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ANATOMICAL STUDY OF THE HUMAN LIVER

Structure, Relations and Clinical Significance

A Anatomical and Clinical Correlation Study

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Research Paper

Abstract

The liver is the largest internal gland and one of the most important organs of the human body. It occupies a major portion of the right upper quadrant of the abdominal cavity and has complex anatomical relationships with the diaphragm, stomach, duodenum, gallbladder, kidneys, inferior vena cava and major vascular structures. Its dual blood supply from the portal vein and hepatic artery, together with venous drainage through the hepatic veins, gives the liver a distinctive vascular organization.

Modern understanding of hepatic anatomy has progressed from the traditional morphological division into right and left lobes to functional segmental anatomy, particularly the Couinaud classification. This system divides the liver into eight functionally independent segments based on portal venous distribution and hepatic venous planes, providing a clinically useful framework for imaging, biopsy, resection and transplantation.

This review describes the gross anatomy, surfaces, borders, lobes, ligaments, vascular supply, biliary drainage, lymphatic drainage, nerve supply, microscopic organization and clinically important anatomical relationships of the human liver. It also correlates hepatic anatomy with laboratory investigations commonly used in liver assessment, including ALT, AST, alkaline phosphatase, bilirubin, albumin and PT/INR.

Keywords: Liver; anatomy; hepatic segments; Couinaud classification; portal vein; hepatic artery; hepatic veins; hepatocytes; liver tests.

1. Introduction

The liver is a large, highly vascular organ situated predominantly in the right upper quadrant of the abdomen. It lies immediately below the diaphragm and extends toward the epigastric and left hypochondriac regions. The organ is protected partly by the lower ribs and is maintained in position by peritoneal reflections and fibrous attachments (Bloomston & Reddy, 2010).

The external morphology of the liver includes a diaphragmatic surface and a visceral surface. The diaphragmatic surface is relatively smooth and convex, whereas the visceral surface contains important anatomical impressions, fissures and the porta hepatis. These relationships explain why enlargement or disease of the liver can affect neighboring abdominal structures.

The classical description identifies a large right lobe and a smaller left lobe, but functional anatomy is more closely related to vascular and biliary territories. Couinaud's system divides the liver into eight segments, each associated with a portal pedicle, while hepatic veins form important intersegmental planes (Nagino et al., 2006; van den Esschert et al., 2013).

2. Aim of the Study

To provide a comprehensive anatomical study of the human liver, including gross structure, anatomical relations, vascular and biliary anatomy, microscopic organization and clinical significance, with particular emphasis on its relevance to diagnostic and laboratory medicine.

3. Objectives

- To describe the gross anatomical structure of the human liver.
- To explain the surfaces, borders and anatomical lobes of the liver.
- To describe the major ligaments and peritoneal relationships.
- To explain arterial and portal venous blood supply.
- To describe hepatic venous drainage and biliary drainage.
- To explain Couinaud segmental anatomy.
- To describe the microscopic organization of hepatic tissue.
- To correlate anatomy with common clinical and laboratory investigations.

4. Materials and Methods

The present study was designed as a narrative anatomical review based on published anatomical, histological, radiological and clinical literature. The literature search emphasized human liver anatomy, functional segmentation, vascular and biliary anatomy, microscopic organization, anatomical variation and laboratory assessment of liver injury.

4.1 Inclusion Criteria

- Human anatomical, histological or radiological studies.
- Peer-reviewed reviews and clinical guidelines relevant to hepatic anatomy.
- Sources describing hepatic arterial, portal venous, hepatic venous or biliary anatomy.
- Authoritative clinical literature describing interpretation of liver chemistries.

4.2 Exclusion Criteria

Duplicate publications, non-human studies without direct relevance to human anatomy, and sources lacking adequate bibliographic information were excluded from the principal evidence base.

4.3 Data Organization

Information was organized into gross anatomy, surface anatomy, anatomical relations, segmental anatomy, vascular anatomy, biliary anatomy, microscopic anatomy, clinical significance and laboratory correlation.

5. Gross Anatomy of the Liver

The liver is located predominantly beneath the right dome of the diaphragm. Its superior surface follows the curvature of the diaphragm, while its inferior surface is related to several abdominal organs. The liver has a diaphragmatic surface and a visceral surface, with the porta hepatis located on the visceral aspect (van den Esschert et al., 2013).

