REVIEW

Anatomy and its Variations in the Liver and Biliary Tract, and their Embryological Basis: A Mini Review

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Abstract

The human biliary tract is a complex duct system that starts to develop by the 3rd week of intrauterine life. Several studies have been done to describe the anatomical as well as the biochemical nature of this developmental process. While the typical anatomy is seen among most of the general population, variations in the hepatobiliary system are not uncommon. The presence of variations can alter the cause of a disease, impact a diagnosis/ investigation, or change the plan of management and result in complications.

This mini narrative review analyses published literature from different scientific databases to organize and illustrate the normal anatomy, variations, embryology, and proposed developmental basis of variations concerning the hepatobiliary system, to give a better perspective from an anatomical point of view.

Keywords: Biliary tract; Embryology; Developmental Variations; Netter's classification

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Introduction

Previous studies have discussed the embryological development of the liver and biliary tract from anatomical and molecular aspects. However, there is a lack of organized information on the developmental basis of its structural variations from an anatomical point of view.

This review discusses the normal anatomy, variations of the liver and biliary tract, and the embryological basis of such variations from an anatomical perspective.

Normal anatomy of the liver and biliary tract

The human hepatobiliary system is responsible for the production of bile, transportation, and delivery into the duodenum. It contains the liver, the intrahepatic biliary system, and the extrahepatic biliary system. The human liver is the largest organ in the body and functions as a storing, synthesizing, detoxifying, and excretory organ. Having diaphragmatic and visceral surfaces with four lobes, the porta hepatis allows the right hepatic duct (RHD), left hepatic duct (LHD), the right hepatic artery (RHA), the left hepatic artery (LHA), and the portal vein (PV) to enter the liver (1). Functionally, it has eight segments: divided by the main branches of the PV and which are numbered I to VIII (1, 2).

The intrahepatic biliary system consists of biliary canaliculi and segmental bile ducts that run parallel to the portal venous system (3, 4). These segmental ducts join to form the main bile ducts. The RHD is formed by the Right anterior hepatic duct (RAHD) and right posterior hepatic duct (RPHD). A combination of left-side segmental branches makes the LHD. This classical pattern is present in around 60% of the population (2, 4, 5).

The extrahepatic biliary system consists of the RHD and LHD and the ducts following them. After a short course, they join to form the Common Hepatic Duct (CHD), which is connected with the cystic duct (CD), to form the common bile duct (CBD). The CD connects the bile-storing gallbladder (GB), to the CHD. The CBD opens into the hepatopancreatic ampulla (of Vater) in the duodenal wall with the main pancreatic duct, as a common channel (2, 6–8).

Anatomical variations of the Liver

The liver has a complex anatomy due to having several lobes with varying sizes and shapes, fissures, and anomalies leading to significant anatomical variations (1, 9). These variations can be external liver morphological variations and/or internal variations, mainly associated with liver vasculature (9–11). Interestingly, often there is more than one anatomical variation in the same liver (12).

These variations can be congenital or acquired (13). The congenital variations occur mainly due to agenesis, atrophy, or hypoplasia of lobes, accessory lobes, and accessory fissures (11, 14). Congenital surface morphological variations in the liver are usually rare, although they often affect the biliary system. Accessory hepatic fissures, accessory lobes including Riedel's lobe, and pons hepatis are among the most common morphological variations observed (12, 15). Knowledge of these variations is essential in radiological interpretations and surgeries. Gross variations of the liver can be classified according to 'Netter's classification' system. This includes 7 types, with type 1 classified as the normal, classic characteristics including a large right lobe and a small left lobe. Other types comprise different characteristics of costal and renal impressions, diaphragmatic grooves, or differently shaped lobes (9, 13). The beaver tail liver or the silver liver is another rare variation involving elongation of the left lobe, which is not described under Netter's classification (16). When considering the vascular variations, replaced right and left hepatic arteries, multiple portal vein anastomoses, accessory hepatic veins, and multiple hepatic veins also have been reported (10, 17).

