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Variations in portal and hepatic vein branching of the liver

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Abstract

The present study provided an overview of the Couinaud's segmentation system of the portal and hepatic veins, the controversies surrounding it and the typical variations the anatomy of the portal and hepatic veins. Even with the advent of three-dimensional CT (3DCT), it goes without saying that a basic knowledge of Couinaud's classification is essential. Future advances in technology are expected to enable the superimposition of preoperative 3D images and intraoperative real-time ultrasound images. Looking forward, a secure knowledge of the fundamentals of liver anatomy is necessary for patient safety during liver transplantation or R0 resection, in which the tumour is not exposed. (Kimura in Kan Tan Sui Gazo 13: 355-363, 2011)

Keywords: Couinaud's classification, Healey & Schroy classification, Japanese General rules for the Clinical and Pathological study of Primary Liver Cancer, multidetector-row CT, right-sided round ligament of liver

Introduction

Astounding progress has been made in recent years in diagnostic imaging techniques and analysis software, which has enabled the anatomical examination of the liver in vivo. Because of these advances, medical practitioners can study the vascular variations in each individual patient before surgery.

The classification of portal vein anatomy is the basis for the surgical anatomy of hepatic segments and subsegments. The main classification system in Europe is the Couinaud' s classification [(1)], whereas the Healey & Schroy classification [(2)] has been widely used in the United States. In general, a blend of both systems is used in Japan. These globally widespread classification systems are essential for understanding the basic hepatic anatomy of a patient before surgery. The anatomy of the hepatic veins, which form an outer frame of the hepatic segments, is also an important.

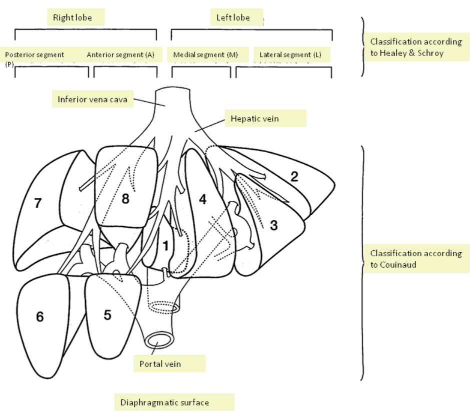
In cases of carcinoma of the liver, gall bladder, and pancreas, it is necessary to achieve curative (R0) resection by surgery [(3)]. However, failure to pay attention to portal vein/hepatic artery and hepatic vein variations during liver resection can lead to inadvertent resection of structures and the risk of uncontrollable haemorrhage. In order to avoid this, it is important to understand the anatomical variations in each patient before performing surgery [(4)].

The advent of multidetector-row CT (MDCT) has now made it possible to obtain data from ≤1-mm slices of organs or tissues, and the use of isotropic voxel data has enabled the reconstruction of stereoscopic 3-dimensional (3D) images. 3D images are fast becoming essential information for preoperative and intraoperative decision making for ensuring safe and precise surgery.

In this study, we have attempted to combine the 3D imaging information with existing anatomical knowledge to illustrate the anatomy and variations of the intrahepatic portal and hepatic veins, as indicators of the hepatic segments and subsegments.

1. Classification of hepatic segments and subsegments in the Japanese General Rules for the Clinical and Pathological Study of Primary Liver Cancer

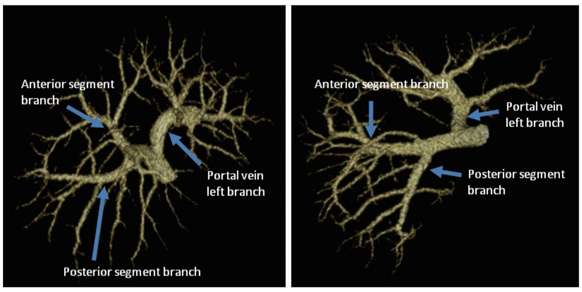
In Japanese General Rules for the Clinical and Pathological Study of Primary Liver Cancer (Japanese General Rules) [5] (Figure 1), the classification of hepatic segments is according to the Healey & Schroy concept of 'lobes' and 'segments', describing right and left lobes, and anterior (A), posterior (P), medial (M) and lateral (L) segments. When further classification into 'subsegments' is required, Couinaud's segmentation system is used. Thus, Japanese General Rules have used a combined classification of the Healy & Schroy classification, which is traditionally used in the United States and Japan, and Couinaud's classification, which is traditionally used in Europe. Consequently, the wording for the lateral and medial segments from the Healey & Schroy classification [2] is widely used in Japan.



