

Clinical and anatomical basis for the classification of the structural parts of liver

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Summary. Progress of diagnostic human's liver imaging (ultrasound, computerized tomography, magnetic nuclear resonance, etc.) stimulates development of modern liver surgery. Therefore, before and during the operation, surgeons and radiologists can determine the site and extent of liver damage, its relationship with blood vessels and ascertain which part of the liver should be resected. For this reason, physicians have to know anatomical and clinical peculiarities of the liver.

Naming of the parts of this complex inner organ is still highly varied: parts, halves, lobes, divisions, sectors, segments, and subsegments. Our understanding and explanation of liver composition are still defined differently among anatomists, surgeons, and radiologists, thus not only confusing less experienced specialists, but also increasing probability of mistakes. Such lack of communication aggravates the design of an operation plan and its documentation, which frequently may even result in undesirable legal consequences.

Unified terms among surgeons and radiologists are of importance not only in clinical settings of one country, but also on the international level (e.g. when comparing results of surgery). The smallest parts of the liver are defined using C. Couinaud's segmentation system, allowing for a precise identification of the site of liver damage, as well as to plan methods of segment resection that would protect the remaining hepatic tissue.

The classification that best meets the needs of surgeons and radiologists was the one proposed by H. Bismuth. We suggest that this classification should also be used by our physicians who are engaged in diagnostics and treatment of hepatic diseases in their practice. We also discuss other classifications used worldwide (those proposed by J. Healey and P. Schroy, N. Goldsmith and R. Woodburne, C. Couinaud, and H. Bismuth) and present recommendations of global societies of anatomists and surgeons.

Introduction

"A good knowledge of the anatomy is a prerequisite for modern surgery of the liver." – H. Bismuth (1).

Throughout the history of knowledge of the human body the liver has been regarded as a central vital organ. From ancient times till the end of the 18th century the main object of interest was its macro-anatomy. Galen (circa 130–200 BC) was one of the first who described the liver. He thought that the liver was five-lobed. Such opinion dominated until the 15th century. In 1654, F. Glisson (1597–1677) studied the liver (Fig. 1). He discussed topography of the intrahepatic vessels and surrounding connective tissue. Even today this is referred to as Glisson's capsule and the triad (portal vein, biliary duct and hepatic artery) is called portal pedicle or Glisson's pedicle. In 1784, A.

von Haller described the external liver surface.

Resection of the liver was started only at the beginning of the 18th century. In 1716, G. Berta performed the first partial liver excision. However, due to unstoppable bleeding and high mortality, surgeons feared to operate on this organ. Only in 1874, C. Langenbuch reported the first successful liver resection (2). Classical liver anatomy was not enough for surgeons; in order to achieve better results, physicians started to explore the internal liver structure.

In 1888, H. Rex studied the arrangement of intrahepatic vessels using corrosion studies on mammalian liver. He concluded that the right and left portal vein branches had a similar distribution and their secondary branches helped to form two separate lobes. In 1898, J. Cantlie found that the left and right lobes were of

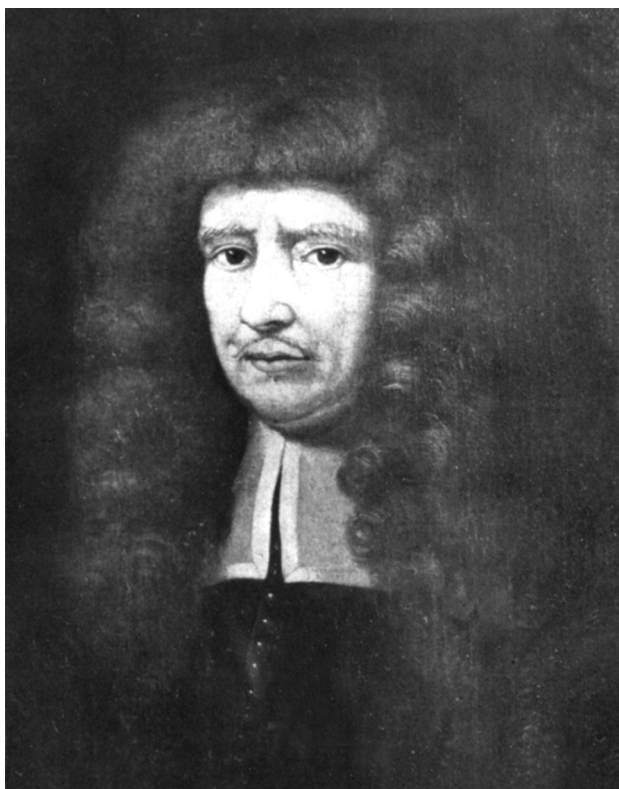


Fig. 1. Francis Glisson, 1597–1677

Portrait in the Royal College of Physicians, London.



