VARIANT ANATOMY OF THE EXTRAHEPATIC BILIARY SYSTEM AND ITS BLOOD SUPPLY AMONG BLACK KENYANS.

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A THESIS SUBMITTED TO THE SCHOOL OF MEDICINE IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS OF THE DEGREE OF MASTER OF MEDICINE IN GENERAL SURGERY OF MOI UNIVERSITY

DECLARATION

Declaration by the Candidate:

This thesis is my original work and has not been presented for a degree in any other University. No part of this thesis may be reproduced without the prior written permission of the author and/or Moi University

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DEDICATION

I dedicate this work to all clinicians who have dedicated their lives to improve the quality of life of their patients.

ABSTRACT

Background: Anatomical variations of the human body including the extra hepatic biliary system exist across various individuals. Understanding the variant anatomy of the extrahepatic biliary system and its blood supply should aid surgeons in avoiding iatrogenic injuries. This is important in resource limited settings where it is not possible to perform adequate radiological investigations of the hepatobiliary system prior to surgery. Local studies have only focused on cystic artery variations; however, this study aims to assess variations in both the extrahepatic biliary system and its blood supply.

Objective: The study described the anatomic variation of the extrahepatic biliary system and its blood supply among Kenyans.

Methods: This was a cross-sectional study conducted at Moi University's Anatomy Laboratories among 42 adult cadaveric specimens. Specimen dissections were conducted as per the fifteenth edition of Cunningham's manual of Practical Anatomy. The variant anatomy data collected were filled in a structured data collection form, analyzed and presented using descriptive statistics.

Study Findings: Of the 42 cadavers sampled, 62% (n=26) were male while 38% (n=16) were female. All the cadavers had a gall bladder being drained by the cystic duct. The length of the cystic duct ranged between 7mm to 35 mm with a median value of 17mm, and it joined the common hepatic duct to form the common bile duct in 98% (n=41) of all the cadavers sampled. This confluence was to the left in 7.1% (n=3), right 42.9% (n=18), anteriorly in 14.3% (n=6) and posteriorly 35.7% (n=14). A single cadaver (2%) had the cystic duct drain into the right hepatic duct. Two thirds (66.7%; n=28) of the cadavers sampled had the confluence of the right and the left hepatic duct outside the liver. There were no cholecystohepatic ducts in this study. Of the study subjects, 71.4% (n=30) had a normal pattern of the extrahepatic supply (Type 1). The normal origin of the right hepatic artery from the proper hepatic artery or common hepatic artery was seen in 81% (n=34) a while 19% (n=8) had an aberrant origin (Type 3 and 4) from the superior mesenteric artery. The course of the right hepatic artery was anterior to common hepatic duct and common bile duct in 26.2% (n=11) of all the cadavers. Less than half of the cadavers 43% (n=18) had a caterpillar hump of the right hepatic artery occupy the Calot's triangle. All cystic arteries were within the Calot's triangle; however, 45.2% (n=19) of the cystic arteries arose from the right hepatic artery outside the Calot's triangle anterior to the common hepatic duct.

Conclusion: The study determined the existence of surgically important variant anatomy of the extrahepatic biliary system and its blood supply among black Kenyans. The caterpillar hump of the right hepatic artery occupying the Calot's triangle was the most frequent variation.

Recommendation: There is need for greater appreciation of the extrahepatic biliary system variant anatomy by both surgeons and radiologists so as to decrease morbidity and improve on surgical outcomes.

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LIST OF ABBREVIATIONS

CHA	Common Hepatic Artery
CT	Computerized Tomography
CVS	critical view of safety
GDA	Gastroduodenal artery
LHA	Left Hepatic Artery
MHA	Middle Hepatic Artery
MTRH	Moi Teaching and Referral Hospital
MU	Moi University
RHA	Right Hepatic Artery
SMA	Superior Mesenteric Arteries
SOM	School of Medicine

DEFINITION OF TERMS

Aberrant (atypical) artery: Arise entirely from some source other than the celiac arterial distribution. Also known as replaced arteries.

Accessory artery: Hepatic arteries originating from the typical as well as aberrant branch.

Calot's triangle: The space bounded medially by the common hepatic duct, inferiorly by the cystic duct and superiorly by the inferior surface of the liver

Caterpillar hump: A tortuous right hepatic artery found within the Calot's triangle.

Common hepatic artery: This gives rise to the right or left hepatic artery and the gastroduodenal artery, irrespective of its origin and course.

Extra hepatic biliary system: Bile ducts located outside the liver consisting of the left and right hepatic ducts, common hepatic duct, cystic duct and common bile duct.

Replaced artery: Arterial blood supply from an ectopic location.

Typical celiac axis: Arterial trunk that gives rise to the common hepatic, left gastric, and splenic arteries.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Anatomical variations within the human body are common (Talpur et al., 2010). The extrahepatic biliary system and its blood supply is no exception (Lamah, Karanjia, & Dickson, 2001). It's known that there exists a common pattern of variations among individuals. Understanding the normal and variant anatomy of the extrahepatic biliary system and its blood supply when present should aid the surgeon (Adams, 1993; Tharao, Saidi, Kitunguu, & Julius, 2007) in avoiding iatrogenic complications in procedures such as: hepatic lobectomy, liver transplant, pancreatic duodenoscopy, laparoscopy and other minimally invasive surgeries, cholecystectomy and vascular surgery of the liver (Cachoeira, Rivas, & Cachoeira, 2012). Sound knowledge of the normal and variant anatomy forms the basis for the interpretation of every imaging examination for the diagnostic and interventional radiologists (Costa, Canelas, Goncalves, Vaz, & Costa, 2009; Kadir, 1991).

1.2 Problem Statement

There exist anatomic variations among individuals and the extrahepatic biliary system and its blood supply is no exception (Mortelé & Ros, 2001; Noussios, Dimitriou, Chatzis, & Katsourakis, 2017). These variations follow racial differences (Mortelé & Ros, 2001; Sharma et 3al., 2017; Tharao, Saidi, Kitunguu, & Julius, 2007). It is important to be aware of these variations prior to surgery and other interventional procedures to prevent iatrogenic injuries that will increase morbidity and undesired outcomes (Dandekar, Dandekar, & Chavan, 2015; Shallaly & Cuschieri, 2000; Talpur et al., 2010). The normal and variant anatomy can be identified through high quality imaging modalities which are not within reach and inaccessible to most patients within our resource limited setup (Karaliotas, Broelsch, & Habib, 2006; Nalaboff, Pellerito, & Ben-Levi, 2001). There is limited local data on surgically important variant anatomy of the extrahepatic biliary system and its blood supply (Michels, 1960; Tharao et al., 2007). This study therefore aims to determine the variant anatomy of the extrahepatic biliary system and its blood supply.

1.3 Justification

There exists pattern of anatomic variations involving the extrahepatic biliary system and its blood supply; however, this is not adequately documented in the black Kenyan population. The prohibitive costs for some of the radiological investigations put such services out of reach to most of the patients. A proper understanding of the anatomy of the extrahepatic biliary system is needed in the adoption of laparoscopic cholecystectomy (considered the gold standard). This laparoscopic cholecystectomy is commonly done in the developed countries; however, it has only become established in a few Kenyan hospitals.

Iatrogenic injury and subsequent complications can be minimized if surgeons will be aware of these variations. Misinterpretation of normal anatomy and anatomical variations contribute to the occurrence of major postoperative complications like biliary duct injuries, excessive bleeding that increases both morbidity and mortality and overall healthcare costs. A look at the basic anatomy is therefore important not only for biliary and minimally invasive surgeons but also radiologist, interventional radiologists and gastroenterologists.

1.4 Research questions

1. What are the anatomic variations of extrahepatic biliary system and its blood supply among black Kenyan cadavers at Moi University human anatomy laboratory?

1.5 Objectives

1.5.2 Main Objective

To describe the variant anatomy of the extrahepatic biliary system and its blood supply among black Kenyan cadavers seen at Moi University human anatomy laboratory.

1.5.2 Specific Objectives

1. To describe surgically important anatomic variations of extrahepatic biliary system among black Kenyan cadavers at Moi University human anatomy laboratory.
2. To describe the surgically important anatomic variation of the vascular supply to the extrahepatic biliary system among black Kenyan cadavers at Moi University human anatomy laboratory.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter describes the normal anatomy of the extrahepatic biliary system and its blood supply. It further reviews studies conducted across the globe on the variation of the extrahepatic biliary tree and its blood supply. Various studies on the anatomic variations of extrahepatic biliary system have been conducted among cadavers, fresh specimens and through radiological imaging techniques. The classical textbook description of the extra hepatic biliary system can be seen in less than 50 percent of the cases (Satarupa, Sujitha, & Muniappan, 2013). Lastly, this chapter describes the surgical importance of the stated anatomic variations.

2.1.1 Embryology and development of biliary system

The basis of the anatomical variations stems from the embryological development (Karaliotas et al., 2006). The liver, gall bladder and the biliary ductal system develop from the hepatic diverticulum of the foregut, in the beginning of the fourth week of development (Gadžijev, 2002). This diverticulum rapidly proliferates into the septum transversum and divides into two parts the cranial part and the caudal part (Gadžijev, 2002). The cranial part is the primodium for the liver and the bile ducts while the caudal part gives rise to the gall bladder and the cystic duct (Blidaru, Blidaru, Pop, Crivii, & Seceleanu, 2010; Gadžijev, 2002; Mortelé, Rocha, Streeter, & Taylor, 2006). Initially the extrahepatic biliary apparatus is occluded with epithelial cells, but later on it gets canalized because of subsequent degeneration of these cells (Gadžijev, 2002). It is quite conceivable that any arrest or deviation from the normal embryological developmental process may result in variation of the extrahepatic biliary system (Adkins, Chapman, & Reddy, 2000).

2.1.2 Anatomy of the extrahepatic biliary system

Once bile has been formed by the liver cells it is drained by the canaliculi to the hepatic ductules (intrahepatic ducts) that eventually coalesce into the right and left hepatic bile ducts for each lobe of the liver (Sinnatamby & Last, 2011). This union could be intrahepatic or extrahepatic (Castaing, 2008). The union of the right and left hepatic ducts form the common hepatic duct that emerge from the liver at the porta hepatis (Gadžijev, 2002; Sinnatamby & Last, 2011). The common hepatic duct is joined by the cystic duct from the gallbladder and form the common bile duct (Hiatt, Gabbay, & Busuttil, 1994). This common bile duct usually is joined by the main pancreatic duct before the two ducts open into the second part duodenum (Mortelé et al., 2006) as shown in figure 1.

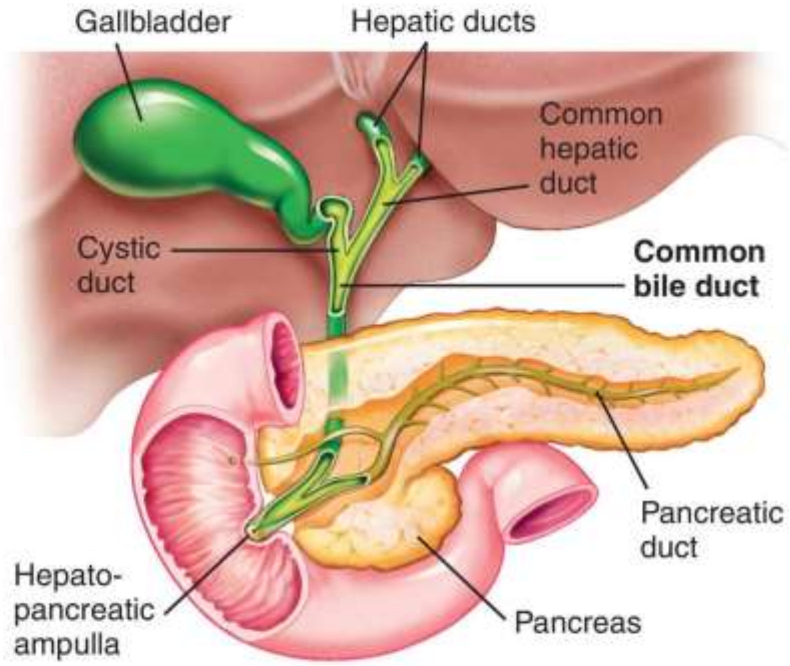

Figure 1: Extrahepatic Biliary ducts (Medical-Dictionary, 2017).

The region of the union of the cystic duct and common hepatic ducts is of importance in cholecystectomy (Shallaly & Cuschieri, 2000). They define the sides of a triangle (Figure 2) whose base is formed by the liver (Cachoeira et al., 2012). The triangle is termed as cystohepatic triangle (of Calot) and contains the right hepatic artery, the cystic artery, and most aberrant or accessory bile ducts may be present (Anandhi & Alagavenkatesan, 2018; Cachoeira et al., 2012). Therefore, careful dissection and identification of all ducts and vessels is paramount in cholecystectomy as damage to hepatic or common hepatic duct can lead to strictures from scar formation and results in bile flow obstruction (Anandhi & Alagavenkatesan, 2018).