(Figure 1) Chart of the Japanese General Rules for the Clinical and Pathological Study of Primary Liver Cancer (cited from reference5)

The concept of hepatic segmentation uses the Healey & Schroy classification terms of 'lobes' and 'segments', dividing the liver into right and left lobes as well as anterior (A), posterior (P), medial (M) and lateral segments. When further classification of each segment into 'subsegments' is required, Couinaud's segmentation system is used. Japanese General Rules use a combination of the Healey & Schroy classification, which is traditionally used primarily in the United States, and the Couinaud's segmentation system, which is traditionally used primarily in Europe.

In the Couinaud's classification, the left liver is divided by the round ligament of liver and the umbilical portion (UP) of the portal vein into the lateral and medial segments, as in the Healey & Schroy classification, with S2 and S3 treated as the lateral segments. However, this division is problematic because it does not correspond to the second-order branching of the portal vein. Although the anterior and posterior segmental branches of the portal vein are thought to bifurcate in the craniocaudal direction, the configuration of the third-order branching may not necessarily be in the craniocaudal direction [6,7]. In addition, there is also the view that the posterior segment of the right liver corresponds to S2 of the left liver, because of the similarities in the second-order branching of the portal vein, and that the two segments should therefore be considered as a single segment [6] (Figure 2). Furthermore, Cho et al. [6] suggested the division of the anterior segment into anterodorsal and anteroventral segments because the third-order branching of the portal vein in the



(Figure 2) 3DCT of the posterior segmental branch of the portal vein (case study)

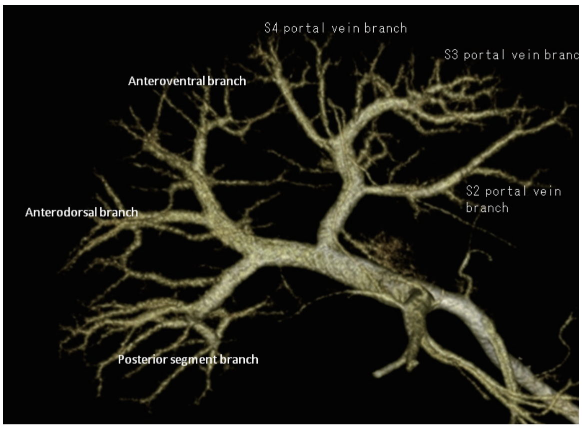
Third-order branching of the posterior segmental branch is not in the craniocaudal direction but is transverse with an arch shape, and the branches follow the slender portal vein branches in the craniocaudal direction. Determining the border between S6 and S7 is difficult in such cases.

right liver corresponds to that in the left liver. We have visualized the portal vein branching in 3D viewed from the caudal end in Figure 3 on the basis of this model. The image shows bilateral symmetry (Figure 3).

The terminology used in this paper is in accordance with that in the Japanese General Rules. In other words, the subdivisions of the liver will be referred to as right and left lobes, anterior (A), posterior (P), medial (M) and lateral (L) segments, and subsegments S1-S8. Furthermore, the portal vein branches that correspond to each subsegment will be referred to as S1-S8 portal vein branches.

2. Branching configuration of the portal vein

The variations in portal vein anatomy are few compared to those in the anatomy of bile ducts and hepatic arteries. In addition, the subsegments of the liver are primarily determined on the basis of the branching of the portal vein and therefore are an important for planning and performing liver resection. In particular, portal vein anatomy is extremely important during systematic subsegmentectomy for treating hepatocellular cancer.



(Figure 3) 3DCT image of the portal vein viewed from the caudal side (case study)
Cho et al. (6) divided the anterior segment into anterodorsal and anteroventral segments because the third-order branching of the portal vein in the right liver corresponds to that in the left liver. We have depicted the portal vein branching viewed in 3D from the caudal end based on this model. The image shows bilateral symmetry.

Couinaud [1] divided the areas supplied by the left and right portal vein branches into the hemilivers, i.e., the right and left liver. Similar to the division of the first-order left portal branch into the S2 portal branch and UP (second-order branch), the left liver is divided into the left lateral sector (S2) and the left paramedian sector (S3+S4). The left paramedian sector divides into the S3 and S4 portal branches (third-order branches) and is classified into the three segments of S2, S3 and S4. Caution must be exercised as the left/right liver and left/right lobe (with round ligament of liver as the border between the lobes) areas are different in the Couinaud classification, which differs from the concept widely used in Japan. In the Healey & Schroy [2] classification, the S2 and S3 are defined as the left lateral segment and the S4 as the left medial segment. In the Couinaud classification, the left hepatic vein passes between the left paramedian sector and the lateral segment, whereas in the Healey & Schroy definition, the left hepatic vein passes between S2 and S3 of the left lateral segment.