Fig. 2. Claude Couinaud (modified from 2)

equal size, divided by a plane of symmetry passing through the gallbladder bed and a notch of the inferior vena cava. Therefore, this plane is often referred to as the Rex–Cantlie line or just Cantlie line. Subsequently, the authors suggested a different course of this plane, but the main liver division into two parts remained.

In 1951, C. Hjorstö studied placement of biliary ducts and hepatic artery branches. He described the pattern of segmental liver structure (3). John E. Healey and Paul C. Schroy (1953) continued similar studies and confirmed the results of C. Hjorstö. They divided the liver into five segments using secondary biliary duct and hepatic artery branching (4).

C. Couinaud (1954–1957) (Fig. 2) (5), N. A. Goldsmith and R. T. Woodburne (1957) (6) proposed liver classification based on the arrangement of portal and hepatic veins. N. A. Goldsmith and R. T. Woodburne supported division of the liver into four segments, each having two subsegments with second order of portal vein branches, while C. Couinaud suggested that the liver should be divided into eight segments, based on third order portal vein distribution.

The liver was the second visceral organ to be allo-transplanted in humans. In 1963, T. Starzl performed the first human liver transplantation in a patient with biliary atresia (2). In 1990, a transjugular intrahepatic portosystemic stent–shunt (TIPS) was first used in clinical practice (7). Until 2002, there were more than 300 liver transplantation centers in the world and over 90,000 liver transplantations were performed. In Lithuania liver transplantations were started in 2002.

Clinical anatomy of the liver

Liver anatomy can be described using two different aspects: morphological anatomy and functional anatomy and, now, the real anatomy, when ultrasound allows a precise intraoperative display in individual cases (1).

Traditionally, based on external appearance, four lobes are distinguished: right, left, quadrate, and caudate (3, 7–12) (Fig. 3). On the diaphragmatic surface, *ligamentum falciforme* divides the liver into the right and left anatomic lobes. On the visceral surface the *ligamentum venosum* and round ligament fissures provide a demarcation. The quadrate lobe is demarcated on the visceral surface by the gallbladder fossa, *porta hepatis*, and *ligamentum teres*. The caudate lobe is demarcated by the inferior vena cava groove, *porta hepatis*, and venous ligament fissure. The right portion of the caudate lobe lengthens into the right lobe by the caudate process, which forms the epiploic foramen superior boundary.

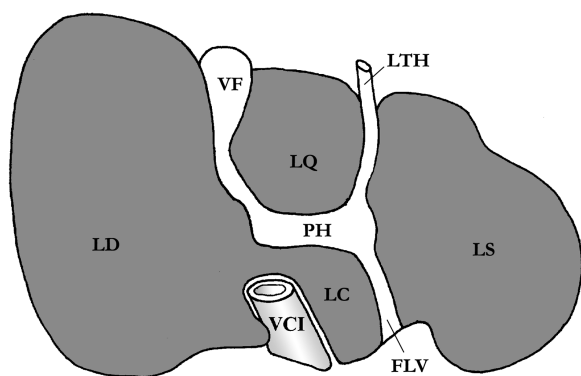


Fig. 3. Visceral surface of the liver

LD – right lobe; LS – left lobe; LQ – quadrate lobe; LC – caudate lobe; VF – gallbladder; LTH – *ligamentum teres*; PH – *porta hepatis*; FLV – *fissure of ligamentum venosum*; VCI – *cava vena inferior*.