No.	Feature	Description	Clinical relevance
1	Location	Mainly right hypochondrium and epigastrium	Physical examination and imaging
2	Position	Inferior to diaphragm	Thoracoabdominal imaging
3	Morphological lobes	Right and left; caudate and quadrate visible on visceral surface	Gross anatomy
4	Functional division	Right and left hemilivers	Surgical planning
5	Functional segments	Eight Couinaud	Lesion localization and

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		segments	resection
6	Blood supply	Portal vein and hepatic artery	Hepatic perfusion
7	Venous drainage	Right, middle and left hepatic veins	Drainage to IVC
8	Biliary drainage	Intrahepatic ducts to hepatic ducts	Obstructive disease
9	Capsule	Fibrous Glisson capsule	Structural support
10	Microscopic organization	Lobular/acinar architecture	Histopathology

6. Surfaces, Borders and Anatomical Relations

6.1 Diaphragmatic Surface

The diaphragmatic surface is convex and conforms to the inferior surface of the diaphragm. The falciform ligament provides an external landmark separating the morphological right and left lobes. The liver's superior and posterior relationships with the diaphragm are clinically relevant in imaging and in the interpretation of referred pain or adjacent thoracic findings.

6.2 Visceral Surface

The visceral surface is directed inferiorly and posteriorly. It bears impressions from neighboring organs and contains the gallbladder fossa, fissures associated with the ligaments, and the porta hepatis. The porta hepatis transmits major structures of the hepatic pedicle.

6.3 Major Anatomical Relations

No.	Structure	Relationship	Significance
1	Diaphragm	Superior and posterior	Separates liver from thoracic structures
2	Stomach	Inferior/left visceral relation	Visceral anatomy
3	Duodenum	Inferior relation	Hepatoduodenal region
4	Gallbladder	Inferior surface	Biliary anatomy
5	Right kidney	Posterior visceral relation	Renal impression
6	Right adrenal gland	Posterior relation	Surgical landmark
7	Inferior vena cava	Posterior relation	Receives hepatic veins
8	Colon	Inferior relation	Colic impression
9	Esophagus	Posterior/superior relation	Portosystemic relevance
10	Abdominal wall	Anterior relation via peritoneal reflections	Surface anatomy

7. Ligaments and Peritoneal Attachments

Important peritoneal reflections include the falciform, coronary and triangular ligaments and the lesser omentum. The ligamentum teres lies in the free inferior margin of the falciform ligament and represents the remnant of the fetal umbilical vein (van den Esschert et al., 2013).

8. Lobes and Functional Segmentation

The external anatomical division into right and left lobes does not fully represent the internal functional organization. Functional division is based on vascular territories. Cantlie's line runs approximately from the gallbladder fossa toward the inferior vena cava and corresponds broadly with the middle hepatic vein (Bismuth, 1982).

Segment	Description	Functional region	Key significance
I	Caudate lobe	Posterior/central	Distinct venous relationships
II	Left lateral superior	Left	Left lateral sector
III	Left lateral inferior	Left	Left lateral sector
IV	Left medial	Left	Between falciform plane and Cantlie line
V	Right anterior inferior	Right	Anterior inferior sector
VI	Right posterior inferior	Right	Posterior inferior sector
VII	Right posterior superior	Right	Posterior superior sector
VIII	Right anterior superior	Right	Anterior superior sector

The Couinaud classification divides the liver into eight functionally independent segments. Each segment contains a branch of the portal vein, hepatic artery and bile duct, while hepatic veins run between major functional territories (van den Esschert et al., 2013). Segmental anatomy is used in radiological reporting and anatomical liver resections.

9. Hepatic Blood Supply

The liver has a dual blood supply. The portal vein provides the majority of hepatic blood flow and carries nutrient-rich venous blood from the gastrointestinal tract and spleen. The hepatic artery supplies oxygenated arterial blood. This arrangement is central to the liver's metabolic and synthetic functions (Bloomston & Reddy, 2010).

10. Portal Vein and Hepatic Artery

The portal vein is formed principally by the union of the superior mesenteric and splenic veins. It enters the liver at the porta hepatis and divides into branches that distribute blood to the functional hepatic territories.

The hepatic artery generally arises through the celiac arterial system. However, replaced and accessory hepatic arteries are clinically important variants. A replaced right hepatic artery may arise from the superior mesenteric artery, while a replaced or accessory left hepatic artery may arise from the left gastric artery (Mathew & Venkatesh, 2018; Covey et al., 2002).

Vessel	Usual source	Main role	Clinical relevance
Portal vein	Splenic + superior mesenteric venous system	Nutrient-rich inflow	Portal hypertension/thrombosis
Hepatic artery	Celiac arterial system	Oxygenated inflow	Surgery/intervention
Right hepatic artery	Hepatic artery proper	Right liver supply	May have variant origin
Left hepatic artery	Hepatic artery proper	Left liver supply	May have variant origin
Hepatic veins	Intrahepatic venous channels	Venous outflow	Resection/transplantation

11. Hepatic Venous Drainage

The right, middle and left hepatic veins drain blood from the liver into the inferior vena cava. Their courses are important intersegmental landmarks and are particularly relevant to anatomical liver resection and transplantation. Detailed preoperative assessment of hepatic venous variants can reduce procedural complications (Mathew & Venkatesh, 2018).

