1 Anatomy of the Gallbladder and Biliary Tract

Vincent Courant, Michael Montalbano,
Anna Zurada, Agnieszka Zurada-Zielińska,
Jerzy Gielecki, and Marios Loukas

1.1 Introduction

Cholecystitis accounts for up to 10% of cases of abdominal pain worldwide. For most patients with acute cholecystitis, the preferred treatment is surgical excision of the gallbladder, commonly via laparoscopic cholecystectomy. Other treatment options are open surgery, percutaneous cholecystostomy tube, antibiotics, and supportive therapy. In the U.S alone, around 600,000 people are subjected to cholecystectomy annually [1]. Anatomical variations with clinical significance are found in 20% of laparoscopic cholecystectomies. These mostly include variations in the cystic artery (10%), cystic duct (4%), right hepatic artery (3%), and the gallbladder itself (2%) [2]. Misinterpretation of the exposed anatomy contributes to complications, which occur in 1–6% of laparoscopic cholecystectomy cases. Common iatrogenic injuries are directed toward the biliary tree and surrounding blood vessels, with such injuries possibly causing severe morbidity and life-threatening situations. As a result, it is crucial for surgeons to have a clear understanding of the underlying anatomy, as well as be aware of possible anatomical variations to ensure the best results for their patients.

V. Courant
Department of Anatomical Sciences, St. George's University School of Medicine, St. George's, Grenada

Department of Internal Medicine, Icahn School of Medicine at Mount Sinai/St. Luke's-Roosevelt Hospital Center, New York, NY, USA
e-mail: vcourant@sgu.edu

M. Montalbano
Department of Anatomical Sciences, St. George's University School of Medicine, St. George's, Grenada
e-mail: mmontal1@sgu.edu

A. Zurada
Department of Radiology, Collegium Medicum, School of Medicine, University of Warmia and Mazury, Olsztyn, Poland

A. Zurada-Zielińska · J. Gielecki
Department of Anatomy, University of Warmia and Mazury, Olsztyn, Poland
e-mail: jerzy.gielecki@uwm.edu.pl

M. Loukas (✉)
Department of Anatomical Sciences, St. George's University School of Medicine, St. George's, Grenada

Department of Anatomy, University of Warmia and Mazury, Olsztyn, Poland
e-mail: mloukas@sgu.edu

1.2 Anatomy of the Gallbladder

The gallbladder is a flask-shaped, hollow organ that may vary in size and shape. In adults, the gallbladder usually measures 7–10 cm in length with a capacity of up to 50 mL. The organ is usually found resting on the gallbladder fossa, which is located on the inferior surface and marks the caudal limit of Couinaud segments 4 and 5 (Fig. 1.1), although this location may change between individuals [1]. However, there are cases of intrahepatic gallbladder where the organ lies within the liver parenchyma or under

I. Di Carlo (ed.), *Difficult Acute Cholecystitis*, https://doi.org/10.1007/978-3-030-62102-5_1

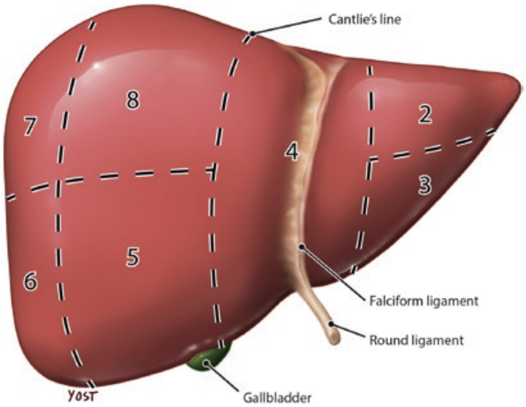

Fig. 1.1 Liver segments and their relation to the gallbladder. (Printed with permission Katie Yost, 2020)

the hepatic capsule at the inferior part of the right lobe. This variation can generate difficulties with dissection as well as heighten the probability of intraoperative hepatic injury. "Floating gallbladders," where the organ hangs freely and is only attached to the cystic mesentery, have also been found [2]. This particular variation may predispose the patient to gallbladder torsion [3]. On rare occasions, additional ectopic locations of the gallbladder have been found to occur at the lesser omentum, falciform ligament, transverse mesocolon, suprahepatic, abdominal wall, retrorenal space, left lower abdomen, and adjacent to the inferior vena cava [2].