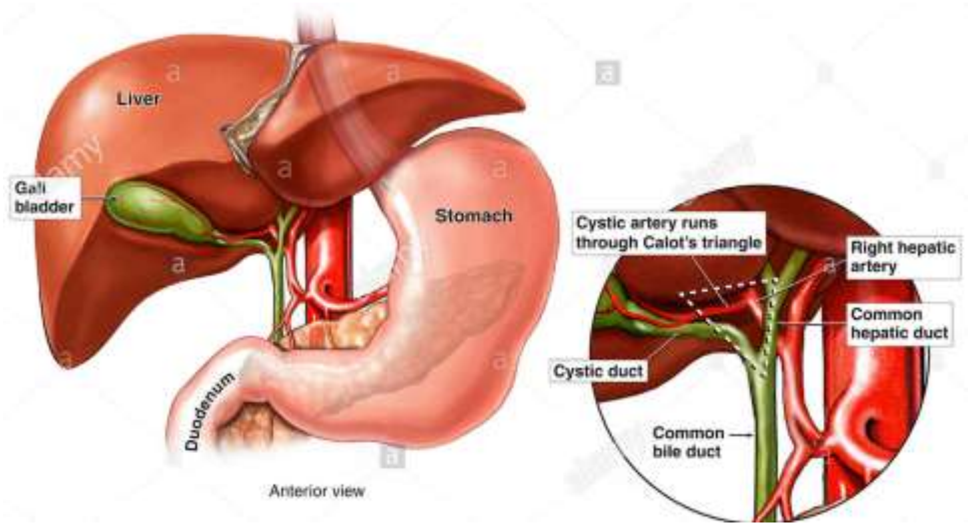

Figure 2: The Calot's Triangle (Nucleus Medical Art, 2003)

2.1.3 Cystic duct

This drains the gallbladder and unite with the common hepatic duct to form the common bile duct. It is between 3 and 4 cm long (Chaudhary et al., 2016). Normally it passes posteriorly and to the left from the neck of the gallbladder and joins the common hepatic duct to form the common bile duct (Ramesh Babu & Sharma, 2014; Turner & Fulcher, 2001) as shown in figure 1. The cystic duct may run a straight or a fairly convoluted course. Its length is variable (Adams, 1993). It almost always runs parallel to, and is adherent to, the common hepatic duct for a short distance before joining it (Ramesh Babu & Sharma, 2014). The junction usually occurs near the porta hepatis but may be lower down in the free edge of the lesser omentum (Gadžijev, 2002; Standring, 2005, 2016).

2.1.4 Hepatic bile ducts

The main right and left hepatic ducts can unite within or outside the liver to form the common hepatic duct and emerges at the porta hepatis (Dandekar et al., 2015). The extrahepatic right duct is short and nearly vertical while the left is more horizontal and lies along the base of segment IV (Anandhi & Alagavenkatesan, 2018). The common hepatic duct descends approximately 3 cm before being joined on its right at an acute angle by the cystic duct to form the common bile duct as shown in figure 3 (Livingston & Rege, 2004). The common hepatic duct lies to the right of the hepatic artery and anterior to the portal vein in the free edge of the lesser omentum (Standring, 2005, 2016).

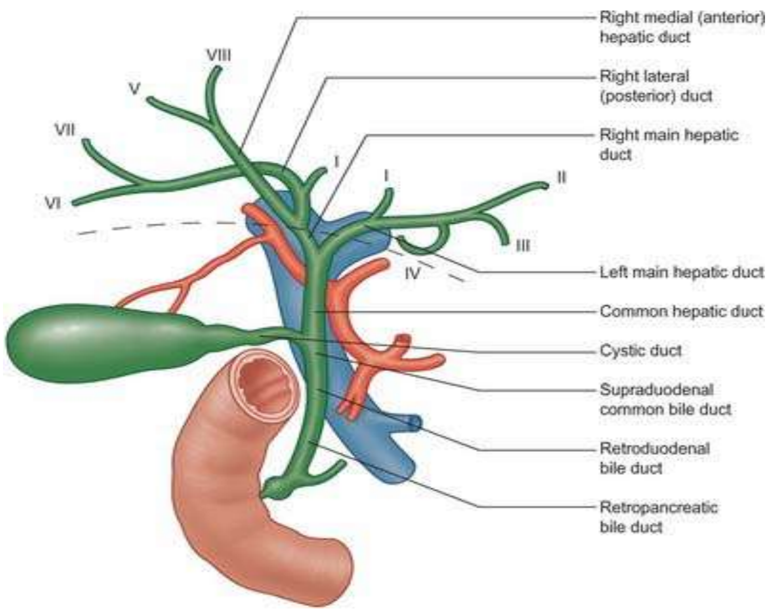

Figure 3: Common Hepatic Duct (Standring, 2005).

2.1.5 Hepatic and cystic artery anatomy

In adults the hepatic artery is intermediate in size between the left gastric and splenic arteries (Hiatt et al., 1994). In fetal and early postnatal life, it is the largest branch of the coeliac axis (Sinnatamby & Last, 2011). The normal type is described as the common hepatic artery arising from the celiac axis to form the gastroduodenal and proper hepatic arteries, and the proper hepatic dividing distally into right and left branches (Standring, 2005) as shown in figure 4. After its origin from the coeliac axis, the hepatic artery passes anteriorly and laterally below the epiploic foramen to the upper aspect of the first part of the duodenum (Skandalakis & Colborn, 2004). It may be subdivided into the common hepatic artery, from the coeliac trunk to the origin of the gastroduodenal artery, and the hepatic artery ‘proper', from that point to its bifurcation (Agur & Grant, 2013; Moore, Dalley, & Agur, 2013). It passes anterior to the portal vein and ascends anterior to the epiploic foramen between the layers of the lesser omentum (Ramesh Babu & Sharma, 2014). Within the free border of the lesser omentum the hepatic artery is medial to the common bile duct and anterior to the portal vein as shown in figure 3. At the porta hepatis it divides into right and left branches before this run into the parenchyma of the liver. The right hepatic artery usually crosses posterior (occasionally anterior) to the common hepatic duct (Standring, 2005). This close proximity often means that the right hepatic artery is involved in bile duct cancer earlier than the left hepatic artery (Tal et al., 2014). Occasionally the right hepatic artery crosses in front of the common bile duct and may be injured in surgery of the common bile duct (Cachoeira et al., 2012).

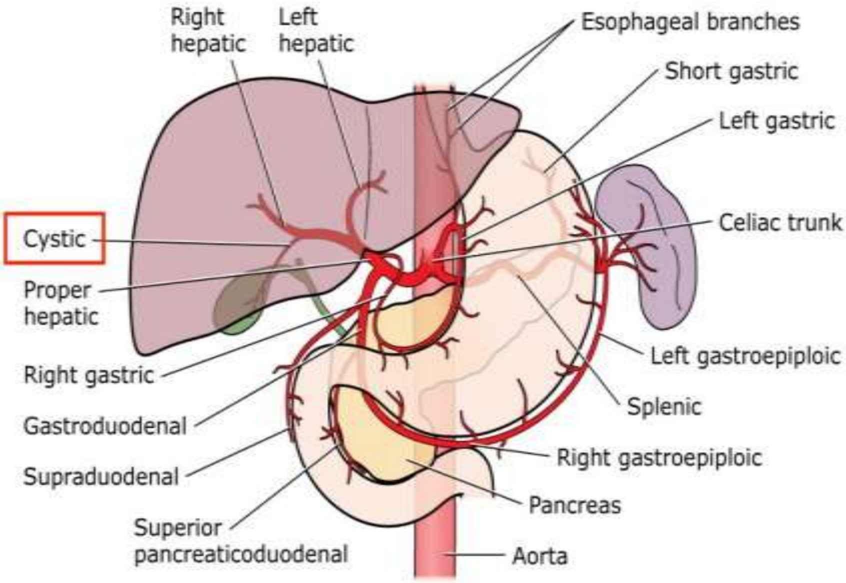

Figure 4: Extrahepatic Biliary System blood supply (stepwards.com, 2015)

2.2.6 Portal Vein

The portal vein is an important blood vessel that conducts blood from the gastrointestinal tract and spleen to the liver (Sureka et al., 2015). The liver receives about 75% of its blood through the portal vein, with the remainder coming from the hepatic artery proper (Sharma et al., 2017). The portal vein is not a true vein in the sense that it does not conduct blood directly into the heart (Standring, 2016). The portal vein is formed by the union of superior mesenteric and splenic vein (Sureka et al., 2015). When the anatomy of portal vein is normal, very few technical difficulties are encountered in surgery (Sureka et al., 2015).

2.2 Anatomic variations of extrahepatic biliary system among cadavers

The anatomy of the extrahepatic biliary tree is remarkably variable. This variability is of great importance to the surgeon. A higher incidence of anomalies has been found in women than in men; and in patients with gallstones compared to those without (Bingener-Casey, Richards, Strodel, Schwesinger, & Sirinek, 2002). Laparoscopy or minimally invasive surgeries is gaining ground (Alfa-Wali & Osaghae, 2017).

Laparoscopic cholecystectomy, one of the surgical procedures performed is considered the gold standard operation for patients with gallstone disease (Bingener-Casey et al., 2002; Vettoretto et al., 2011). According to Bingerner-Casey et al (2002), a number of patients required conversion of laparoscopic cholecystectomy to open surgery, in which 50% of the cases were due to inability of the surgeon to correctly identify the variant anatomy of the patient intraoperatively. Other indications for conversion included: difficult dissections, unsuspected intraoperative findings, misdiagnosis, equipment failure, inability to establish pneumo peritoneum and injury of other organs (Bingener-Casey et al., 2002). The conversion resulted in a significant change in patient outcomes that required hospital admission and longer recovery period significantly resulting in higher costs of medical care (Annemans, Redekop, & Payne, 2013; Pavlidis et al., 2007).

Furthermore, in low- and middle-income countries (LMIC) it is difficult to access advanced imaging modalities that are routinely done in high income countries (Alfa-Wali & Osaghae, 2017). Since the 1980s, laparoscopic surgeries have been present and offer the benefit of minimizing morbidity and potential mortality associated with laparotomies. These laparotomies are used in LMIC countries for diagnosis and management of biliary diseases, due to limited radiological investigative and intervention options. Minimally invasive surgeries are advantageous due to the fact that; there is lower surgical site infections and earlier return to work for patients (Cachoeira et al., 2012; Nagral, 2005). Diagnostic laparoscopy could be used for the evaluation of abdominal tuberculosis, peritoneal pathology and abdominal trauma (Udwadia, 2004; Vecchio, Macfayden, & Palazzo, 2000).

The five surgically important ductal anomalies that include: Long cystic duct with low fusion with the common hepatic duct; abnormal fusion of the right and left hepatic ducts with the cystic duct entering the confluence; accessory hepatic ducts; cystic duct entering the right hepatic duct and cholecystohepatic ducts (Benson & Page, 1976; Hassan, Zargar, Malik, & Shah, 2013; Lamah & Dickson, 1999).

2.2.1 Cystic Ducts

The classic anatomic position, course and relationship with other adjacent structures occurs only in 33% of the patients (Karaliotas et al., 2006). The junction which is formed between the cystic duct and the common hepatic duct is the most important anatomic point of the cystic duct as this denotes the commencement of the common bile duct (Cachoeira et al., 2012; Lamah et al., 2001). Cystic duct variations are common (figure 5) (Kostakis et al., 2017). From a surgical point of view, there are three important variations in the cystic duct namely: a low insertion into the common hepatic duct, medial insertion and parallel course to the common hepatic duct (Chaudhary et al., 2016).