12. Anatomical Variations

Hepatic arterial, portal venous and biliary variations are common enough to require careful assessment before hepatobiliary surgery. Imaging methods such as multiphasic CT and MR angiography can demonstrate clinically relevant vascular anatomy (Mathew & Venkatesh, 2018).

13. Biliary Anatomy

Hepatocytes secrete bile into canaliculi, which drain into progressively larger intrahepatic ducts. Right and left hepatic ducts form the common hepatic duct. The common hepatic duct joins the cystic duct to form the common bile duct.

No.	Structure	Function	Clinical relevance
1	Bile canaliculi	Receive bile from hepatocytes	Initial bile drainage
2	Intrahepatic ducts	Transport bile within liver	Cholestasis
3	Right hepatic duct	Drains right liver	Biliary surgery

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4	Left hepatic duct	Drains left liver	Biliary surgery
5	Common hepatic duct	Union of right and left ducts	Extrahepatic drainage
6	Cystic duct	Connects gallbladder to bile duct	Gallbladder disease
7	Common bile duct	Transports bile toward duodenum	Obstruction/ERCP

14. Lymphatic Drainage and Nerve Supply

The liver has a substantial lymphatic network. Lymphatic vessels accompany portal structures and drain toward hepatic and celiac lymphatic pathways. Neural innervation is derived from sympathetic and parasympathetic components through the hepatic plexus. These relationships are important in understanding visceral innervation and the spread of disease.

15. Microscopic Anatomy

The liver is composed predominantly of hepatocytes arranged in plates around vascular channels. The classical hepatic lobule is centered on a central vein, with portal tracts located at the periphery. A complementary functional model is the hepatic acinus, which divides parenchyma into zones according to the direction and composition of blood flow (Kmieć, 2001).

15.1 Hepatic Acinar Zones

Zone	Location	Relative oxygenation	Clinical relevance
Zone 1	Periportal	Highest	First exposed to portal/arterial nutrients
Zone 2	Intermediate	Moderate	Transitional region
Zone 3	Pericentral	Lowest	More vulnerable to hypoxic injury

16. Hepatic Sinusoids and Cellular Components

Hepatic sinusoids are specialized vascular channels between hepatocyte plates. They contain sinusoidal endothelial cells, Kupffer cells and hepatic stellate cells. The space of Disse lies between the sinusoidal endothelium and hepatocytes and supports exchange between blood and hepatic parenchyma (DeLeve, 2013; Kmieć, 2001).

Sinusoidal endothelial cells have fenestrations that facilitate exchange. Kupffer cells act as resident macrophages and contribute to phagocytosis and immune regulation. Hepatic stellate cells are located in the space of Disse and have important roles in extracellular matrix regulation and fibrosis (Wisse et al., 1996; Friedman, 2008).

17. Clinical Significance

17.1 Hepatitis

Hepatitis refers to inflammation of hepatic tissue. Viral hepatitis may be caused by hepatitis A, B, C, D or E viruses. Some infections resolve, while chronic hepatitis can progress to fibrosis, cirrhosis and hepatocellular carcinoma (World Health Organization, 2024).

17.2 Cirrhosis

Cirrhosis is characterized by chronic liver injury with fibrosis and distortion of normal hepatic architecture. Altered vascular resistance can contribute to portal hypertension. Architectural distortion also changes the normal relationships between portal inflow, sinusoidal channels and hepatic venous outflow.

17.3 Portal Hypertension

Portal hypertension may result in development of portosystemic collateral pathways. Clinically important collateral sites include gastroesophageal and paraumbilical regions. Understanding these vascular relationships is essential for interpreting complications of advanced chronic liver disease.

17.4 Liver Tumors

Segmental anatomy is important when describing focal hepatic lesions. Radiological localization by Couinaud segment can assist treatment planning, including resection or image-guided ablation.

18. Laboratory Correlation

For BMLT students, anatomical knowledge is particularly useful when linked to laboratory investigations. Commonly used liver-related tests include ALT, AST, alkaline phosphatase, bilirubin, albumin and PT/INR. The ACG guideline recommends interpreting these tests according to patterns of hepatocellular injury and cholestatic injury rather than treating every abnormal value as a direct measure of liver function (Kwo et al., 2017).