The classical description of liver anatomy does not show internal features of vessels and biliary ducts branching, which are of obvious importance in hepatic surgery. For example, quadrate lobe belongs to the right lobe of the liver, but functionally it is part of left lobe. Caudate lobe is described as a separate part of the liver with an independent supply of blood, hepatic and biliary drainage (13). Besides, this classical description of liver anatomy, a second more recent description, involves the functional anatomy. This description, initiated by J. Cantlie in 1898, was followed by works of J. Healey and P. Schroy, N. Goldsmith and R. Woodburne, C. Couinaud, and H. Bismuth.

Classification of Healey and Schroy. John E. Healey and Paul C. Schroy (1953) were the first to divide the liver into functional parts (4). They suggested a classification based on biliary ducts and hepatic artery branching (Fig. 4 A, B). They divided the liver into left and right livers and five segments: medial, lateral, posterior, anterior and caudate. They divided the liver by principle plane or Cantlie's line. Cantlie's line goes from the left side of gallbladder fossa to the left side of the inferior vena cava.

The left liver is divided into medial and lateral segments by a plane defined by the falciform ligament on the diaphragmatic surface and round ligament on the visceral surface. The right liver consists of anterior and posterior segments, divided by the right fissure. Each segment is further divided into superior and inferior subsegments by a transverse line. Caudate lobe is divided into left and right subsegments by Cantlie's line. The largest part of the caudate lobe is in the medial segment, but the caudate process further continues into the right lobe. Quadrate lobe consists of the inferior part of the medial segment of the left liver (Table 1).

Classification of Goldsmith and Woodburne. N. Goldsmith and R. Woodburne (1957), unlike J. E. Healey and P. C. Schroy (1953), performed studies *in vivo* and suggested a classification based on portal and hepatic veins (6). They described right and left lobes and four segments: lateral, medial, anterior and posterior (Fig. 5). Each segment consists of two subsegments: superior and inferior.

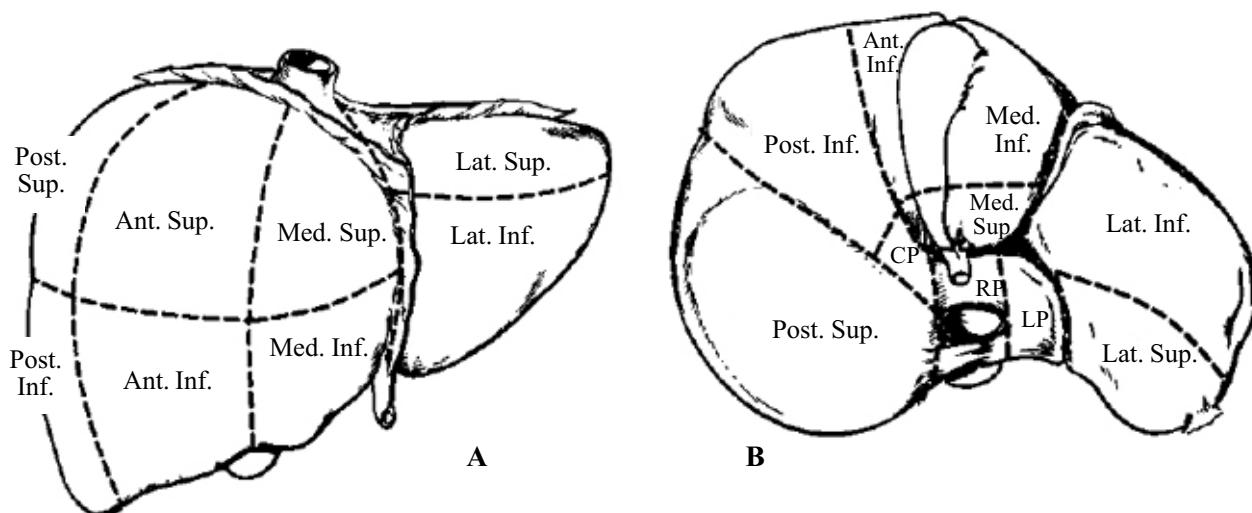


Fig. 4. Terminology of J. E. Healey and P. C. Schroy (1953)

A – diaphragmatic surface; B – visceral surface. Ant. Inf. – anterior inferior subsegment; Ant. Sup. – anterior superior subsegment; Lat. Inf. – lateral inferior subsegment; Lat. Sup. – lateral superior subsegment; Med. Inf. – medial inferior subsegment; Med. Sup. – medial superior subsegment; Post. Inf. – posterior inferior subsegment; Post. Sup. – posterior superior subsegment; CP – caudate process; LP – left subsegment; RP – right subsegment (modified from 2).