Intrahepatic biliary tract variations

The most observed pattern of ductal confluence is the formation of RHD with RAHD and RPHD, then joining of RHD with LHD to form the CHD. Apart from that, there are several anatomical variations in the biliary system. Among these, variations in the intrahepatic ducts are quite common but are rarely clinically significant. The most common anatomic variations of the intrahepatic biliary tract are reported in the literature according to the pattern of confluence of RAHD: RPHD draining into the LHD before joining with the RAHD, RPHD emptying into the right side of the RAHD, simultaneous emptying of RAHD, RPHD, and LHD into the CHD (triple confluence), and RPHD draining into the CD or CHD directly (Figure 1) (3, 18).

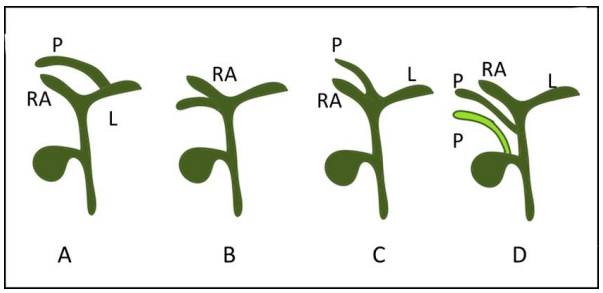


Figure 1: Variations of the intrahepatic biliary tract. A - RPHD draining into the LHD, B - RPHD emptying into the right side of the RAHD, C - Triple confluence, D - RPHD draining into the CD or CHD directly. (RA – Right anterior hepatic duct, P - Right posterior hepatic duct, L – Left hepatic duct)

Precise knowledge of the anatomy of the intrahepatic biliary tract is essential for the selection of donors for liver transplantation surgeries. While triple confluence is a contraindication for safe right hepatectomy, RPHD draining to LHD is a contraindication for both right and left hepatectomy (3).

Extrahepatic biliary tract variations

Variations in extrahepatic ducts are comparatively less common. Their clinical significance is greater since they may lead to intraoperative complications, especially during laparoscopic surgery, if unknown or undetected before surgery (19).

The variations in the extrahepatic biliary tract can occur anywhere from the RHD and LHD to the CBD. Low or medial CD insertion, parallel course of the CD and CHD, high fusion of the CD with the CHD, and absence of the CD are common CD variations reported (Figure 2) (3, 18).

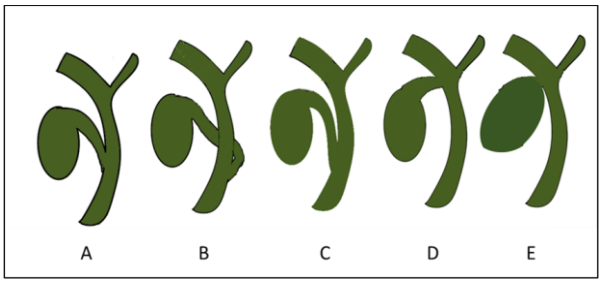


Figure 2: Common cystic duct variations. (A - Low CD insertion, B - Medial CD insertion, C - Parallel course of the CD and CHD, D - High fusion of the CD with the CHD, E - Absent CD)

Identification of the anatomy of the CD may help prevent complications associated with cholecystectomies. A parallel course between CD and CHD is especially at high risk of transection of the extrahepatic bile duct (3).

GB variations are rare. These can be the absence of GB (Isolated congenital absence is very rare), ectopic GB, intrahepatic GB, double and triple GBs, or duplication of the GB (20).

CBD variations are rare. The most common variation among these rare varieties is double CBD, in which one CBD has normal drainage while the other has accessory drainage (20).

Congenital anomalies may be present at the pancreaticobiliary junction where the common bile duct and the pancreatic duct join outside of the duodenal wall. As the sphincter of Oddi is unable to control the channels, this may lead to reflux of pancreatic juice into the biliary tract and bile into the pancreatic ducts, causing

choledochal cysts and pancreatitis. This requires surgical correction (3).