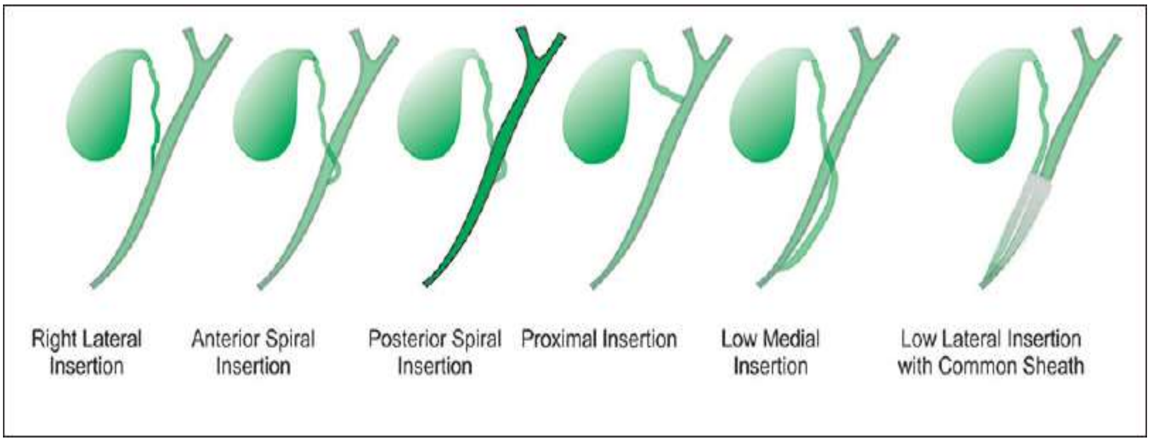

Figure 5: Cystic Duct Variants (Sureka, Bansal, Patidar, & Arora, 2016)

Cystic duct length also varies. The close proximity of the course between the cystic duct and common bile duct is a major cause of iatrogenic injuries to the common hepatic and common bile ducts (Karaliotas et al., 2006). The cystic duct may run alongside and parallel with the common hepatic duct before joining it; or twist around the common hepatic duct fusing with it either anteriorly or at its left border (Chaudhary et al., 2016; Mortelé et al., 2006).

The cystic duct usually measures 2–4 cm in length (Turner & Fulcher, 2001). An American study found that the cystic duct enters the extrahepatic bile duct from the right lateral aspect in 49.9% of cases, from the medial aspect (left) in 18.4%, and from an anterior or posterior position in 31.7% (Hiatt et al., 1994). Another American study by (Mortelé et al., 2006) found a medial (left) insertion in 10%-17%.

An Indian study by (Chaudhary et al., 2016) found that cystic duct may join the right hepatic duct in 0.6%-2.3% cases. In surgery, when the cystic duct drains into the right hepatic duct, the right hepatic duct may be mistaken for the cystic duct, tied off and divided where it joins the left hepatic duct (Ramesh Babu & Sharma, 2014). This patient may later present with biliary peritonitis, biliary fistula and liver cirrhosis (Cachoeira et al., 2012).

During cholecystectomy, a variable length of the cystic duct is left as a remnant (Catalano et al., 2008). Usually, a cystic duct remnant of 1-2 cm is left at surgery (Turner & Fulcher, 2001). A longer remnant may be left after cholecystectomy when a long, parallel cystic duct or low medial insertion is present (Turner & Fulcher, 2001). This long cystic duct remnant may be associated with inflammatory changes and formation of calculi resulting in post-cholecystectomy syndrome, a cause of persistent or recurrent biliary symptoms in affected patients (Costa et al., 2009; Kostakis et al., 2017).

Vigorous traction of long cystic duct may produce marked agglutination and tenting of the common hepatic and bile ducts which may then be caught in a clamp; resulting in iatrogenic injury of the common hepatic and bile ducts (Kostakis et al., 2017).

2.2.2 Hepatic Ducts

First, variations on the hepatic ducts occur at different levels of convergence (confluence) of the two (right and left) hepatic ducts as shown in figure 6 (Anandhi & Alagavenkatesan, 2018). This confluence of the two hepatic ducts (right and left) varies greatly (Cachoeira et al., 2012). Rarely does non-confluence of the right and left hepatic ducts occur (Benson & Page, 1976; Kaprio & Koskenvuo, 2002; Karaliotas et al., 2006).

Secondly, an accessory hepatic duct can occur from the liver (the right lobe), entering the common hepatic duct (Anandhi & Alagavenkatesan, 2018). Inadvertently damaging of the accessory hepatic duct during surgery may cause bile leakage contaminating the surgical field (Lamah et al., 2001). In the event that accessory hepatic duct damage is not noticed during surgery; post-operative bile leakage may cause biliary peritonitis, subphrenic abscess, biliary fistula and the development of bile duct stricture (Turner & Fulcher, 2001).

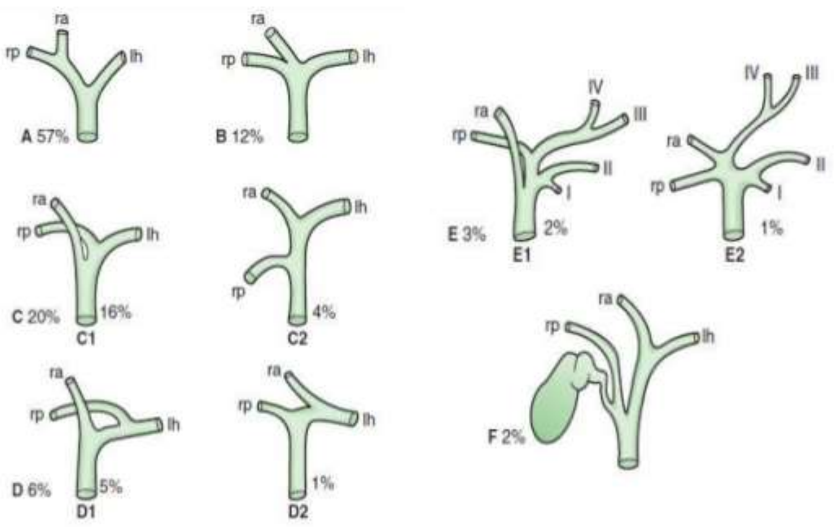

Figure 6: Variations in the Hepatic Duct Confluence (Prashanth, 2017)

Lastly, cholecystohepatic ducts may be present as shown in figure 7 (Prashanth, 2017). The dangers on the cholecystohepatic ducts are similar to those of failing to recognize and inadvertently dividing an accessory hepatic duct (Shallaly & Cuschieri, 2000).

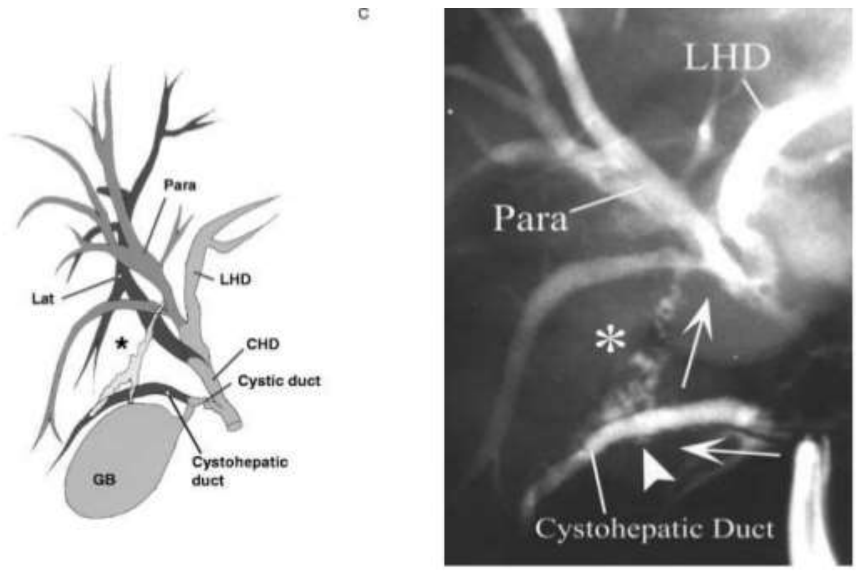

Figure 7: Cholecystohepatic ducts (Das, 2014)
(Key: *LHD Left hepatic duct, CHD: common hepatic duct, CBD: common bile duct, Lat lateral*).

In a radiological study by Mortele who found the cystic duct ran a parallel course to the common hepatic duct in 1.5%-25% (Mortelé et al., 2006). However, Cachoeira did not find accessory and cholecystohepatic ducts (Cachoeira et al., 2012) while a Brazilian study found the length to vary between 0.4 and 5.6 cm, with a mean average of 2.17 cm (Goke, Leite, & Chagas, 2018).

2.2.3Common Bile Duct

The common bile duct unlike the cystic duct is more constant in length and course with variations mainly in the area of porta hepatis and the lower third of the common bile duct (intrapancreatic part) (Blidaru et al., 2010; Cachoeira et al., 2012). However, the length of the common bile duct may vary from person to person (Anandhi & Alagavenkatesan, 2018b; Cachoeira et al., 2012). Variations occur at different levels of convergence (confluence) of the two hepatic ducts. The common bile duct may present a number of anatomical peculiarities regarding its size, course and relations, which should be taken into consideration by the anatomists and by the surgeons as well, during the surgery of the gallbladder, pancreas and duodenum. The common bile duct is divided into four segments namely: supraduodenal, retroduodenal, retropancreatic and intra-parietal segments (Ramesh Babu & Sharma, 2014).

2.3Anatomic variations of hepatic and cystic arteries among cadavers

According to Benson & Page, 1976 and Jansirani, et al 2012, the three surgically important vascular arterial anomalies were the caterpillar hump (tortuous) right hepatic artery, right hepatic artery anterior to the common bile or common hepatic ducts (or cystic artery anterior to these structures) and the accessory cystic artery (Benson & Page, 1976; Devi Jansirani, 2012) as shown in figures 8.

Hiatt, Gabbay and Busutill (1994) who conducted a study on 1,000 patients who underwent liver harvesting for orthotopic transplantation classified the arterial variations into six types modified from Michels (1966) classification as: Type I: Common hepatic artery arising from the coelic axis, normally forming the gastroduodenal artery and proper hepatic artery Type II: Replaced or accessory left hepatic artery from left gastric artery. Type III: Replaced or accessory right hepatic artery from the superior mesenteric artery. Type IV: Double replacement (coexisting variation of Type II and Type III). Type V: Common hepatic artery arises from the superior mesenteric artery. Type VI: The common hepatic artery arising directly from the aorta as shown in figure 8 (Favelier et al., 2015; Hiatt et al., 1994; Michels, 1966)

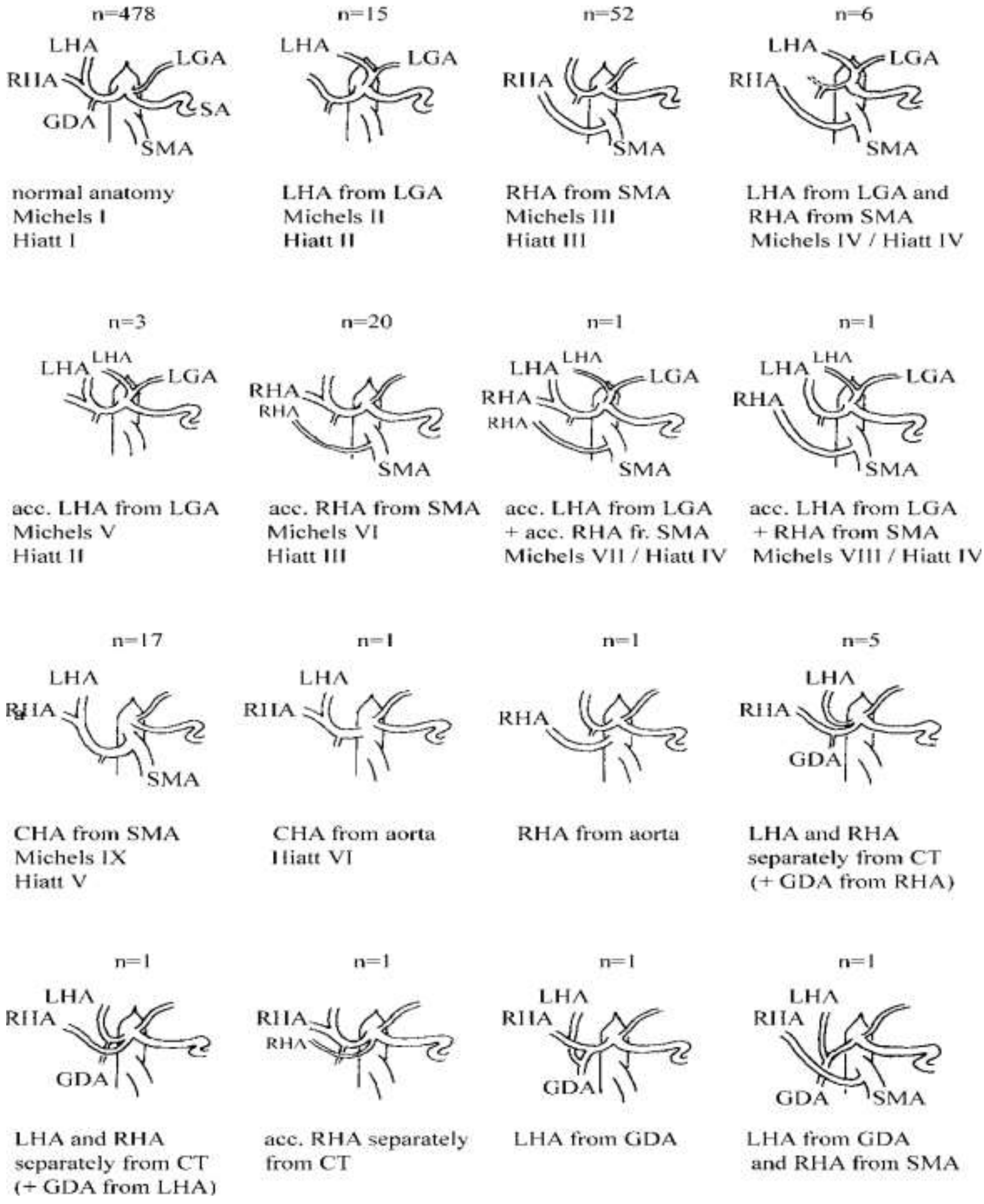

Figure 8: Michel and Hiatt's Classification of Extrahepatic biliary blood supply (Koops, Wojciechowski, Broering, Adam, & Krupski-Berdien, 2004).(Key: CT: celiac trunk, SA: splenic artery, LGA: left gastric artery, CHA: common hepatic artery, HA: hepatic artery, LHA: left hepatic artery, RHA: right hepatic artery, CA: cystic artery, GDA: gastroduodenal artery, SMA: superior mesenteric artery).