Table 1. The summary of the classifications of the liver

Part	Classification									
	J. E. Healey and P. C. Schroy (1953)		N. Goldsmith and R. Woodburne (1957)		C. Couinaud (1957)		H. Bismuth (1982)		FCAT (1998)	
	Segment	Subsegment	Segment	Subsegment	Sector	Segment	Sector	Segment	Sector	Segment
Dorsal	Caudate	Right	Caudate lobe		Caudate lobe	I	Caudate lobe	I	Caudate lobe	Posterior, I
		Left								
Left	Lateral	Superior	Lateral	Superior	Lateral	II	Posterior	II	Lateral	Posterior, II
		Inferior		Inferior		Paramedian		III		Anterior
	Medial	Superior	Medial	Superior		IV		IVa, IVb	Medial	
		Inferior		Inferior						
Right	Anterior	Inferior	Anterior	Inferior	Paramedian	V	Anteromedial	V	Medial	Anterior,V
		Superior		Superior				VIII		VIII
	Posterior	Inferior	Posterior	Inferior	Lateral	VI	Posterolateral	VI	Lateral	Anterior, VI
		Superior		Superior				VII		VII

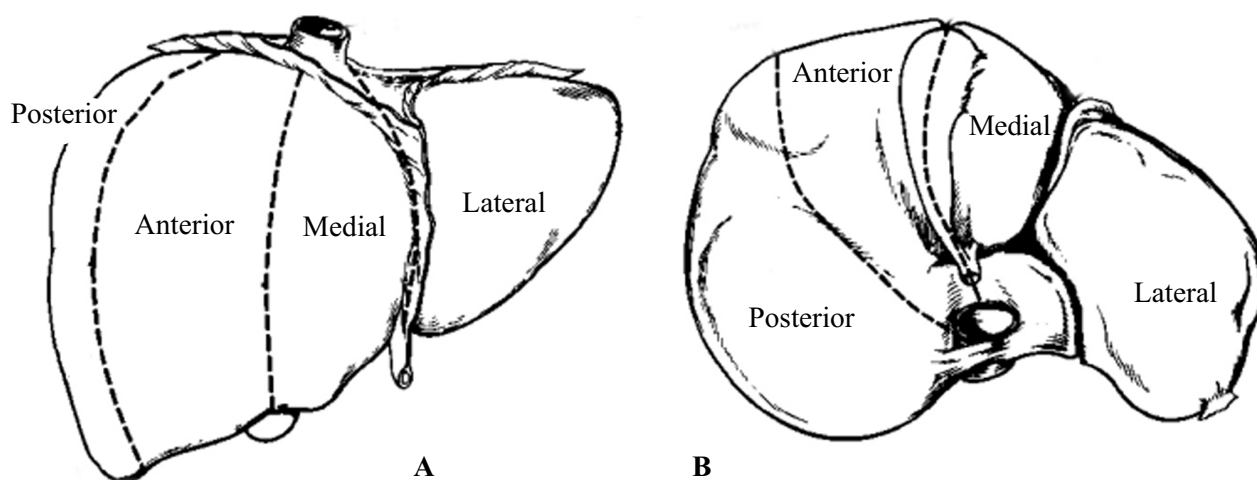
In this table we tried to compare five most popular classifications of the liver. The left and right parts of the liver are involved in all systems. For example, right anterior superior subsegment according to the classification of Healey and Schroy corresponds to segment VIII of Couinaud's classification; left lateral superior subsegment according to the classification of Goldsmith and Woodburne corresponds to segment III of left lateral sector of Bismuth's classification. Sometimes segment IV of Couinaud's classification called in Anglo-Saxon system as a quadrate lobe.

FCAT – Federative Committee on Anatomical Terminology.