The gallbladder is typically separated into three components: the fundus, the body, and the neck.

The neck is defined as the posterosuperior limit of the gallbladder connected to the cystic duct. It is typically 5–7 mm in diameter and takes an S-shaped curve. The neck is located close to the porta hepatis, which is a 5-cm deep fissure extending transversely underneath the left portion of the right hepatic lobe. The porta hepatis is located within the hilum of the liver and contains, from posterior to anterior, the portal vein, the right and left hepatic arteries, as well as the right and left hepatic ducts. A reflection of the peritoneum covering the inferior surface of the liver forms a sleeve around these structures referred to as the hepatoduodenal ligament or free edge of the lesser omentum. A fold of peritoneum connects the hepatoduodenal ligament to the peritoneal layers around the gallbladder, forming the cholecystoduodenal ligament. Of note, on the medial surface of the neck there is a spiral groove that may run along the spiral valves of the cystic duct. The valves are made of several crescentic folds projecting into the lumen of the duct and may be absent in 2% of the population [2].

On the lateral side of the neck, there may be an outpouching referred to as Hartmann's pouch. This expansion is often measured via sonographic imaging to find evidence of dilation or presence of stones. While the pouch may vary in size, a larger Hartmann's pouch can obscure the cystic duct, common hepatic duct, and cystic artery. Similarly, a large stone in a Hartmann's pouch causes an erosion into the bile duct in a condition referred to as Mirizzi's syndrome. These cases can create major difficulties during cholecystectomy.

The body represents the central portion of the gallbladder between the neck and fundus. The body is typically in contact with the liver at the gallbladder fossa, which is usually found anteriorly in relation to the second part of the duodenum and to the right of the transverse colon. The fundus is the most distal part of the gallbladder and forms the anteroinferior margin. It is lateral to the body and often contacts the anterior abdominal wall at the costal margin [4]. The fundus usually folds back on the body of the gallbladder. The gallbladder lumen is widest at the junction of the body and fundus and gets narrower as it travels toward the neck with the most rapidly narrowing segment called the infundibulum.

In some cases, the fundus and body might be separated by an external cleft leading to the formation of a "double" or "bilobed" gallbladder. The second gallbladder is referred to as "accessory" if it drains into a separate cystic duct. An accessory gallbladder may vary in size and may either be separated from its counterpart or contained together within a single peritoneal envelope. The gallbladder might also display a diverticulum along its length, measuring up to 5 cm. In rare cases (0.07%), the gallbladder is entirely absent, with the rest of the biliary tree anatomy remaining normal. In these cases, ultrasound imaging may fail to make the correct diagnosis of absent gallbladder, which can lead to patients undergoing unnecessary surgery [2].

The shape of the gallbladder may also vary. There have been cases of septate gallbladder, which are constituted with the presence of a septum that partly or entirely divides the gallbladder into chambers that are empty via a single cystic duct. The gallbladder might also display a diverticulum along its length, measuring up to 5 cm.

1.3 Biliary Tree

1.3.1 Cystic Duct

The cystic duct is one of the main structures that need to be identified during cholecystectomy. The cystic duct measures from 2 to 4 cm in length and 2 to 3 mm in width. However, size may vary, and a cystic duct larger than 5 mm could be mistaken for the common bile duct. It is also important to note that about 20% of the U.S. population has a cystic duct measuring less than 2 cm, which will make ligations more difficult. The duct commonly travels posteriorly and to the left of the gallbladder neck. The duct usually follows a tortuous course until it meets the common hepatic duct, from the right lateral aspect to form the common bile duct at a variable site ranging from the right hepatic duct to the ampulla of Vater region (Fig. 1.2). Less commonly, the cystic duct may also be S-shaped, curved with acute flexures, or straight.