According to Michels' study, over 40% of the 200 autopsy dissections have revealed variations in the origin and course of the hepatic artery (Michel, 1962). A replaced hepatic artery originates from a source different to that in the standard description and substitutes the typical vessel. An accessory artery is a vessel additional to those originating according to the standard description. The commonly observed variations of the hepatic artery are: Accessory left hepatic artery originating from the left gastric artery (about 10% of the cases); the right hepatic artery originating from superior mesenteric artery (in about 10% of the cases). Surgically, it is important to note that in 25% of the 200 cases, the left gastric gave rise to a left hepatic artery half of which was an accessory left hepatic artery (Hiatt et al., 1994; Lamah et al., 2001a). The other half had only a replaced left hepatic artery. The inadvertent severance of such a replaced left hepatic from the left gastric artery during a gastric resection would cause ischemic necrosis of the left lobe of the liver, with resultant death of the patient (between the seventh and sixteenth day postoperatively). In 17% of 200 cases, there was an additional right hepatic from the superior mesenteric artery, 12% of the cases being instances in which the entire blood supply to the right lobe of the liver came from this source. Severance of such a hepatomesenteric artery, likewise, would cause an ischemic necrosis of the right lobe of the liver with fatal results (Michels, 1960).

2.3.1 Right Hepatic artery

According to Michels' study, over 40% of the 200 autopsy dissections have revealed variations in the origin and course of the right hepatic artery (Michels, 1951). Right hepatic artery originates from the superior mesenteric artery. This variation is frequently observed (Perkins, 2007) and may be problematic in pancreaticoduodenectomy (Traverso & Freeny, 1989) due to its course near the vascular margin, especially the superior mesenteric artery margin. In some cases, a pancreatic head carcinoma can invade the right hepatic artery and require its resection with or without reconstruction. However, any intraoperative damage of the right hepatic artery can lead to bile duct or liver ischaemia, entailing a risk of anastomotic leakage at the site of the pancreaticojejunostomy, liver abscesses and patient death. Indeed, most of the blood supply to the remnant bile ducts is derived from the replaced or accessory vessel following ligation of the gastroduodenal artery during pancreaticoduodenectomy (El Amrani, Pruvot, & Truant, 2016). In this particular situation, the challenge is to achieve a curative resection without compromising the biliary vascularization. On the other hand, not all variations of the right hepatic artery are likely to affect the course of pancreaticoduodenectomy. For instance, resection without reconstruction of an accessory right hepatic artery (in contrast with replaced right hepatic artery) may be safe (Yamamoto, Kubota, Rokkaku, Nemoto, & Sakuma, 2005). Moreover, in some cases, the periampullary tumor is distant from the right hepatic artery allowing adopting a more conservative approach. As a whole, preoperative identification of a hepatic artery variation and its relationship with the tumor is mandatory to avoid intraoperative vascular injury and subsequent complications after pancreaticoduodenectomy (Gaujoux et al., 2009).

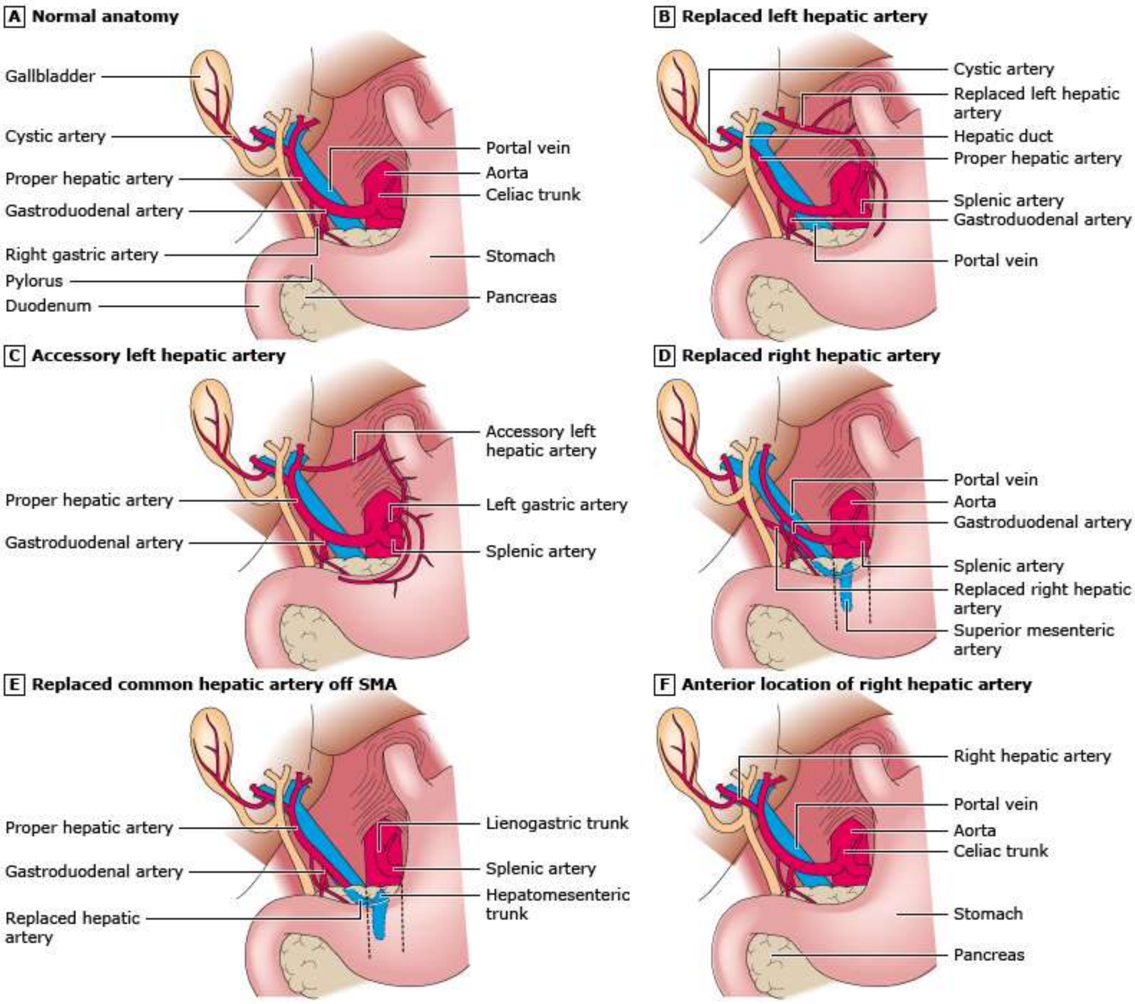

Figure 9: Variant Anatomy of the Hepatic Arteries (Adapted from (Mulholland et al., 2012)).

2.3.2 "*Caterpillar hump*" right hepatic artery

Studies have found that the prevalence of Caterpillar hump ranges between 3-16% (Bhargava, Singh, Singh, & Gupta, 2014; Dandekar et al., 2015). The caterpillar hump either passes in front of or behind the common hepatic or common bile duct within the Calot's triangle (Devi Jansirani, 2012). This has surgical implications: First, it could be mistaken for the cystic artery (where vigorous traction is applied) and an attempt may be made to ligate it. In the event it is tied off, this can be fatal in the presence of impaired liver function (Devi Jansirani, 2012; Zefelippo & Fornoni, 2017). Secondly, in the event the ligature slips off the vessels as the tied ends spring away from one another; there could be massive bleeding that could obscure the operative field (Zefelippo & Fornoni, 2017). When a clump is hurriedly applied in this situation of excessive bleeding, it may directly injure the common hepatic or common bile ducts or both. Lastly, the cystic artery arising from the *caterpillar hump* is often short and stubby; it is easily avulsed from the parent trunk (when strong traction is applied from the gall bladder), producing brisk bleeding with possible unfortunate sequence of events.

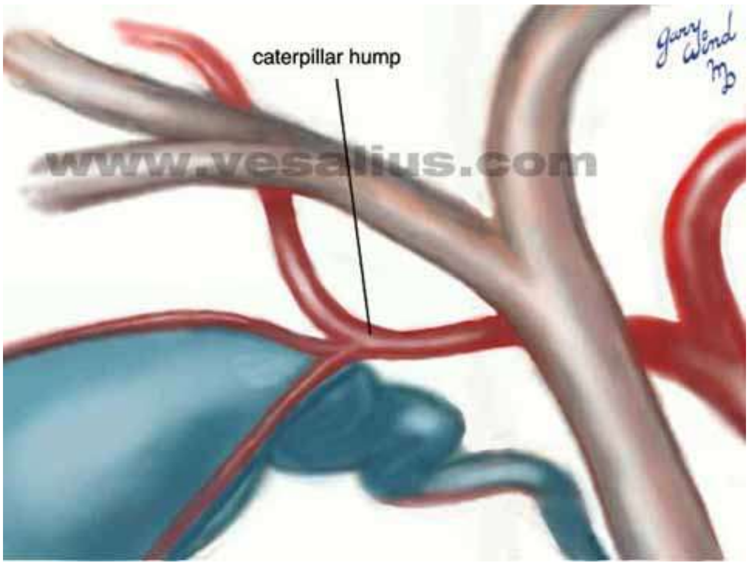

Figure 10: Caterpillar hump

(Adapted From: http://www.vesalius.com/cfoli_frms.asp?VID=806&StartFrame=28&tnVID=807 on 24.09.2017)

Strasberg and colleagues in 1995 first suggested a three-pronged strategy called the “critical view of safety” (CVS), to minimize the risk of bile duct injuries in laparoscopic cholecystectomy. The “critical view of safety” approach has only been recently discussed in controlled studies (figure 11). It is characterized by a blunt dissection of the upper part of Calot’s space, which does not usually contain arterial or biliary anomalies and is therefore ideal for a safe dissection, even in less experienced hands. The critical view of safety can be identified by: dissection of fatty and fibrous tissue from the Calot's triangle; mobilization of the lowest part of the gallbladder from its bed and the unambiguous identification of two and exclusively of two structures (cystic duct, cystic artery) entering the gallbladder (Dziodzio, Weiss, Sucher, Pratschke, & Biebl, 2014).

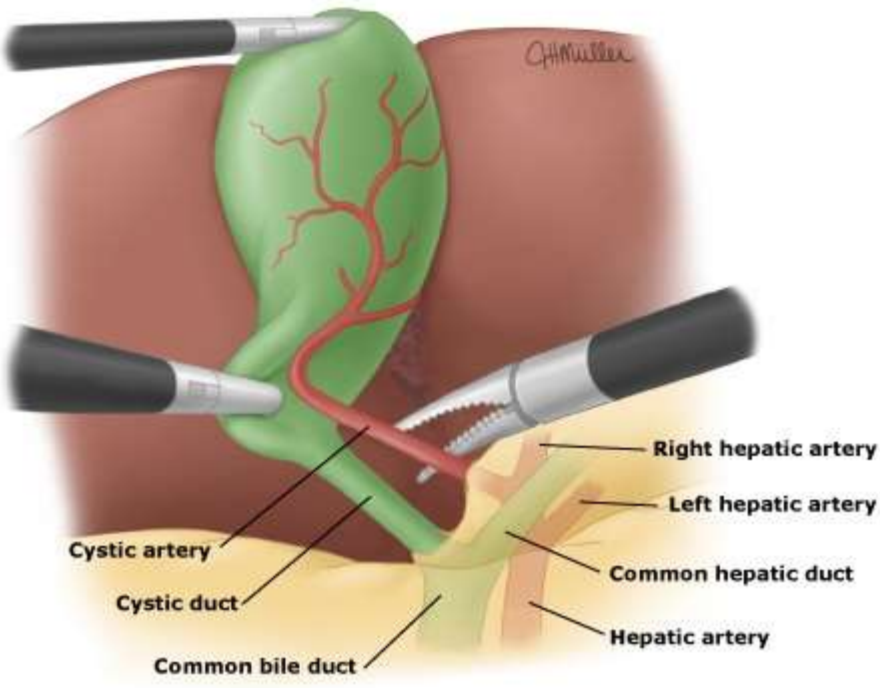

Figure 11: Laparoscopic Critical View of Safety

(Adapted from https://www.slideshare.net/drrahulsingh31/safe-laparoscopic-cholecystectomy-finale on 02/05/2018).