The right and left lobes are divided by a vertical plane, passing from the gallbladder fossa inferiorly to the middle hepatic vein superiorly. This plane is oriented diagonally from the gallbladder fundus anteriorly to inferior vena cava posteriorly. The right lobe consists of anterior and posterior segments and the left lobe – of medial and lateral segments (Table 1). The caudate lobe derives its arterial blood supply

from both the right and left hepatic arteries and its venous blood drains directly into the inferior vena cava.

The anterior and posterior segments of right lobe are divided by a vertical plane through the hepatic vein. The medial and lateral segments of left lobe are divided by another vertical plane through a fissure from the round ligament inferiorly and left hepatic

**Fig. 5. Classification of N. Goldsmith and R. Woodburne**

A – diaphragmatic surface; B – visceral surface. Posterior – posterior segment; anterior – anterior segment; medial – medial segment; lateral – lateral segment; CL – caudate lobe (modified from 2).

vein superiorly. The main hepatic veins run between hepatic segments. The right hepatic vein lies between anterior and posterior segments of the right lobe, the middle hepatic vein lies between the medial and anterior segments, whereas the left hepatic lobe lies between medial and lateral segments of the left lobe. The portal triads stretch through the central portion of the hepatic segments.

However, no distinction is made in the classification of Goldsmith and Woodburne between superior and inferior subsegments within each major segment. Due to development of surgical techniques allowing resection of such subsegments, it is important to distinguish these hepatic subdivisions for more precise lesion localization.

Couinaud's classification. C. Couinaud (1957) (Fig. 2), similarly to N. Goldsmith and R. Woodburne, suggested dividing the liver based on portal and hepatic veins (5). However, his nomenclature differed – he proposed a division into eight segments by the third order branch of portal vein (Fig. 6).

From a personal collection of vasculobiliary casts and analysis of anatomical data the authors argue that portal and hepatic vein segmentation is preferred over arteriobiliary segmentation (classification of Healey and Schroy). C. Couinaud reported that portal vein branching appears first, while arteriobiliary branching follows the portal vein distribution. Also portal segmentation is much simpler than the arteriobiliary one because portal vein duplication of the first-order branches is found in 23.5% of livers, while arteriobiliary duplication of first-order branches is found in 50% (14).

C. Couinaud divided the liver into functional parts: left and right liver (in French – *gauche et droite foie*) by a main portal scissurae containing the middle hepatic vein and which is known as Cantlie's line. The surface markings of Cantlie's line are inexact but correspond to a plane passing from the middle of the gallbladder fossa anteriorly to the left side of the inferior vena cava posteriorly. Each right and left liver is subdivided by the left and right hepatic veins, lying in the left and right portal scissurae, respectively.

The right portal scissura (in French – *scissure portale droite*) is also poorly defined by surface features but passes at an angle of 40° with the horizontal from a point at the right gallbladder fossa border back to the confluence of right hepatic vein with the inferior vena cava posteriorly, forming a 75° angle with the horizontal. The right liver is hence divided into two sectors: right lateral sector (in French – *secteur lateral*), lying posterolateral and another right paramedian sector (in French – *secteur paramedian*), lying anteromedial. Each sector consists of two segments: the right lateral sector consists of segments VI and VII and right paramedian sector of segments V and VIII. The left portal scissura (in French – *scissure portale gauche*) or umbilical scissura lies posterior to the ligamentum teres within the liver parenchyma and corresponds to a plane passing from the confluence of the left hepatic vein with the inferior vena cava towards the most lateral left lobe tip, dividing it into left paramedian and left lateral sectors. The left paramedian sector consists of segments III and IV. The left lateral sector is comprised of only one segment II, which is the posterior part of the left lobe.