No.	Laboratory test	Primary significance	Possible interpretation
1	ALT	Hepatocellular injury	Often elevated in hepatocellular injury
2	AST	Hepatocellular/muscle injury	Interpret with clinical context
3	ALP	Cholestatic/biliary marker	May rise in cholestasis
4	GGT	Supports hepatobiliary source of ALP	Useful in cholestatic evaluation
5	Total bilirubin	Bilirubin metabolism/excretion	May rise in hepatocellular or cholestatic disease
6	Direct bilirubin	Conjugated bilirubin	May increase in cholestasis
7	Albumin	Synthetic function marker	May fall in chronic disease and non-hepatic states
8	PT/INR	Coagulation/synthetic assessment	Prolongation has multiple causes

19. Anatomy-Laboratory Correlation

The anatomical site and type of injury can influence laboratory patterns. Hepatocellular injury is commonly reflected by greater elevations of ALT and AST, whereas cholestatic injury is more strongly associated with alkaline phosphatase elevation. Bilirubin abnormalities may occur in both hepatocellular disease and cholestasis. Albumin and coagulation studies provide additional information but are not exclusively liver-specific (Kwo et al., 2017).

20. Importance in Radiology and Surgery

Modern hepatic surgery depends on accurate knowledge of internal liver anatomy. External morphology alone is insufficient for many procedures. CT and MRI can demonstrate vascular anatomy and segmental organization, allowing lesions to be localized according to Couinaud segments (Mathew & Venkatesh, 2018).

The Couinaud system is especially important for segmentectomy, hepatectomy, transplantation and image-guided procedures. Each segment has a portal pedicle, while hepatic veins define intersegmental planes. This organization permits surgeons to remove selected liver territories while preserving adequate residual parenchyma.

21. Discussion

The present review demonstrates that liver anatomy is best understood by integrating gross morphology, functional segmentation, vascular anatomy, biliary anatomy and microscopic organization. Traditional anatomical lobes remain useful for basic description, while functional segmentation provides a more clinically applicable framework.

The liver's dual blood supply is particularly important. Portal venous inflow provides nutrient-rich blood, while the hepatic artery supplies oxygenated blood. Blood passes through specialized sinusoids before entering hepatic veins. This arrangement connects hepatic anatomy directly with metabolic processing and the interpretation of disease-related laboratory changes.

Microscopic zonation explains why injury may not be distributed uniformly throughout hepatic tissue. Zone 3, for example, is relatively distant from incoming oxygenated blood and may be particularly vulnerable to hypoxic injury. Hepatic stellate cells, sinusoidal endothelial cells and Kupffer cells also contribute to the response to chronic injury and fibrosis (DeLeve, 2013; Friedman, 2008).

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22. Anatomical Variations and Their Clinical Importance

Anatomical variation is an important feature of the hepatobiliary system. Variations may involve the hepatic arteries, portal vein, hepatic veins and bile ducts. Such variations can influence the safety and technical approach of surgery and interventional radiology (Mathew & Venkatesh, 2018).

No.	Structure	Example of variation	Clinical importance
1	Right hepatic artery	Replaced origin from SMA	Important during pancreatic/hepatobiliary surgery
2	Left hepatic artery	Replaced/accessory origin from left gastric artery	Important during upper abdominal surgery
3	Portal vein	Variant branching pattern	Affects segmental resection
4	Hepatic veins	Accessory or variant veins	Important in transplantation
5	Bile ducts	Variant drainage patterns	Risk during biliary surgery
6	Segmental anatomy	Variable vascular territories	Important for lesion localization

23. Conclusion

The human liver is a complex organ characterized by a highly organized relationship between gross anatomy, vascular supply, biliary drainage and microscopic architecture. Although it is externally described as right and left morphological lobes, functional anatomy is more accurately represented by the Couinaud segmental system.

The liver receives dual blood supply from the portal vein and hepatic artery and drains through the hepatic veins into the inferior vena cava. Its biliary system is closely integrated with portal structures, while hepatocytes, sinusoidal endothelial cells, Kupffer cells and hepatic stellate cells form the microscopic environment responsible for many hepatic functions.

For BMLT students, understanding hepatic anatomy provides an essential foundation for interpreting liver-related biochemical and histopathological findings. Integration of anatomy with laboratory testing improves the conceptual understanding of hepatocellular injury, cholestasis, chronic liver disease and portal hypertension.

24. Recommendations

- BMLT curricula should emphasize clinically relevant liver anatomy.
- Couinaud segmental anatomy should be taught with anatomical diagrams and radiological images.
- Students should correlate gross anatomy with liver chemistry investigations.
- Anatomical variations should be included in advanced anatomy teaching.
- Histological study of hepatic lobules and sinusoids should accompany gross anatomy.
- Laboratory professionals should understand the anatomical basis of hepatocellular and cholestatic injury patterns.
- Imaging, laboratory and histopathological findings should be interpreted together when clinically appropriate.

25. Limitations

This was a narrative review rather than a primary cadaveric, imaging or patient-based study. Therefore, no original patient measurements or laboratory dataset were generated. The purpose was to synthesize established anatomical knowledge and demonstrate its clinical and laboratory relevance.

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