2.3.3 Cystic Arteries

The cystic artery usually originates from the right hepatic artery within the cystic Calot's triangle (Sinnatamby & Last, 2011). It typically divides into the anterior branch for the free surface of the gallbladder and a posterior branch for its bed surface. Cystic artery in 20% of the cases arises from the left or middle hepatic artery, outside the Calot's triangle or less frequently from the common hepatic artery (Andall et al., 2016).

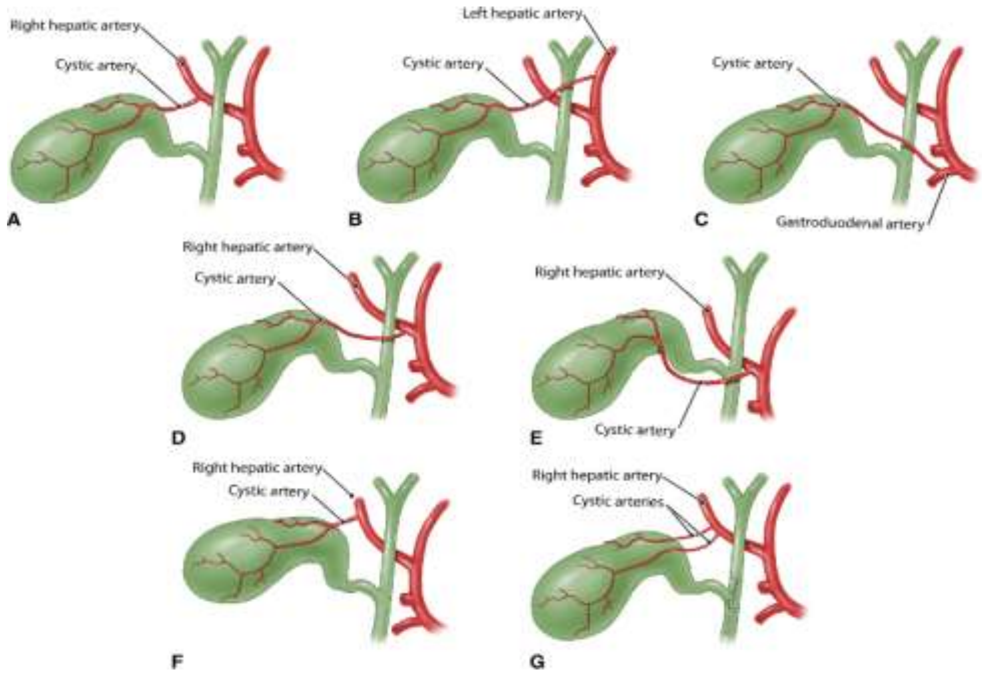

Figure 12: Cystic Artery Variations **Adapted from (Andall et al., 2016).**

Replacements of the cystic artery, including origins from the gastroduodenal, celiac axis or independently from aorta are rarely found. An aberrant right hepatic artery coming from the superior mesenteric artery may also give origin to the cystic artery (Kostakis et al., 2017). This occurs in about 25% of the cases.

The ligation of cystic artery presents a risk of direct injury to either the common hepatic or common bile duct; based on where the anterior cystic vessel runs, how closely it is to the ductal structures and how far proximally the ligature is placed (Afroze et al., 2015; Tharao et al., 2007). When not properly identified, the accessory cystic arteries may be torn leading to bleeding that may not only obscure the operative field but that the hurried clamping may be disastrous (Tharao et al., 2007).

2.3.4 Portal Vein

According to (Gadžijev, 2002), the portal vein is hidden in the hepatoduodenal ligament behind the extrahepatic bile ducts and hepatic artery. Important changes in the anatomical situation are encountered after injury to the portal vein, as a consequence of portal obstruction after thrombosis, or with cirrhosis accompanied by portal hypertension, when collateral veins encircle bile ducts and bulge into the soft tissue of the hepatoduodenal ligament (Ramesh Babu & Sharma, 2014; Talpur et al., 2010). Portal vein anatomical variations such as portal trifurcation or quadrifurcation can be found in the hepatic hilum (Gadžijev, 2002; Ohkubo et al., 2004). This, however, has no impact on laparoscopic cholecystectomy and is more important during liver resections and transplants (López-Andújar et al., 2007). Variation in branching patterns like portal vein trifurcation and quadrifurcation which result in difficult and unstable catheterization carry a higher risk for migration of embolic materials and thus result in non-target embolization (Sharma et al., 2017; Sureka et al., 2015). The detailed anatomical knowledge of hepatic artery, portal vein, hepatic veins and biliary anatomy is of clinical and radiological relevance when dealing with such complex procedures (Moore et al., 2013; Sherlock & Dooley, 2008).

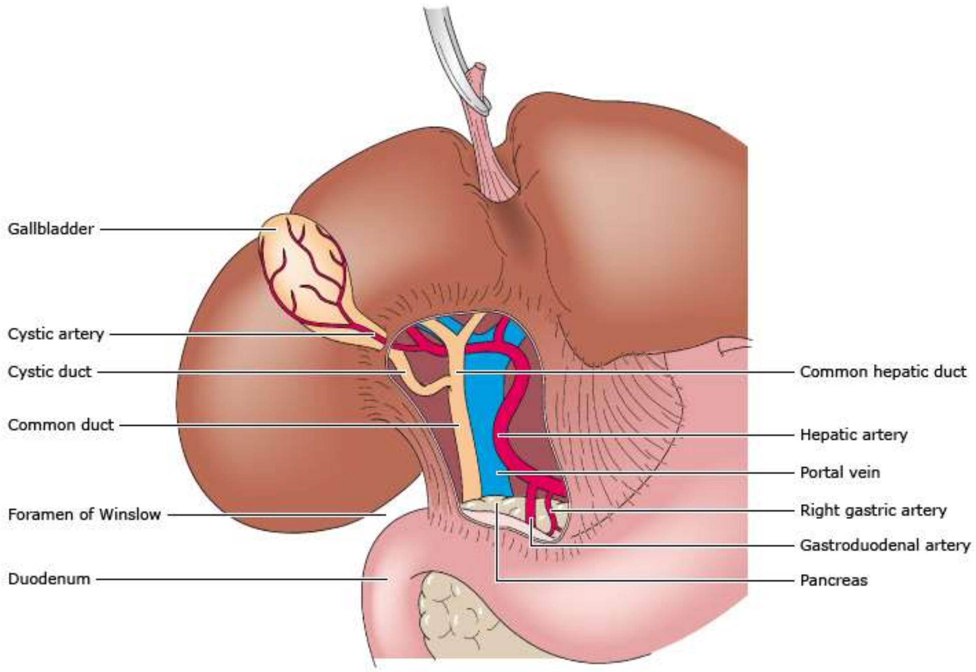

Figure 13: Structures in the hepatoduodenal ligament

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Design:

This was a cross sectional descriptive study involving observation of the extrahepatic biliary system and its blood supply anatomic patterns of cadavers seen at human anatomy laboratory of Moi University School of Medicine.

3.2 Study Setting

The study was conducted at Human anatomy department of Moi University. Moi University School of Medicine is based at the Moi Teaching and Referral Hospital complex, one of the schools at the College of Health Sciences.

3.3 Study Population.

The study included all the male and female cadaveric specimen at the Moi university school of medicine human anatomy laboratory according to Anatomy Act of Kenya (Attorney General, 2012).

3.4Eligibility Criteria

3.4.1 Inclusion criteria:

a) Kenyan adult cadavers of either sex from the Human Anatomy Laboratory of Moi University

34.2 Exclusion Criteria

a) Mutilated or decomposed cadavers/bodies whose anatomy on the abdominal region has been distorted.

b) Patients with pathologies such as gross abdominal tumors, liver cirrhosis and documented communicable diseases.

3.6 Sample size determination

Census sampling was adopted.

3.7 Recruitment and Methods

Authorization was sought from the both institutional research ethics committee (IREC) and department of Human anatomy, at Moi University. Careful dissection and examination for variations was done and documented and pictures taken.

3.7.1Study Procedure

(Cunningham's Manual of Practical Anatomy, Volume 2. Thorax and Abdomen (14th Edition) .

This was done according to the Cunningham manual of Practical Anatomy (Romanes, 1979).

Midline incision from xiphisternum towards umbilicus. Incision extended laterally, from xiphisternum along the coastal margin. Rectus muscle cut open transversely from the umbilicus entering the abdominal cavity.

Stomach identified and its curvatures were defined. Pulling the lesser curvature, lesser omentum identified and its right free margin was defined and then hepatoduodenal ligament was identified. Now the greater omentum was cut transversely below it was pushed forwards towards the right. Loops of small intestine were pushed towards left and second part of duodenum was exposed. Now, the stomach was reflected fully upwards to expose the pancreas and then it was cut at the neck of the pancreas making the visceral surface of the liver, free along with duodenum and head of the pancreas. The ribs were cut open along the midaxillary line on both sides and reflected upwards along with sternum, to make the parietal surface of liver free.

Dissection of the celiac trunk to the origin and its terminal branches, common hepatic artery and its branches, superior mesenteric artery and its branches, cystic artery, the gallbladder, cystic duct, right, left and common hepatic ducts and common bile duct till it entered the second part of the duodenum were dissected in all specimen. The hepatoduodenal ligament was opened by tracing the bile duct upwards and to secure the point where the cystic duct and common hepatic duct unite. Cystic duct traced upwards up to the neck of the gall bladder. The common hepatic duct was then traced upwards to locate the right and left duct emerging from porta hepatis. Lateral to the duct system, towards left the common hepatic artery was identified and traced upwards where it divides into right and left hepatic arteries and also to its origin. The right and left hepatic arteries were traced to their point of origin. From the right hepatic artery, the cystic artery was identified and traced. The boundaries of Calot's triangle were defined and the cystic artery inside the triangle was traced up to the gall bladder. Posterior to all above structures, the portal vein was defined. During the above procedure, the mode of formation of the duct system, the course, and arrangement of the ducts, the mode of termination along with related vessels was studied. Then the length of the individual ducts was measured. The exposed structures were then cleaned of any connective tissue, findings recorded and photographed.

The cystic duct length was measured from the neck of the gallbladder to the confluence of the cystic duct and common hepatic duct or right hepatic duct. The common hepatic duct length was measured from the confluence of the left and right hepatic ducts either within or outside the liver up to the confluence with the cystic duct. The common bile duct length was measured from the confluence of the cystic duct and common hepatic duct to the point when the common bile duct entered the second part of the duodenum.

Figure 14: Digital Vanier Caliper for measuring the length of the ducts

3.8 Data Management and Analysis

3.8.1 Data entry and data management

A structured data collection form was used to collect the data. The completed data collection form was stored in locked cabinets with restricted access. The data was entered and analyzed using the SPSS version 24.

3.8.2 Data analysis

Data analysis was performed using SPSS version 24 special edition. Categorical variables were summarized as frequencies and the corresponding percentages. Continuous variables were presented as interquartile ranges.

3.9 Ethical considerations

In order to protect and respect the rights of the participants who took part in the study the following steps were taken;

Seeking relevant permission and clearance to conduct the study from IREC and Moi University.

To ensure confidentiality and privacy of the study subjects, each subject was given a serial number that was only known by the researcher.

3.10 Limitation of the study

Some of the ductal and vascular structures could not be studied in fixed cadaveric specimens since most had collapsed by the time the study was done.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

This study focused on the surgically significant anatomic variations of the extrahepatic biliary system. These were categorized as either ductal or vascular variations.

Overview of study subjects

The study enrolled 42 cadavers of which 62% (n=26) were male while 38% (n=16) were female.

4.2 Anatomic variations of extrahepatic biliary system among cadavers

4.2.1 Gallbladder

All the study subjects had a gall bladder sited on the right side of the falciform ligament and being drained by the cystic duct.