The cystic duct has been found to exhibit several anatomic variations. The cystic duct junction with the common hepatic duct may occur at a more inferior point in the free margin of the lesser omentum. The cystic duct has also been observed taking different routes as it travels away from the gallbladder. In 75% of cases, the cystic duct joins the common bile duct at an acute angle. It has also been observed to run parallel to the right side of the common hepatic duct in 20% of cases. Rarely, the cystic duct may take a spiral course posterior to the common hepatic duct before entering on its left side (5%) [2].

Since such variations are possible, ligating the cystic duct at its connection with the common bile duct may predispose patients to biliary tree injury. It is helpful to remember that, even with its variations, the cystic duct rarely runs posterior to the duodenum. Therefore, ductal structures that pass behind the duodenum are more likely to be common bile ducts [1]. Another way that may distinguish the two structures is that the cystic duct usually will not have vessels traversing its surface, while the common bile duct does [4].

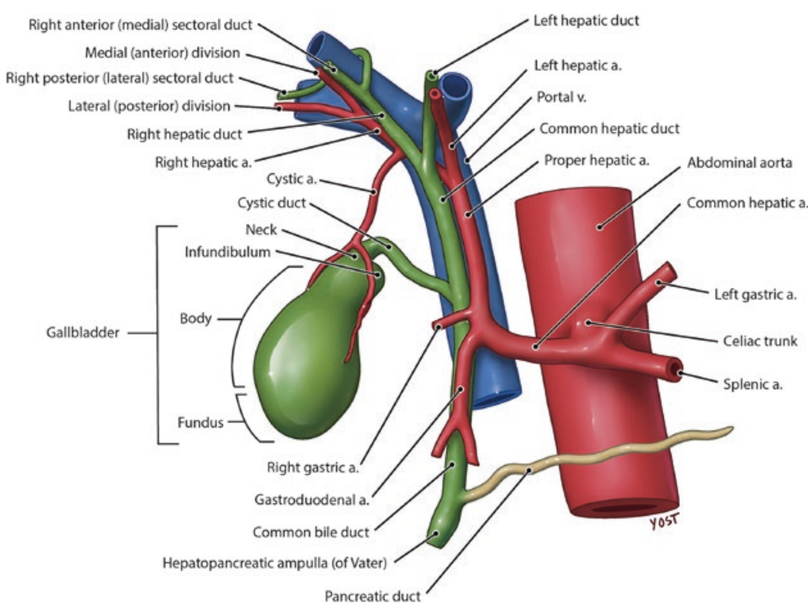

Fig. 1.2 Anatomy of the gallbladder and biliary tree. (Printed with permission Katie Yost, 2020)

The cystic duct may also display aberrant drainage to the left and right hepatic duct, right intrahepatic sectional duct, or drain into the left side of the common hepatic duct. Accessory intrahepatic ducts draining into the cystic duct may also occur. Additionally, the cystic duct may vary numerically as it may be completely absent or present as a double cystic duct, although they are exceedingly rare. As a result, if two ducts are seen entering the gallbladder surgeons should keep a high suspicion that one of the ducts is part of another structure related to the biliary tree [1].

1.3.2 Hepatic Bile Duct

In the liver parenchyma, bile canaliculi fuse to form segmental bile ducts, each draining one hepatic segment. The segmental ducts then combine in a specific pattern to form sectional ducts. Ducts from segments 6 and 7 form the right posterior sectional duct, and ducts from segments 5 and 8 form the right anterior sectional duct. The right hepatic duct arises from the meeting of the right anterior and right posterior sectional ducts at a variable intrahepatic point (Fig. 1.2).