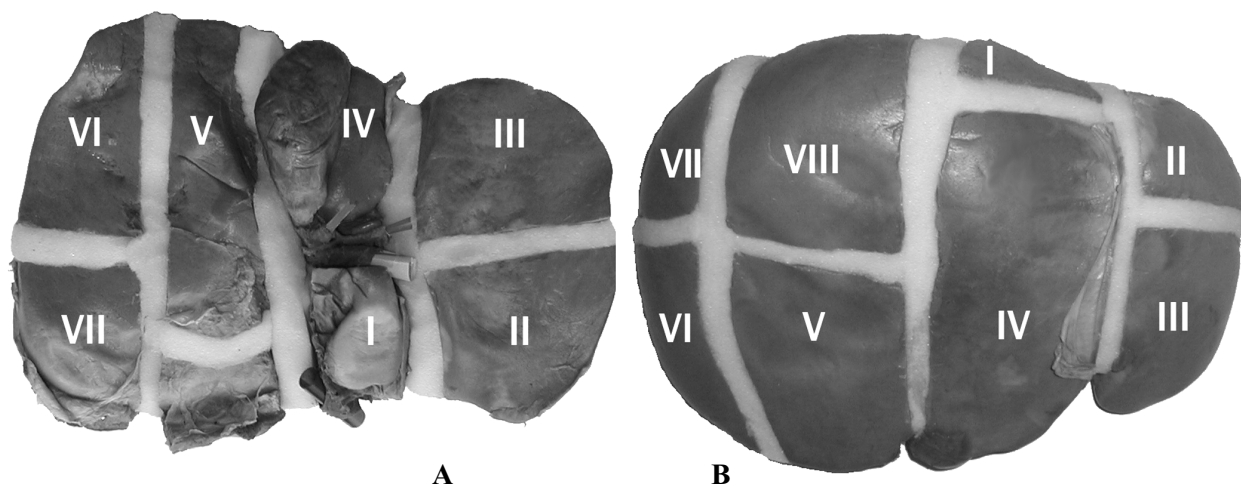


Fig. 6. C. Couinaud's classification (preparation of Institute of Anatomy of Kaunas University of Medicine)

A – visceral surface; B – diaphragmatic surface. Segment I – caudate lobe; segment II corresponds to the left lateral sector; segments III and IV – to the left paramedian sector; segments V and VIII – to the right paramedian; segments VI and VII – to the right lateral sector.

From a functional point of view, the caudate lobe (or segment I) must be considered an autonomous segment, for its vascularization independent of the portal division and three main hepatic veins. It receives vessels both from the left and right branches of the portal vein and hepatic artery: its hepatic veins are independent and drain directly into the inferior vena cava (15). However, in more recent studies C. Couinaud suggested that the caudate lobe could be divided into a left part or Spiegel's lobe or segment I and the right part or segment IX or paracaval portion (13).

C. Couinaud described eight segments: one for the caudate lobe (segment I), three on the left (segments II, III and IV) and four on the right (segments V, VI, VII and VIII). All segments are numbered clockwise on the diaphragmatic surface and counterclockwise on a visceral view (Fig. 6).

Bismuth's classification. H. Bismuth (15) brought together the Couinaud's cadaveric system *in situ* and the system of Goldsmith and Woodburn *in vivo* (1, 2, 15, 16). His classification became more popular among surgeons in Europe and America (17). He distinguished three planes (scissurae), hosting the hepatic veins and a transverse plane passing through the right and left portal branches (Fig. 7). Additionally, H. Bismuth described the caudate lobe as a separate segment I.

Three hepatic veins divided the liver into four

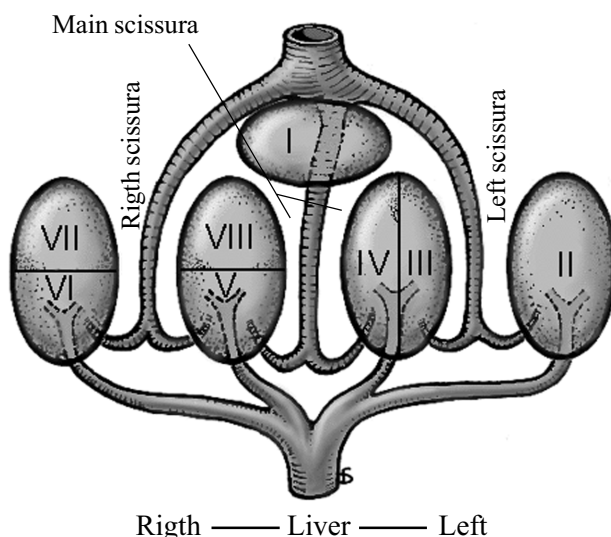


Fig. 7. H. Bismuth's functional classification of the liver

The liver is divided into four sectors by three portal scissurae. Each sector is supplied by a portal pedicle. The hepatic veins and portal pedicels are intertwined, as are the fingers of two hands (modified from 1).

sectors. The sectors are termed portal sectors as each is supplied by a portal pedicle. The separation line between sectors (which contain a hepatic vein) is called a portal scissura and scissurae containing the portal pedicles are called hepatic scissurae.