4.2.2Long cystic duct with low fusion with the common hepatic duct

The cystic duct length ranged from 7mm to 35 mm with a median value of 17mm. 98% (n=41) of the study subjects had cystic duct join the common hepatic duct to form the common bile duct. The cystic duct joined the common hepatic duct to form the common bile duct either to the Left (7.5%), the right (45%), anteriorly (15%) and posteriorly (32.5%) in a straight (55%), tortuous (27.5%) and spiral (17.5%) course. The common bile duct was formed by the confluence of the cystic duct and common hepatic duct in nearly all of the cadavers (95.2%; n=40).

Table 1: Common Bile Duct as a confluence of Cystic Duct and Common Hepatic Duct

		Percent (n)
CBD formed by the confluence of CD and CHD	Yes	97.6 (41)
	No	2.4 (1)
	Total (N)	100 (42)

Image 1: Low fusion of cystic duct with common hepatic duct

(Key: HA: hepatic artery, LHA: left hepatic artery, RHA: right hepatic artery, CA: cystic artery, CD: cystic duct, CHD: common hepatic duct, CBD: common bile duct, PV: portal vein, GB: gall bladder)

4.1.3 Abnormal fusion of the right and left hepatic ducts with the cystic duct entering the confluence

The study observed that 33.3% (n=14) had the confluence of the right and the left hepatic duct within the liver while 66.7% (n=28) were outside the liver. However, there was no abnormal fusion of the right and left hepatic ducts with the cystic ducts entering the confluence. There was no trifurcation observed in this study.

Table 2: Confluence of the right and left hepatic ducts

		Percentage (n)
Confluence of the right and left hepatic ducts	Within the liver	33.3 (14)
	Outside the liver	66.7 (28)
	N	42

The study determined the length of the common hepatic duct to be between 1.0-4.2 cm with a mean length of 2.26 cm.

There were no accessory hepatic ducts found in this study.

4.2.4 Cystic duct entering the right hepatic duct

A single cadaver (2%) had the cystic duct draining into the right hepatic duct (Image 2).

Image 2: Cystic duct joining the right hepatic duct

(Key: CHA: common hepatic artery, HA: hepatic artery, LHD: Left hepatic duct, RHD: right hepatic duct CD: cystic duct, CBD: common bile duct, PV: portal vein, GB: gall bladder)

4.2.5 Cholecystohepatic and Accessory duct(s)

There were no Cholecystohepatic and accessory ducts found in this study.

4.3 Anatomic variations of hepatic and cystic arteries among human cadavers

All the study subjects had an arterial supply present. Majority of all the study subjects (71.4%; n=30) had a normal pattern of the extrahepatic supply (Type 1) as shown in Image 3. This was followed by Type 4 (all replaced with the right hepatic artery arising from superior mesenteric artery) at 11.9% (n=5), then Type 2 (replaced or accessory left hepatic artery from the left gastric artery) at 9.5% (n=4) and lastly Type 3 (replaced or accessory right hepatic artery arising from the superior mesenteric artery) at 7.1% (n=3).

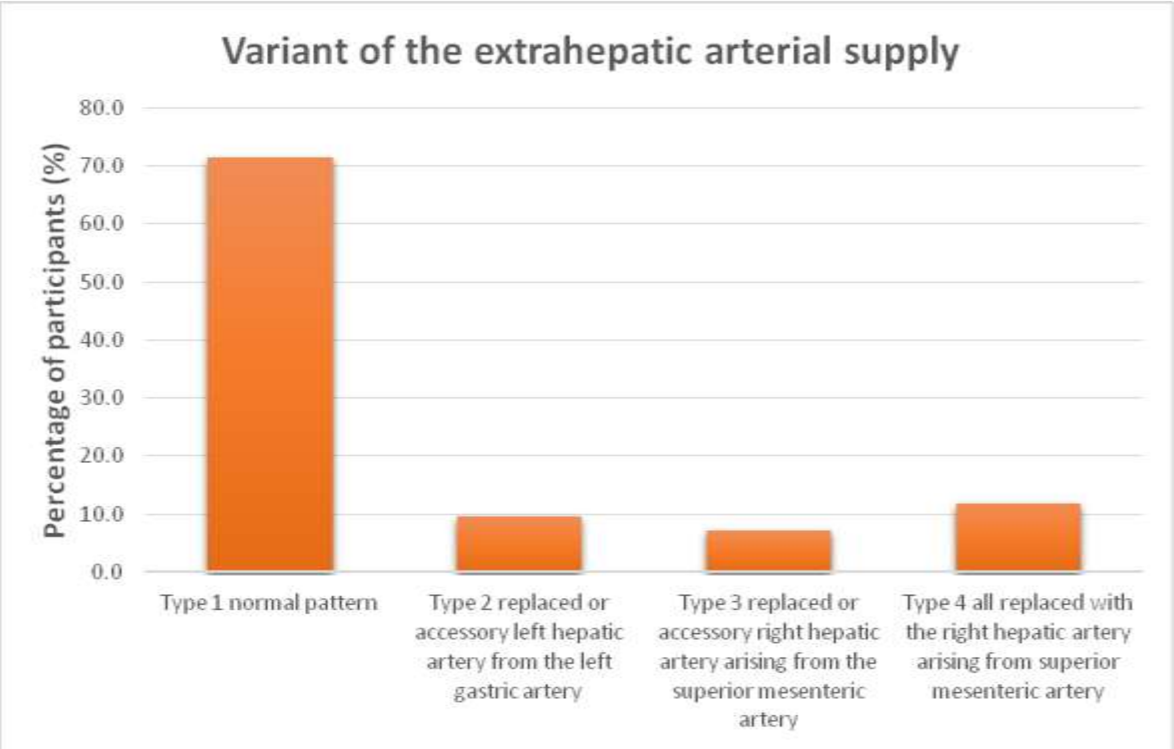

Figure 15: Variant Extrahepatic arterial supply.

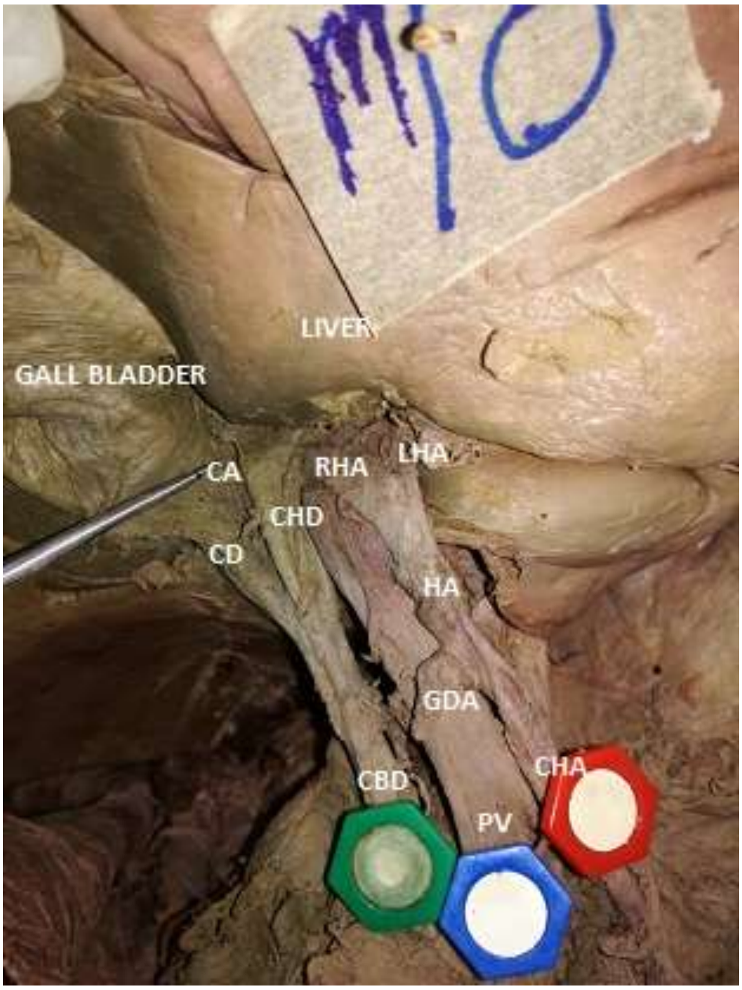

Image 3: Normal Anatomy (as described in Classical Textbooks)

(Key: CHA: common hepatic artery, HA: hepatic artery, LHA: left hepatic artery, RHA: right hepatic artery, CA: cystic artery, CD: cystic duct, CHD: common hepatic duct, CBD: common bile duct, PV: portal vein, GB: gall bladder).

The aberrant origin of right hepatic artery

19% (n=8) of all study subjects had an aberrant origin of the right hepatic artery (Image 4) while the rest had a normal origin from the proper or common hepatic artery. All the aberrant right hepatic artery was replaced and originated from the superior mesenteric artery.

Image 4: Replaced right hepatic artery from superior mesenteric artery

(Key: CT: celiac trunk, SA: splenic artery, LGA: left gastric artery, CHA: common hepatic artery, HA: hepatic artery, LHA: left hepatic artery, RHA: right hepatic artery, CA: cystic artery, GDA: gastroduodenal artery, CD: cystic duct, CHD: common hepatic duct, CBD: common bile duct, PV: portal vein, GB: gall bladder, SMA: superior mesenteric artery.)

Table 3: Origin of the Right Hepatic Artery

		Percent (n)
Origin of the right hepatic artery	Normal (from proper hepatic artery or common hepatic artery)	81 (34)
	Aberrant	19 (8)
	Total (N)	**100 (42)**

4.3.1 Right Hepatic artery anterior to the common bile or common hepatic ducts (or cystic artery anterior to these structures)

The right hepatic artery was found to cross the common hepatic duct posteriorly in 69.4% of the study subjects, 27.8% anteriorly (Image 5) and 2.8% to the right.

Table 4: Course of the right hepatic artery as it crosses the common hepatic duct

		Percent (n)
Course of the right hepatic artery as it Crosses the common hepatic duct	Anterior	27.8 (10)
	Posterior	69.4 (25)
	Right	2.8 (1)
	Total (N)	**100 (36)**

Image 5: Right hepatic artery anterior to the common hepatic duct

(Key: CHA: common hepatic artery, HA: hepatic artery, LHA: left hepatic artery, RHA: right hepatic artery, CA: cystic artery, GDA: gastroduodenal artery, CD: cystic duct, CHD: common hepatic duct, CBD: common bile duct,GB: gall bladder)

All the study subjects (n=42) had a cystic artery with 54.8% (n=23) of them having it originate from the Right hepatic artery within the Calot's triangle while the rest (45.2%; n=19) had it arise from outside the Calot's triangle. Nearly all study subjects (92.9%; n=39) had the cystic artery located within the Calot's triangle. Among the study subjects who had cystic artery arise outside the Calot's triangle (n=19); majority (84.2%; n=16) had it anterior to the common hepatic duct while 15.8% (n=3) had it posterior to the common hepatic duct. The only (2.4%, n=1) other cystic artery variation arose directly from the common hepatic artery.

Table 5: The relation of the cystic artery to the common hepatic duct when it arises from outside the Calot's triangle

		Percent (n)
The relation of the cystic artery to the common hepatic duct when it arises from outside the Calot's triangle	Anterior	85.7 (18)
	Posterior	14.3 (3)
	Total	100 (21)

4.2.2 "*Caterpillar hump*" right hepatic artery

The study found that 42.9% (n=18) of all study subjects had a caterpillar hump of the right hepatic artery.

Table 6: Does caterpillar hump occupy the Calot's triangle?

		Percent (n)
Does the tortuosity (caterpillar hump) of the right hepatic artery occupy the Calot's triangle?	Yes	42.9 (18)
	No	57.1 (24)
	Total (N)	100 (42)

The study further observed that the right hepatic artery occupied upper part of the Calot's triangle in 43.5% (n=10), 26.1% (n=6) in the middle and 30.4% (n=7) in lower part of the cases that had the right hepatic artery within Calot's triangle.

Table 7: What part of the Calot's triangle does the right hepatic artery occupy?