Segments 2 and 3 contribute segmental ducts that coalesce to form the left lateral section duct, which then unites with the duct from segment 4 to form the left hepatic duct. The right and left hepatic ducts meet to form the common hepatic duct near the medial end of the porta hepatis.

The right hepatic duct takes a short vertical course of about 1 cm, while the left hepatic duct travels horizontally for 3 cm along the inferior border of segment 4 (Fig. 1.1). The right hepatic duct system has a higher frequency of variation than the left ductal system. The right hepatic duct may be absent in 15% of cases. In this variation, the common bile duct is formed by a triple confluence from the right anterior, right posterior, and left hepatic ducts. Additionally, a right sectoral duct may join the left hepatic duct in 15% of cases. Occasionally, a right segmental duct may join the common hepatic duct below the normal meeting point. This variation may cause the right segmental duct to be misidentified for the cystic duct during surgery. Consequently, if a structure similar to the cystic duct is to be divided, careful dissection toward the infundibulum should be performed to verify that it is directly connected to the gallbladder [5].

Rarely, the duct from segment 5 or the right posterior sectoral duct drains directly into the cystic duct or the gallbladder itself. Also, infrequently, some branches of the right posterior sectional duct may enter the distal bile duct supraportally and the remaining branches infraportally.

The left intrahepatic ductal system may vary in the arrangement of the segmental duct from segment 5. This segmental duct may drain into the bile ducts from segments 2 or 3, the right anterior sectoral duct, or the common hepatic duct. The bile ducts from segment 1 usually join the origin of the left hepatic duct but may drain into both hepatic ducts.

Finally, there might be multiple accessory hepatic ducts. A more detailed review on accessory ducts will be covered later in this chapter.

1.3.3 Common Bile Duct

The common bile duct is on average between 6 and 8 cm long and travels infero-posteriorly within the right border of the lesser omentum. It travels anterior and to the right of the portal vein, as well as to the right of the hepatic artery. The common bile duct then runs posterior to the first part of the duodenum and to the left of the gastroduodenal artery. It passes posterior to the head of the pancreas, forming its retropancreatic portion. Finally, the common bile duct passes through the sphincter of Oddi to enter the second part of the duodenum at the major papilla, where it may be palpated during surgery [4, 5]. Of note, the pancreatic duct forms a common channel with the common bile duct in 85% of cases; however, the two ducts may enter the duodenum separately. The common bile duct may also vary numerically. In some cases, the common bile duct is completely absent. In this rare variation, the left and right hepatic ducts drain into the gallbladder while the cystic duct directly joins to the duodenum [2]. Conversely, there can be a “double” common bile duct where the ducts run parallel to each other and are separated by a septum.

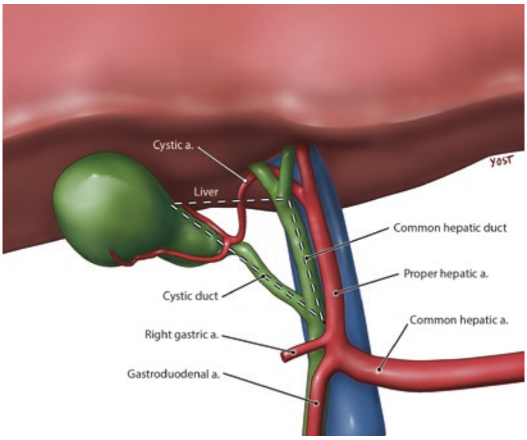

Fig. 1.3 Calot's triangle. (Printed with permission Katie Yost, 2020)

1.3.4 Calot's Triangle

Calot's triangle, or the hepatocystic triangle, was first described in 1891 and represented the triangular space formed by the cystic duct, the common hepatic duct, and the cystic artery [6]. Today, the upper border is now commonly referred to as the inferior edge of hepatic segment 4, while the lateral and medial borders represent the cystic and common hepatic bile ducts, respectively (Fig. 1.3). The triangle usually contains the cystic artery, lymphatics, the cystic lymph node of Lund, small cystic veins, autonomic nerves, and loose connective tissue. Calot's triangle may also contain any accessory hepatic ducts and blood vessels draining into the gallbladder's surrounding anatomy.

