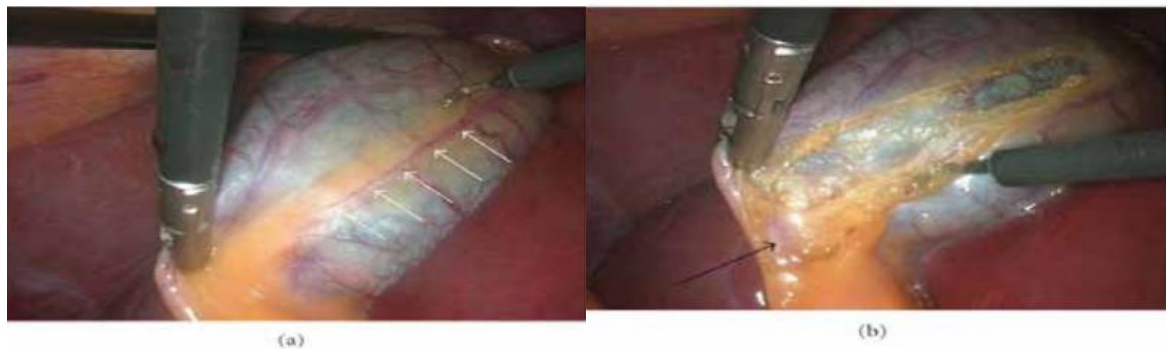


**Figure (14):** Localization of the starting point for LC dissection [26]

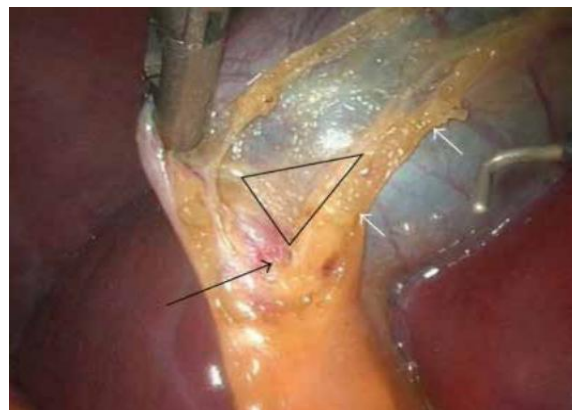
### Triangle of Safety Technique

**Triangle of Safety Technique (TST)** is a new anatomical triangle relatively away from CBD, thus reducing misidentification issue and other factors leading to ductal injury. Its borders are cystic artery medially, cystic duct laterally and the gallbladder wall superiorly. It provides better definition of anatomy in a relatively safer area of dissection and so its routine use for laparoscopic cholecystectomy is recommended (**Figure 15**) [26]. It is considered a useful adjuvant dissection technique to help achieve CVS.

The cystic artery is identified and mobilized from the GB medial wall down towards the cystic duct which would simultaneously divide the medial GB peritoneal attachment. This is then followed by dividing the lateral peritoneal attachment. The GB will be unfolded and the borders of the triangle of safety are achieved, the floor of the triangle is then divided to delineate both cystic duct and artery in an area relatively far from CBD [27].



**Figure (15):** Triangle of Safety Technique: (a) Identifying and dissecting the GB peritoneum above cystic artery (white arrows). (b) Continuing dissection toward cystic duct-infundibular Junction (black arrow) [27].



**Figure (16):** Triangle of Safety outlining borders: Cystic Artery (white arrows) and junction between cystic duct and artery (black arrow) and the triangle of safety [27]

### The difficult laparoscopic cholecystectomy

Patient-specific factors including increased BMI, increased age, male gender, increased American Society of Anesthesiologists (ASA) score and abnormal LFT are significant predictors of prolonged LC duration and may be indicators of increased procedural difficulty [28]

Laparoscopic cholecystectomy though considered as safe and effective, yet can become difficult, The following are indications of difficult cases:

- (1) Dense adhesions at the triangle of Calot,
- (2) Contracted and fibrotic gallbladder,
- (3) Previous upper abdominal surgery with dense scar marks,
- (4) Gangrenous gallbladder,
- (5) Acutely inflamed gallbladder,
- (6) Gallbladder empyema,
- (7) An unclear anatomy,
- (8) Mirizzi syndrome [29]

### 1- Bailout surgery

#### Bailout Surgery in Difficult Laparoscopic Cholecystectomy:

Bailout surgery refers to a group of alternative operative strategies employed when safe completion of a standard laparoscopic cholecystectomy is not possible because of severe inflammation, dense adhesions, distorted anatomy, uncontrolled bleeding, or inability to achieve the **Critical View of Safety (CVS)**. The primary objective of bailout procedures is to minimize the risk of vasculobiliary injury by avoiding hazardous dissection within Calot's triangle. Current international guidelines recommend that surgeons adopt a bailout strategy whenever the biliary anatomy cannot be clearly identified despite appropriate exposure, rather than persist with unsafe dissection. [5, 30, 31]

The most widely accepted bailout procedure is **subtotal cholecystectomy**, in which part of the gallbladder is intentionally left in situ after removal of the gallstones and diseased mucosa, thereby avoiding dissection close to the common bile duct.

Subtotal cholecystectomy may be performed using either the **fenestrating** technique, in which the gallbladder remnant is left open with or without cystic duct closure, or the **reconstituting** technique, in which the gallbladder remnant is closed to recreate a small pouch. Other bailout options include conversion to open cholecystectomy, fundus-first (top-down) dissection, placement of a cholecystostomy tube for damage control in critically ill patients, and aborting the procedure when patient safety is compromised. The choice of bailout technique depends on the intraoperative findings, the patient's physiological status, and the surgeon's experience [2, 5, 30].

Subtotal cholecystectomy has gained widespread acceptance because it significantly reduces the incidence of major bile duct injury while maintaining the advantages of minimally invasive surgery. Although this technique is associated with a higher incidence of postoperative bile leakage and retained gallstones compared with total cholecystectomy, these complications are generally manageable by endoscopic retrograde cholangiopancreatography (ERCP) and rarely require reoperation. Conversely, conversion to open surgery should not be considered a complication or surgical failure but rather a sound clinical judgment when safe laparoscopic dissection cannot be achieved. The decision to convert should be made early before major vascular or biliary injury occurs [4, 30, 31].

Overall, bailout surgery represents an essential component of modern hepatobiliary surgery and plays a pivotal role in preventing catastrophic bile duct injuries during difficult laparoscopic cholecystectomy.

Early recognition of hazardous operative conditions, strict adherence to the principles of the Critical View of Safety, and timely implementation of an appropriate bailout strategy are fundamental to improving surgical safety and patient outcomes, particularly in patients with severe acute cholecystitis, Mirizzi syndrome, previous ERCP, or dense inflammatory adhesions [2, 4, 5] Distorted anatomy, surgeons should proceed to alternative bailout strategies rather than continue unsafe dissection [21]

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