		Percentage (n)
What part of the Calot's triangle does the right hepatic artery occupy?	Upper	42.9 (10)
	Middle	23.8 (6)
	Lower	33.3 (7)
	Total (N)	100 (23)

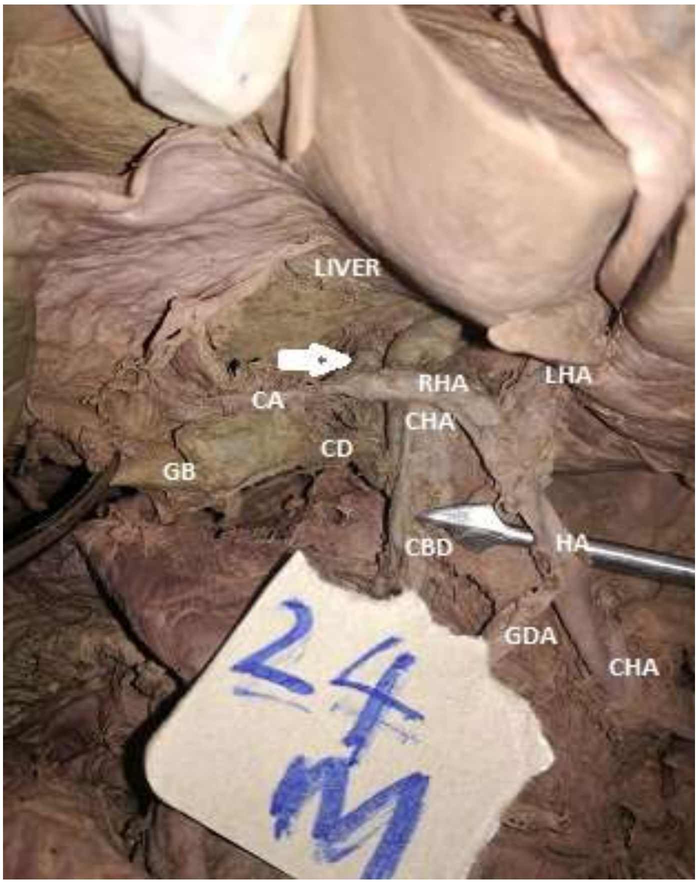

Image 6: Caterpillar Hump

(Key: CHA: common hepatic artery, HA: hepatic artery, LHA: left hepatic artery, RHA: right hepatic artery, CA: cystic artery, GDA: gastroduodenal artery, CD: cystic duct, CHD: common hepatic duct, CBD: common bile duct,GB: gall bladder)

4.3.3 Cystic Arteries

All the study subjects had a cystic artery, of which nearly all (92.9%) having it within the Calot's triangle while more than half (54.8%) of all study subjects had it arise from the right hepatic artery within the Calot's triangle. When the cystic artery was arising outside the calot's triangle, it was observed to be anterior to the common hepatic duct in 85.7% of the cases and right in 14.3%. It was noted in 2.4% (n=1) of the study subjects that cystic artery originated directly from common hepatic artery. The study found no accessory cystic arteries.

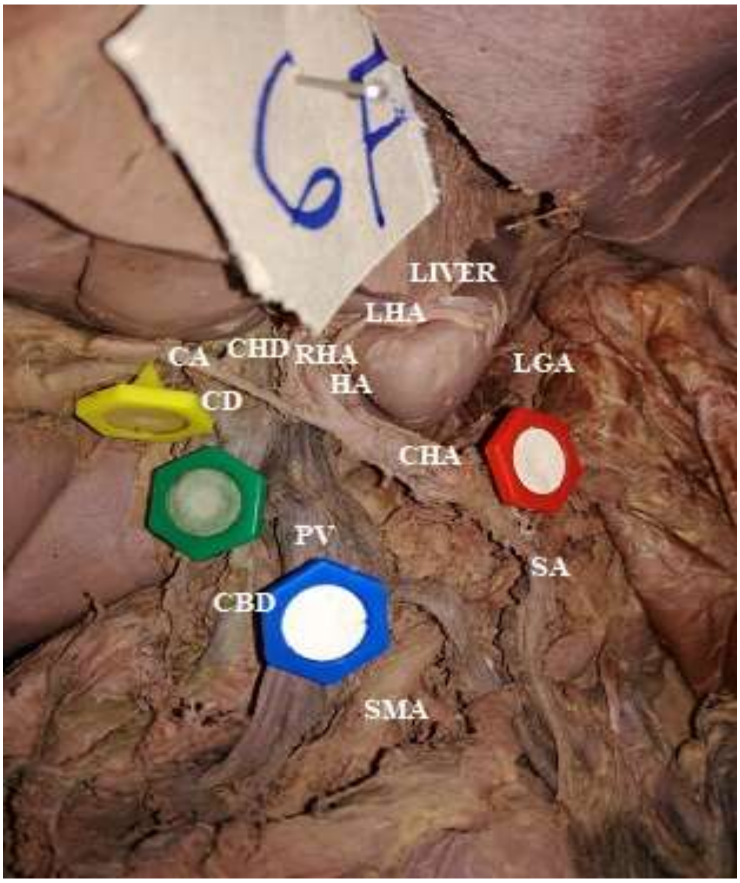

Image 7: Cystic artery anterior to common hepatic duct

(Key: SA: splenic artery, LGA: left gastric artery, CHA: common hepatic artery, HA: hepatic artery, LHA: left hepatic artery, RHA: right hepatic artery, CA: cystic artery, CD: cystic duct, CHD: common hepatic duct, CBD: common bile duct, PV: portal vein, GB: gall bladder, SMA: superior mesenteric artery.)

4.3.4 Portal Vein

All study subjects had a portal vein. The portal vein was normally (posterior to the common bile duct and hepatic artery) positioned in the hepatoduodenal ligament in 85.7% of all study subjects, anteriorly in 4.8%, on the left in 7.1% and in-between among 2.4% of all study subjects.

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Anatomic variations of extrahepatic biliary system among human cadavers

The five surgically important ductal anomalies are: Long cystic duct with low fusion with the common hepatic duct; Abnormal fusion of the right and left hepatic ducts with the cystic duct entering the confluence; Accessory hepatic ducts; Cystic duct entering the right hepatic duct and Cholecystohepatic ducts (Benson & Page, 1976).

5.1.1 Cystic Ducts

This study determined that the cystic duct's length ranged from 0.7cm to 3.5 cm with a median value of 1.7cm. The cystic duct usually measures 2–4 cm in length (Turner and Fulcher, 2001). This variance could be attributed to the difference in the investigation technique adopted by Turner and Fulcher (2001) who used magnetic resonance imaging (Turner & Fulcher, 2001).

The study also showed that cystic duct joined the common hepatic duct to form the common bile duct either to the left (7.5%), the right (45%), anteriorly (15%) and posteriorly (32.5%) in a straight (55%), tortuous (27.5%) and spiral (17.5%) course. These findings compare to an American study which found that the cystic duct enters the extrahepatic bile duct from the right lateral aspect in 49.9% of cases, from the medial aspect (left) in 18.4%, and from an anterior or posterior position in 31.7% (Hiatt et al., 1994). An Indian study found a medial (left) insertion in 10%-17% (Chaudhary et al., 2016).

A single (2%) study participant had the cystic duct drained through the right hepatic duct. This corresponds to the findings of (Chaudhary et al., 2016) who found that cystic duct may join the right hepatic duct in 0.6%-2.3% cases. 0.0.

5.1.2 Hepatic Ducts

First, variations on the hepatic ducts occur at different levels of confluence of the two (right and left) hepatic ducts. The study determined that 33.3% (n=14) had the confluence of the right and the left hepatic duct within the liver while 66.7% (n=28) were outside the liver. When the confluence what outside the liver, it only ran parallel to join the cystic duct to form the common bile duct in one cadaver (3.6%). This is similar to a radiological study by Mortele who found the cystic duct ran a parallel course to the common hepatic duct in 1.5%-25% (Mortelé et al., 2006). However, this study like that of Cachoeira did not find accessory and Cholecystohepatic ducts (Cachoeira et al., 2012). Cholecystohepatic ducts were not found in this study due the fact that most delicate structures collapse in formalin preserved cadavers.

The study determined the length of the common hepatic duct to be between 1.0-4.2 cm (mean: 2.26 cm) which compares closely to a Brazilian study which found the length to vary between 0.4 and 5.6 cm, with a mean average of 2.17 cm (Cachoeira et al., 2012).

5.2 Anatomic variations of hepatic and cystic arteries among human cadavers

The three surgically important arterial anomalies were the caterpillar hump right hepatic artery, right hepatic artery anterior to the common bile or common hepatic ducts (or cystic artery anterior to these structures) and the accessory cystic artery (Benson and Page, 1976; Jansirani, D et al 2012).

In this study, all the participants had an arterial supply present. The classification system used in this study was Michels (Michels, 1966). Majority of all the study subjects (71.4%; n=30) had a normal pattern of the extrahepatic supply (Type I). This was followed by Type IV (both replaced or accessory right hepatic artery and left hepatic artery) at 11.9% (n=5), then Type II (replaced or accessory left hepatic artery from the left gastric artery) at 9.5% (n=4) and lastly Type III (replaced or accessory right hepatic artery arising from the superior mesenteric artery) at 7.1% (n=3). Our study did not find type V and type VI anatomic variations. These findings compare to those of Hiatt, Gabbay and Busutill (1994) who conducted a study on 1,000 patients who underwent liver harvesting for orthotopic transplantation. They classified the variations into six types modified from Michel (1962) classification as: Type I (75.7%): Common hepatic artery arising from the coelic axis, normally forming the gastroduodenal artery and proper hepatic duct. Type II (9.7%): Replaced or accessory left hepatic artery from left gastric artery. Type III (10.6%): Replaced or accessory right hepatic artery from the superior mesenteric artery. Type IV (2.3%): Double replacement (coexisting variation of Type II and Type III). Type V (1.5%): Common hepatic artery arises from the superior mesenteric artery. Type VI (0.2%): The common hepatic artery arising directly from the aorta. In this study, there were no accessory hepatic or cystic arteries.

5.2.1 Right Hepatic artery

The study found that 81% (n=34) of all study subjects had a normal origin of the right hepatic artery from the proper hepatic artery or common hepatic artery while 19% (n=8) had an aberrant (replaced or accessory) origin from the superior mesenteric artery. According to Michels' study, over 40% of the 200 autopsy dissections have revealed variations in the origin and course of the hepatic artery. The commonly observed variation was the right hepatic artery originating from superior mesenteric artery (in about 10% of the cases). This demonstrates that anatomic variations occur in different proportions among different populations (Michel, 1966). This study's findings are also similar to a British study by Jones and Hardy (2001) who found aberrant right hepatic artery in 18% of all their study participants.

The right hepatic artery was found to cross the common hepatic duct posteriorly in 69.4% of the study subjects, 27.8% anteriorly and 2.8% to the right. 2.4% (n=1) of all the study subjects had the right hepatic artery anterior to the common bile duct.

5.2.2 "*Caterpillar hump*" right hepatic artery

The study found that 43% (n=18) had a caterpillar hump of the right hepatic artery occupy the Calot's triangle. This finding is higher than previously conducted studies that ranged between 3-16% in prevalence (Bola, 2015; Dandekar, 2015; Bhargava, 2014). This variance could be attributed to racial differences among the study subjects.

5.2.3 Cystic Arteries

In this study all the study subjects had a cystic artery, of which nearly all (97.6%; n=41) had the cystic artery originate from the right hepatic artery. This compares to previous studies conducted in other regions. In a Sri Lankan study (DeSilva, 2001), Bangladesh (Khalil, 2008) and the groundbreaking British study (Flint, 1923) who found proportions of 96%, 90% and 98% respectively. Only a single study subject (2.4%) had the cystic artery originating from the common hepatic artery. This was comparable to two American (Daseler, 1947 and Michele, 1953) and Bangladesh (Khalil, 2008) studies who found proportions of 2.7%, 1.5% and 4%. However, these findings contrasted an Indian study (Sachin, 2014) who found 50% of all study participants with cystic arteries arising from the right hepatic artery and 43.3% arising from the common hepatic artery. These differences could be attributed to population dynamics.

This study further determined that 92.9% of all the study participants had their cystic artery within the Calot's triangle. This is comparable to studies in Ethiopia (Futura, 2001) and Poland (Flinski, 2004) who found proportions of 89% and 97.6% respectively.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study determined the existence of surgically important variant anatomy of the extrahepatic biliary system and its blood supply among black Kenyans.

A small (2%) proportion of the participants had the cystic duct draining through the right hepatic duct. When the confluence of the right and left hepatic ducts was outside the liver, it ran parallel to the cystic duct to form the common bile duct. There was no marked difference in the length of the common bile duct noted between the male and female cadavers.

More than one quarter of the study subjects had a variant arterial supply present. The most frequent arterial variation was a caterpillar hump of the right hepatic artery occupying the Calot's triangle. 19% of the study subjects had an aberrant (replaced or accessory) origin of the right hepatic artery from the superior mesenteric artery. The right hepatic artery was found to cross the common hepatic duct anteriorly in 27.8% of the cases. When the cystic artery originated outside the Calot's triangle, it was observed to be anterior to the common hepatic duct in nearly all of the cases with only one originating directly from the common hepatic artery.