This triangular space is clinically important as it is dissected during cholecystectomy to identify and ligate the cystic artery and duct. As a result, it is crucial to be aware of the anatomical structures contained within Calot's triangle to avoid unnecessary damage to the surrounding structure.

1.3.5 Accessory and Aberrant Ducts

The normal biliary anatomy exists in only about 50% of the population [5]. Several accessory ducts are detailed in the biliary drainage system of the liver. The accessory ducts most frequently encountered in a cholecystectomy are those that drain portions of the right lobe, as they remain near the gallbladder. These ducts are usually miniscule and travel through Calot's triangle. Then, they usually join the common hepatic duct where the right and left hepatic ducts merge. In some cases, the cystic duct was found to join an accessory duct prior to its connection with the common hepatic duct. Rarely, a cholecystohepatic duct has been found to join the gallbladder directly. Occasionally, there may be multiple ducts draining segment 4 into the left duct, or the segment 4 duct may join the segment 3 duct before uniting with the segment 2 duct [2].

In 30% of the population, a small bile duct from segment 5 crosses the gallbladder fossa and is referred to as Luschka's duct. It may drain into the right hepatic duct, the common hepatic duct, or rarely the cystic duct [2]. Since the majority of these accessory ducts are small and insignificant, any additional ducts encountered in the gallbladder fossa could be ligated safely [1]. Occasionally, there might also be multiple ducts draining segment 4 into the left hepatic duct, or the segment 4 and 3 ducts may unite before joining the segment 2 duct [2]. However, some accessory ducts may drain significant portions of the right hepatic lobe. These cases are defined as "aberrant" ducts, and studies have emphasized they might need to be protected during surgery [1]. Ligation of these ducts may lead to severe biliary stasis or leak, and the size of the duct can indirectly indicate its functional importance. It is recommended that any injury to a duct over 3 mm in width should be drained into a Roux-en-Y anastomosis. This surgical technique aims at relieving biliary obstruction by creating an anastomosis between the duct and jejunum via choledochojejunostomy. Alternatively, a cholangiogram could be performed through the duct to evaluate the amount of liver drainage and identify whether it is accessory or aberrant.

Detailed classification of iatrogenic bile duct injuries following cholecystectomy needs to include clinically relevant data on every injury pattern since this will influence surgical treatment and outcome [7, 8]. There have been numerous categorizations of common bile duct injury

(BDIs), since Bismuth first introduced them in 1982 [9]. Bismuth classification ranked BDI based on its location in the biliary duct. Since the adaptation of laparoscopic cholecystectomy, more recent classifications have also focused on size, bile leakage, vascular involvement, mechanism of BDI, and severity of injury. A recent classification was introduced by Stewart-Way, whose most common injury type involves the transection and excision of a variable length of the common bile duct and always includes the junction between the common and cystic ducts [10].

1.4 Imaging of the Gallbladder and Biliary Tree

The normal anatomy of the gallbladder may be demonstrated using the imaging techniques that have been developed to examine diseases of the gallbladder. These include oral cholecystography, sonography, scintigraphy, CT scan, and MRI [11]. Right upper quadrant ultrasound is the preferred initial modality when investigating pain that is suggestive of cholecystitis. The normal gallbladder should be visualized in nearly all patients after a 10-h fast. In patients with cholecystitis, imaging may include the presence of stones, distension of the lumen, wall thickening (>3 mm), a positive sonographic Murphy sign, pericholecystic fluid, and a hyperemic wall on color doppler. Detailed information of the biliary anatomy can be obtained by relying on techniques such as magnetic resonance cholangiography or intraoperative cholangiogram. Both of these techniques use a contrast agent that accumulates in the gallbladder and bile duct system. These methods are particularly useful for the diagnosis of biliary tree obstruction by evidence of bile duct dilation and filling defect.