H. Bismuth suggests dividing the liver into left and right livers (hemilivers). A right portal scissura divides the right liver into two sectors. Each sector has two segments: right anteromedial sector – segment V anteriorly and segment VIII posteriorly; right posterolateral sector – segment VI anteriorly and VII posteriorly. Sectors of the right liver are called anterior and posterior in the classification of Goldsmith and Woodburne. This is simple and practical for imaging studies of the liver (ultrasound, computed tomography or magnetic nuclear resonance). When the liver is out of the body and is placed on the flat surface, for example during the preparation of an injection corrosion cast (Couinaud's classification), these sectors are called lateral and paramedian.

The left portal scissura divides the left liver into two sectors: anterior and posterior. Left anterior sector consists of two segments: segment IV, which is the anterior part of quadrate lobe and segment III, which is anterior part of anatomical left lobe. These two segments are separated by the left hepatic fissure or umbilical fissure. Left posterior sector consists of only one segment II. It is the posterior part of left lobe. This is an exception to this nomenclature (1, 15, 16).

FCAT liver terminology. Anatomical terminology has been a subject of considerable controversy and disagreement (18). The International Anatomical Nomenclature Committee (IANC) is responsible for anatomical terminology and has published the *Nomina Anatomica* in six editions. In 1989, the General Assembly of the International Federation of Associations of Anatomists (IFAA) founded the Federative Committee on Anatomical Terminology (FCAT) (18). FCAT worked for 9 years and in 1998 published *Terminologia Anatomica* (19). FCAT's aim was to unify terminology and make it an internationally accepted living language of anatomy (18, 20).

Also, year after year liver terminology changes. In 1965, the VIII Federative International Congress of Anatomy agreed on dividing liver as proposed by J. E. Healey and P. C. Schroy. In 1998, FCAT suggested using the liver Couinaud's classification (19).

FCAT describes the liver lobes, parts, sectors or divisions and segments (19). These are developmental, functional and surgically separable units of the liver and are based on distributions of the portal vein, hepatic arteries and biliary ducts. Segment I corresponds

Table 2. IHPBA Brisbane 2000 terminology of liver anatomy

Sector	Second-order division (Couinaud's segments)		Sector
	based on bile ducts and hepatic artery	based on portal vein	
Left lateral	II, III	II	Left lateral or left posterior
Left medial	IV	III, IV	Left medial or left paramedian
Right anterior	V, VIII		Right anterior or right paramedian
Right posterior	VI, VII		Right posterior or right lateral

We offer guidelines based on an anatomical view, where differences between biliary ducts, hepatic artery and portal vein branches in segments and sectors are amplified. Terminology Committee of the International Hepato-Pancreato-Biliary Association (IHPBA) suggests calling the *section* of liver based on bile ducts and hepatic artery and the *sector* based on portal vein.

to a proper caudate lobe or posterior part of the liver. The remainder segments II–VIII are numbered clockwise from the left, beginning with the left lateral posterior segment (segment II). The left lateral sector (II – left lateral posterior segment and III – left lateral anterior segment) is separated from the left medial sector (IV – left medial segment) and from the posterior part of the liver (segment I) by the umbilical fissure. The liver is divided into left and right parts by the main portal fissure or Cantlie's line running anteriorly from a line between the long axis of the gallbladder fossa and middle of the inferior vena cava as it lies in contact with the liver posteriorly and transects the quadrate lobe. The right medial sector (V – right medial anterior segment and VIII – right medial posterior segment) is separated from the right lateral sector (VI – right lateral anterior segment and VII – right lateral posterior segment) by the right portal fissure (Table 1).

IHPBA terminology. International Hepato-Pancreato-Biliary Association (IHPBA) (www.ihpba.org) promotes understanding of causes, investigation and treatment of liver, pancreas and biliary tree disorders. In 1998, the Terminology Committee of IHPBA has been established, which solves the problems of terminology of liver anatomy (Table 2) and resections (21). In 2000, during the recent World Congress of IHPBA in Brisbane, this Committee presented their recommendations (for example, right hemiliver = right hepatectomy, right anterior section = right anterior sectionectomy, segments 1–9 = segmentectomy).