6.2 Recommendations

1. There is need for greater appreciation of the extrahepatic biliary system's variant anatomy and its blood supply by both surgeons and radiologists so as to decrease morbidity and improve on surgical outcomes.
2. There is need for adoption of imaging techniques on the biliary tree and its blood supply in this era of minimally invasive surgery, radiological interventional procedures and liver transplants.

6.3 Recommendation for Future Studies

Future studies using both cadaveric and operative specimens alongside radiological techniques should be conducted.

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APPENDICES

Appendix I: Data Collection Form

1. Serial number
2. Gender? male/ female
3. Is the gall bladder present? yes /no
4. Which side of the falciform ligament is the gallbladder sited? Left/right
5. Does the cystic duct drain the gall bladder? Yes/ no
6. Does the cystic duct join the common hepatic duct to form the common bile duct? Yes/ no
7. If yes at what angle does it join the common hepatic duct? Acute/right angle/obtuse
8. Which side does the cystic duct as it joins the common hepatic duct to form the common bile duct? Left/right/anterior/posterior
9. What is the course of the cystic duct as it joins the common hepatic duct to form the common bile duct? Straight/tortuous/spiral
10. If no, where does the cystic duct drain into other than joining the common hepatic duct to form the common bile duct? Right hepatic duct/ left hepatic duct
11. What is the length (in mm) of the cystic duct?
12. Does the common hepatic duct formed by the confluence of the right hepatic duct and left hepatic duct? Yes/no
13. Where is the confluence of the right and left hepatic ducts? Within the liver/outside the liver
14. If the confluence is outside the liver, do they run parallel to join the cystic duct to form the common bile duct? Yes / no
15. What is the length (in mm) of the common hepatic duct?
16. Is the common bile duct formed by the confluence of the cystic duct and the common hepatic duct? Yes/no
17. Where does it lie in relation to the portal vein? Anterior/posterior/ left/right
18. Where does it lie in relation to the hepatic artery? Right/left/anterior/posterior
19. What is the length (in mm) of the common bile duct from the confluence of the cystic duct and the common hepatic duct to the entry of the common bile to the duodenum (extraduodenal portion)?
20. Is the arterial supply present? Yes /no
21. What variant of the extrahepatic arterial supply is present?
    a. Type 1 normal pattern where the common hepatic artery arises from the celiac axis to form the gastroduodenal and proper hepatic arteries and the proper hepatic artery divided distally into right and left branches
    b. Type 2 replaced or accessory left hepatic artery from the left gastric artery
    c. Type 3 replaced or accessory right hepatic artery arising from the superior mesenteric artery

   d. Type 4 all replaced with the right hepatic artery arising from superior mesenteric artery and the left hepatic artery arising from left gastric artery
   e. Type 5 the entire common hepatic artery originating from the superior mesenteric artery
   f. Type 6 common hepatic artery arising directly from the aorta

22. What is the origin of the right hepatic artery? Normal (from proper hepatic artery or common hepatic artery)/aberrant
23. What is the aberrant right hepatic artery? replaced/accessory
24. If aberrant what is the origin? Aorta/superior mesenteric artery/gastroduodenal artery/right gastric artery/celiac trunk
25. What is the course of the right hepatic artery as it Crosses the common hepatic duct? Anterior/posterior/
26. What is the relation of the right hepatic artery to the common bile duct? Anterior/posterior
27. Is the course of the right hepatic artery torturous? Yes/no
28. Does the tortuosity (caterpillar hump) of the right hepatic artery occupy the Calot's triangle? Yes/ no
29. What part of the Calot's triangle does the right hepatic artery occupy? Upper/middle/lower
30. Is the cystic artery present? Yes/no
31. What is the origin of the hepatic artery? Right hepatic artery within the Calot's triangle/other
32. Is the cystic artery found within the Calot's triangle? Yes/no
33. What is the relation of the cystic artery to the common hepatic duct if it arises from outside the Calot's triangle? Anterior/posterior
34. Is there any other cystic artery variation? Yes/no
35. What are this other cystic artery variations?
36. Is the portal vein present? Yes/no
37. What is the position of the portal vein in the hepatoduodenal ligament? Normal (posterior to the common bile duct and hepatic artery)/ other
38. What are the other positions of the portal vein within the hepatoduodenal ligament? Anterior/left/right.

Appendix II: Variant Anatomy Images

CT: celiac trunk, SA: splenic artery, LGA: left gastric artery, CHA: common hepatic artery, HA: hepatic artery, LHA: left hepatic artery, RHA: right hepatic artery, CA: cystic artery, GDA: gastroduodenal artery, CD: cystic duct, CHD: common hepatic duct, CBD: common bile duct, PV: portal vein, GB: gall bladder, SMA: superior mesenteric artery.

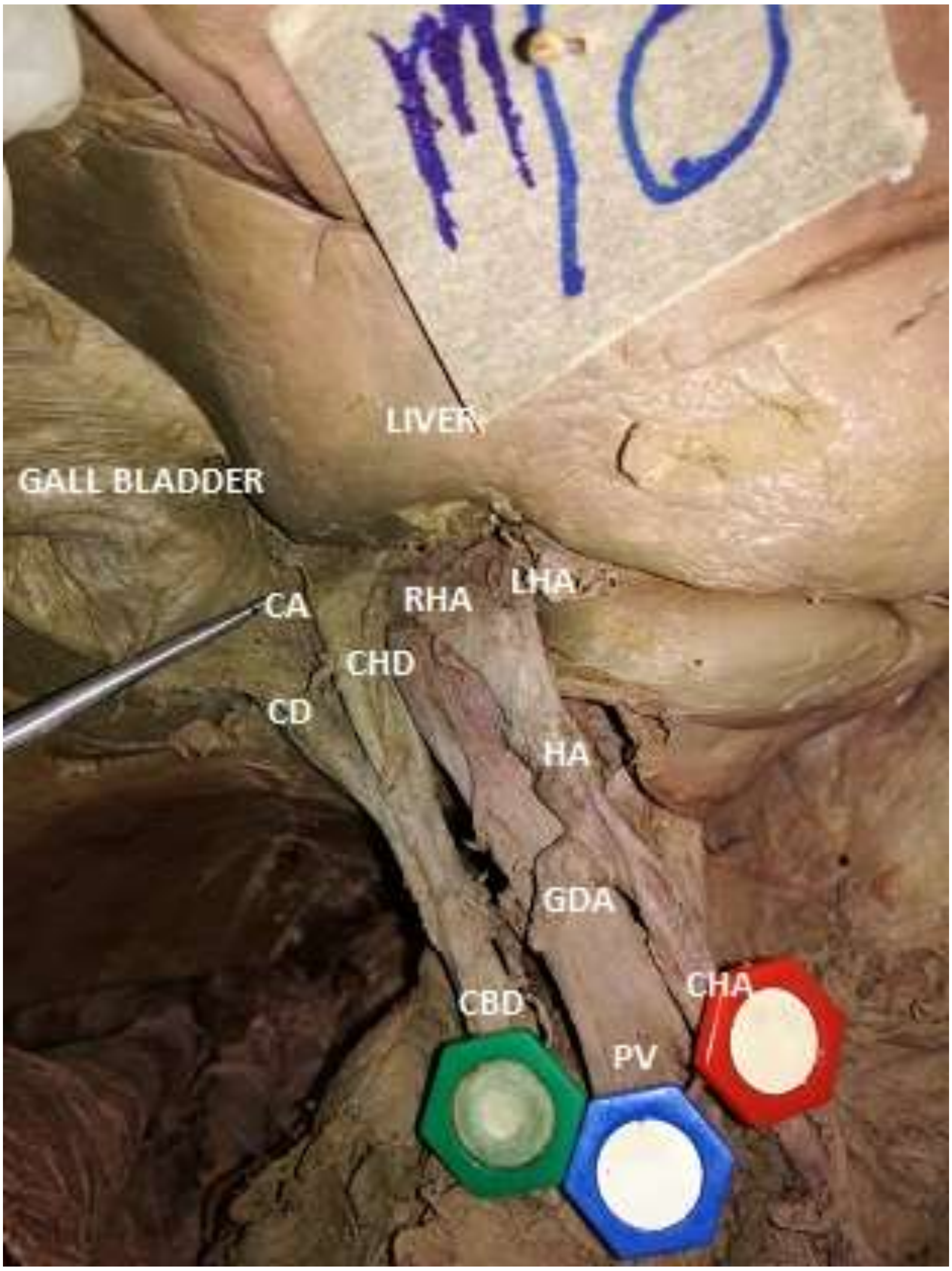

Image 8: Normal Anatomy (as described in Classical Textbooks)

Image 10: Cystic artery anterior to common hepatic duct

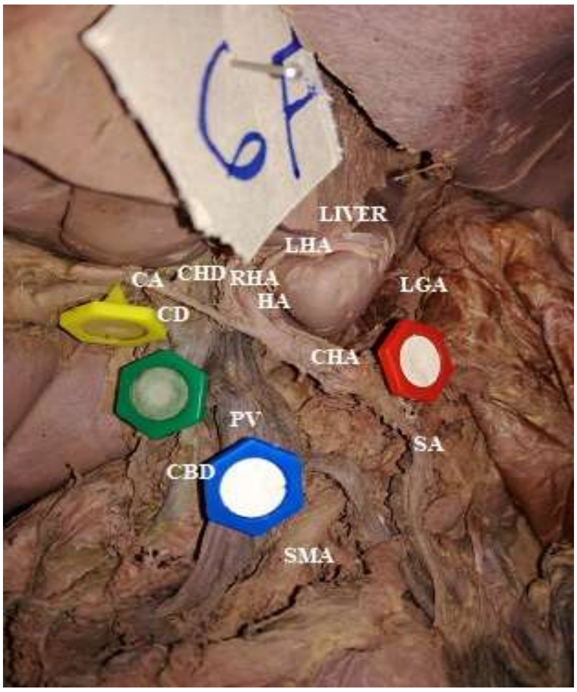

Image 9: Caterpillar Hump

Image 11: Cystic duct joining the right hepatic duct

Image 12: Low fusion of cystic duct with common hepatic duct

Image 13: Replaced right hepatic artery from superior mesenteric artery

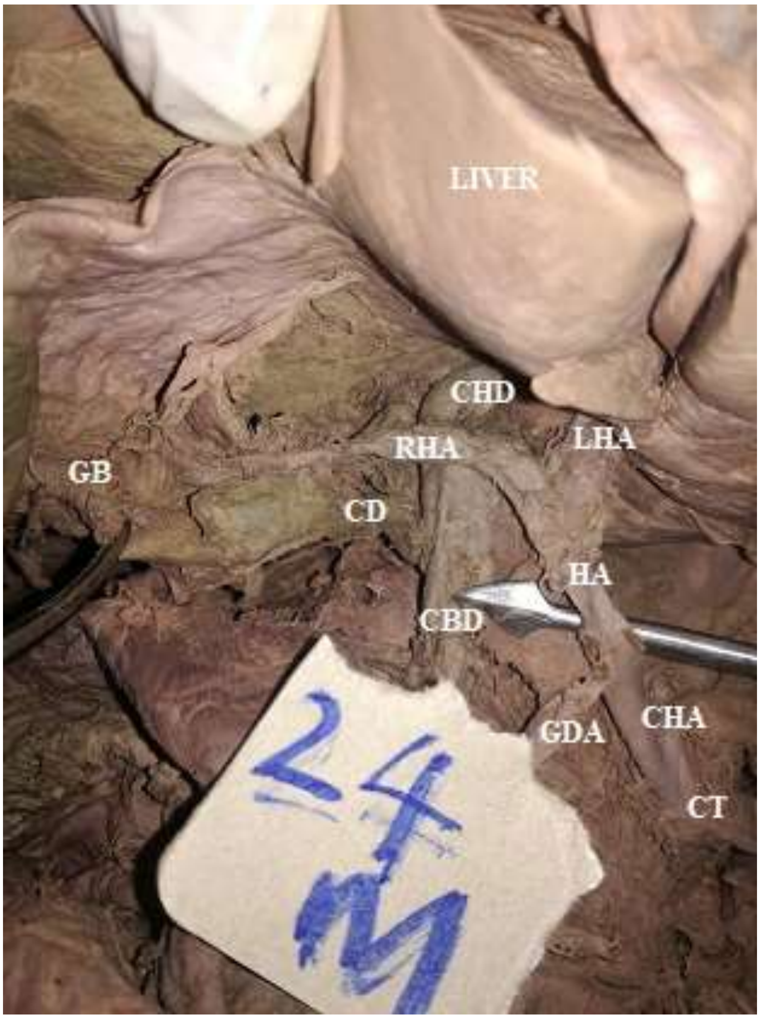

Image 14: Right hepatic artery anterior to the common hepatic duct