Development of the hepatobiliary system

The hepatobiliary system starts to develop in the 3rd week of intrauterine life (IUL) as an endodermal outgrowth of the distal foregut. It is called the hepatic diverticulum/liver bud (21–23).

At the beginning of the 4th week, the hepatic diverticulum shows distinctive cranial and caudal buds. Later, the cranial bud develops into the liver and pars hepatica, with the latter eventually forming the hepatic ducts. The caudal bud divides into superior (pars cystica) and inferior buds. The pars cystica becomes the GB, CD, and CBD; the inferior bud becomes the right and left ventral pancreatic buds (22, 24). The hepatic diverticulum proliferates rapidly and forms the liver by invading the mesenchymal tissue of the septum transversum. The connection between the developing liver and the foregut narrows and elongates, forming the bile duct (22, 23).

During the 5th week of IUL, the initial funnel-shaped CHD undergoes a rapid proliferative stage and gives rise to several channels at the porta hepatis. This initiates the formation of right and left hepatic ducts (22,25). By the end of the 5th week, the biliary tract is recognizable and complete (24).

The intrahepatic duct system starts to develop from the ductal plates near the hilum of the liver by the 6th week (22,24). The position of the opening of the bile duct changes from its anterior position to the posterior side of the foregut (duodenum) due to the rotation of the gut (23). The sphincter of Oddi develops from the 7th week of IUL up to the 28th week, involving the differentiation of the muscles of the intestinal wall (24).

There are two theories regarding the development phases of the extrahepatic biliary tract. The popular being; the ducts of the extrahepatic biliary tract undergo a solid phase, with plugging of the lumen by epithelial cells followed by a recanalization process at the end of the 5th week, keeping the GB solid until the 12th week. According to some authors, failure in the process may lead to pathologies like biliary atresia and bile duct dilatation (23, 24). Conversely, others provide evidence against this theory and disapprove of the existence of a solid phase with subsequent recanalization (22, 25).

Any aberration or change in the regulation of the above processes may result in anatomical variations in the biliary tract.

Embryological basis of liver and biliary tract variations

Variations in the biliary tract may be linked to changes in the responsible genetic components and functional interactions among the liver mesenchyme, ducts, and hepatic arteries, as their development is tightly cross-regulated (21, 22).

Several authors have described the development of the biliary tract either solely from an anatomical perspective or biochemically at the molecular level (21, 22, 24–26).

The presence of biliary variants has not been related to age, thus indicating an embryological origin of anatomical variations of the extrahepatic biliary tract rather than age-related changes. These can be explained by hepatobiliary embryology, and they arise from aberrations of embryological development (27).

Further, others suggest that the remodeling process of channels at the porta hepatis gives rise to anatomical variations in the hepatic ducts at the porta hepatis (22, 25).

Some authors report that the process of intrahepatic duct system development is completed by the 10th week of intrauterine life (24), while others say it requires an additional 4 to 6 weeks after birth, with completion during the first year of life (22). This

incompleteness is stated as the reason for the lower bile duct-to-portal tract ratio in premature infants. Accordingly, the peribiliary capillary plexus and hilar peribiliary glands are fully developed by the age of 15 years. The same applies to the liver, which continuously grows into adult life to be 10 times the weight of the newborn liver (22).

Some researchers have reported gender as a factor contributing to extrahepatic biliary anatomy variations, which may be due to different embryological developmental factors (27–30), while other researchers have disproven these claims (31).

Conclusion

The liver and the biliary system are one of the most complex systems in the human body with remarkable anatomical diversity. Even though many variations are clinically silent, with the advancement of interventional hepatobiliary procedures, recognition of these variations is essential for safe and effective diagnostic imaging, hepatobiliary surgeries including liver transplantation, and minimally invasive procedures. Better knowledge of embryological principles underlying these variations provides valuable insights leading to accurate anatomical interpretation and clinical decision-making. Integrating anatomical knowledge with embryological mechanisms will improve radiological interpretations, operative planning and understanding of complications, leading to better patient outcomes.

Conflicts of interests

The authors have no conflicts of interest to declare.

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