1.5 Vasculature and Lymphatics

1.5.1 Cystic Artery

The arterial supply of the gallbladder arises from the cystic artery. The cystic artery originates from the right hepatic artery and is commonly found within Calot's triangle (Fig. 1.3). The cystic artery then runs anterior to the cystic duct and posterior to the common hepatic duct. As the artery approaches the gallbladder neck, it separates into anterior and posterior branches that ultimately meet on the gallbladder surface. Multiple smaller branches may also supply the hepatic ducts and the superior portion of the common bile duct. Close attention must be made to these vessels during surgery as injury to the artery may lead to severe bleeding.

Additionally, the cystic artery is variable in origin. It could arise from the common hepatic artery, left hepatic artery, and gastroduodenal artery. Rarely, the cystic artery has also been found to originate from the right gastric, celiac, superior pancreaticoduodenal, and superior mesenteric arteries. As seen in these variations, the cystic artery usually crosses the common bile duct anteriorly.

Finally, a double cystic artery has been found to occur in 2–15% of cases. In these cases, the accessory artery has been described arising from the right hepatic artery, common hepatic artery, and left hepatic artery [1, 4]. If the cystic artery branches from the common hepatic or the left hepatic arteries, the cystic artery may cross the bile duct anteriorly, predisposing patients to iatrogenic injury.

1.5.2 Ductal Arteries

The biliary tree is supplied by a network of blood vessels originating from multiple surrounding sources. Blood vessels to the common bile duct run along its entire length. The main contributors to this network of vessels are coming from the retroduodenal branch of the gastroduodenal artery as it nears the upper boundary of the duodenum. Other common sources are the cystic and right hepatic arteries. A retroportal artery has also been found to originate from the celiac or superior mesenteric arteries, the vessel usually runs superior-posteriorly along the portal vein before joining the retroduodenal artery. Rarely, the retroportal artery has also been seen joining the right hepatic artery. The hepatic ducts are supplied by multiple fine blood vessels arising from segmental arteries contained within the Glissonian sheath, which is a layer of connective tissue enveloping the hilar structures inside the liver.

1.5.3 Right Hepatic Artery

The right hepatic artery rises from the bifurcation of the common hepatic artery, usually to the left of the hepatic hilum. The vessel typically courses posterior to the bile duct and anterior to the portal vein until it joins the right pedicle in the Calot's triangle. One common variation occurs when the right hepatic artery runs within the lower end of the Calot's triangle in a tortuous course referred to as "caterpillar" or "Moynihan's" hump. This variation can have an incidence as high as 50% [1]. A Moynihan's hump is clinically relevant as the cystic artery is significantly shorter in these patients. As a result, the right hepatic artery could be misidentified as the cystic artery and could result in erroneous ligation. It is recommended to divide the cystic artery close to the gallbladder wall in order to avoid confusion with other possible blood vessels. In other cases, the right hepatic artery has been found to take another aberrant course in which it passes anterior to the bile duct or even posterior to the portal vein. In addition, an accessory or replaced right hepatic artery from the superior mesenteric artery may occur in approximately 17% of individuals. In these cases, the right hepatic artery courses posterior to the portal vein and the inferior end of the common bile duct.

1.5.4 Venous Drainage

The venous drainage of the gallbladder arises from a system of multiple fine veins. Vessels exiting the superior surface of the body and neck typically enter the liver to join segmental portal veins. The rest of the gallbladder vein system forms small cystic veins that join the intrahepatic drainage either directly or indirectly via veins from the hepatic ducts. Rarely, cystic veins may drain into the right portal branch. There have been only a few reports of clinically significant veins injury involving the portal vein after biliary tree surgery.