Conclusions

Some main classifications of liver structure are outlined. Unfortunately, presently used classifications with different terminology raise many problems. Ana-

tomists (7, 22), surgeons (23–33) and radiologists (34–39) use different classifications of the liver.

Definition of segments according to Couinaud's nomenclature is different from that of Goldsmith and Woodburne. American and UK radiologists tend to use the classification of Goldsmith and Woodburne (or Anglo-Saxon classification). The concepts “segments” (second order branching of portal vein) and “subsegments” (third order branching of portal vein) are used in this classification. According to Couinaud's classification, which is most popular in Asia and Europe, “segment” is called “sector” and “subsegment” is called “segment”.

Segment III can be used as an example. It is a part of the left lateral sector according to the FCAT, while many authors (10, 14, 15, 24, 25, 27, 28, 36) describe it as a part of left medial (paramedian) sector. FCAT suggests using third order branches of portal vein according to Couinaud's classification and second order branches according to the classification of Healey and Schroy (Table 1).

FCAT's aim was to unify the terminology of anatomy and make it a living language. Future terminology versions should accommodate the needs of all who use it, both in clinical and scientific worlds (18–20).

A single, worldwide-accepted classification of the liver still does not exist. Clinicians use Couinaud's segmentation system for the smallest parts of the liver. It is important to localize small lesions before a segmentectomy with preservation of undamaged liver parenchyma, for example, in a setting of cirrhosis. However, some opine that Bismuth's classification offers a sufficiently detailed level for description of anatomy involved in modern hepatic surgery and radiology (17, 39).

Klinikiniai ir anatomiciniai kepenų struktūros dalių klasifikacijos pagrindai

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Raktažodžiai: kepenų anatomija, klasifikacija, kepenų segmentas.

Santrauka. Tobulėjant gyvo žmogaus kepenų vidinės sandaros pažinimo technologijoms (ultragarsas, kompiuterinė tomografija, magnetinis branduolių rezonansas ir kt.), plėtojama moderni kepenų chirurgija. Prieš operaciją ar jos metu chirurgai ir radiologai gali nustatyti kepenų pažeidimo vietą, dydį, santykį su kraujagyslėmis ir numatyti, kokią kepenų dalį reikės pašalinti. Todėl gydytojai turi žinoti anatomines ir klinikines kepenų struktūros ypatybes. Šio vidaus organo sudėtingos sandaros dalys vis dar įvairiai vadinamos: dalys, pusės, skiltys, skyriai, sektoriai, segmentai, subsegmentai. Anatomen, chirurgai ir radiologai iki šiol skirtingai supranta ir aiškina kepenų dalių sandarą, taip neretai klaidindami ne tik mažiau patyrusių specialistą, bet klysdami ir patys. Toks nesusikalbėjimas apsunkina operacijos plano parengimą, operacijos dokumentavimą, o tai neretai gali turėti ir nepageidaujamų juridinių pasekmių. Vienodas chirurgų ir radiologų kepenų sandaros supratimas svarbus ne tik vienos šalies klinikose, bet ir tarptautiniu mastu, pavyzdžiui, lyginant operacijų rezultatus. Mažiausioms kepenų dalims apibūdinti vartojama C. Couinaud segmentų sistema, kurią naudojant galima tiksliai nustatyti pažeidimų vietą kepenyse, numatyti kepenų audinį saugojantį segmento pašalinimo būdą. Geriausiai chirurgų ir radiologų poreikius atitinka H. Bismuth klasifikacija. Šia klasifikacija mes siūlome naudotis ir mūsų gydytojams, savo praktikoje susiduriantiems su kepenų ligų diagnostika bei gydymu. Straipsnyje aptariamos ir kitos plačiausiai pasaulyje žinomos kepenų struktūros dalių klasifikacijos (J. Healey ir P. Schroy, N. Goldsmith ir R. Woodburne, C. Couinaud, H. Bismuth) ir pateikiamos pasaulio anatomų ir chirurgų draugijų rekomendacijos.

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