1.5.5 Lymphatics

A multitude of lymphatic vessels arises from the plexuses of the gallbladder and cystic duct.

The lymphatic drainage of bile ducts diverges into two pathways. The superior pathway involves lymph nodes along the cystic duct, hepatic artery, and celiac plexus. In contrast, the inferior pathway involves the nodes along the cystic lymph nodes, located superiorly to the cystic duct and embedded within Calot's triangle. This pathway also drains into the anterolateral aspect of the portal vein, the posterior pancreas, and the aortocaval region. Chyle leakage is an extremely rare complication after cholecystectomy.

1.5.6 Nerve Supply

The hepatic plexus innervates the gallbladder and biliary tree. In addition, the common bile duct also receives branches from the pyloric branch of the vagus nerve. Pain sensation arising from these structures is commonly referred to as the epigastric region, while stimulation of the overlying somatic peritoneum will lead to pain in the right upper quadrant. The Murphy's sign is elicited in patients suffering from acute cholecystitis by having the patient hold a deeply inhaled breath while conducting palpation of the right subcostal area. If pain occurs, Murphy's sign is positive. While nerve injury during cholecystectomy is a very rare occurrence, a few cases of unilateral phrenic nerve palsy have been reported in the literature. It has been hypothesized that this might be due to pneumoperitoneum that leads to stretching of the phrenic nerve [12].

1.6 Conclusion

The anatomy of the gallbladder and biliary tract is complex and displays a wide range of variations. Detailed knowledge of the anatomy is needed for surgeons to avoid potential complications and perform a successful procedure.

References

1. Nagral S. Anatomy relevant to cholecystectomy. J Minim Access Surg. 2005;1(2):53–8.
2. Bergman RA, Tubbs RS, Shoja MM, Loukas M. Bergman's comprehensive encyclopedia of human anatomic variation. Hoboken, NJ: Wiley; 2016.
3. Garciavilla PC, Alvarez JF, Uzqueda GV. Diagnosis and laparoscopic approach to gallbladder torsion and cholelithiasis. JSLS. 2010;14(1):147–51.
4. Standring S, editor. Gray's anatomy: the anatomical basis of clinical practice, 40th ed, anniversary ed [Edinburgh]. Philadelphia: Churchill Livingstone/ Elsevier; 2008.
5. Fischer JE, Ellison EC, Henke PK, Hochwald SN, Tiao GM. Fischers mastery of surgery. Philadelphia: Wolters Kluwer; 2019.
6. Abdalla S, Pierre S, Ellis H. Calot's triangle. Clin Anat. 2013;26(4):493–501. https://doi.org/10.1002/ca.22170.
7. Chun K. Recent classifications of the common bile duct injury. Korean J Hepatobiliary Pancreat Surg. 2014;18(3):69–72. https://doi.org/10.14701/kjhbps.2014.18.3.69.
8. Bismuth H, Majno PE. Biliary strictures: classification based on the principles of surgical treatment. World J Surg. 2001;25(10):1241–4.
9. Renz BW, Bösch F, Angele MK. Bile duct injury after cholecystectomy: surgical therapy. Visc Med. 2017;33(3):184–90. https://doi.org/10.1159/000471818.
10. Way LW, Stewart L, Gantert W, Liu K, Cm L, Whang K, Hunter JG. Causes and prevention of laparoscopic bile duct injuries: analysis of 252 cases from a human factors and cognitive psychology perspective. Ann Surg. 2003;237(4):460–9.
11. Meilstrup JW. Imaging atlas of the normal gallbladder and its variants. CRC Press; 2018.
12. De U, Maitra D, Mukherjee M. Unusual complications of laparoscopic cholecystectomy: a case series. Int J Case Rep Images. 2012;3(4):5–9.