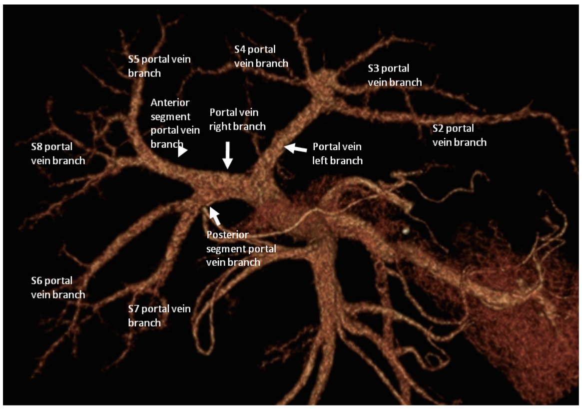
Nonetheless, the two systems are in alignment with regard to the anatomy of the right liver. The Healey & Schroy classification divides the right lobe into right posterior and right anterior segments, and further subclassification is the same as the Couinaud classification. Because the first-order right portal branch divides into the right lateral sector branch and the right paramedian sector branch (second order), the right liver is divided into the right lateral sector (S6+S7) and the right paramedian sector (S5+S8). With the right portal branch running transversely as the border, the right lateral sector is further divided craniocaudally into the caudal right lateral sector (S6) and cranial right lateral sector (S7). The right paramedian sector is divided into the caudal right paramedian sector (S5) and the cranial right paramedian sector (S8). Consequently, these four sectors are classified as segments (Figure 4). Furthermore, the segment receiving branches from the main portal vein or the first-order right and left portal branches is classified as S1, and are divided into a total of eight hepatic segments. Some reports also claim the superiority of an embryological classification of the anterior segment into ventral and dorsal subsegments [6].

3. Branching configuration of the hepatic vein

Because the hepatic vein is a reference for the hepatic segments, an understanding of hepatic vein anatomy is essential for liver surgeons. Reconstruction of the hepatic vein during liver transplant is necessary to enable venous drainage of the graft and prevent postoperative graft failure. This paper describes the process of reconstruction based primarily on Couinaud's surgical anatomy [1] and reports by Nakamura et al [7].

1) Right hepatic vein

Couinaud's surgical anatomy [1] describes the right hepatic vein drainage area as having numerous variations. In 27 of 102 cases, the right hepatic vein was small, and drainage was via the inferior right hepatic vein (IRHV) or the middle hepatic vein. In 36 cases, drainage was via the branch from S8 (V8).



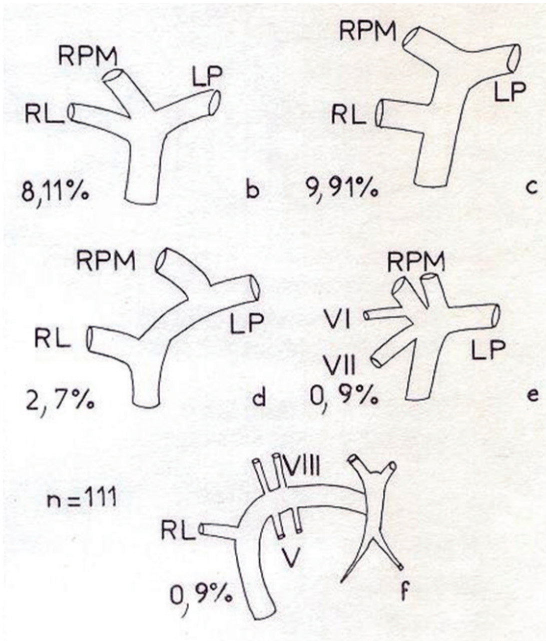
(Figure 4) 3DCT image of the portal vein viewed from slightly the caudal side

The left and right portal veins divide at the first-order branching. The left portal branch diverges with the S2 portal branch at the second-order branching and the S3 and S4 portal vein branches divide at the third-order branching. The right portal branch divides into the anterior portal vein branch and the posterior portal vein branch at the second-order branching; then, at the third-order branching, the former branch divides into S5 and S6 portal branches whereas the latter divides into and S7 and S8 portal branches.

Nakamura et al. [7] described that the right hepatic vein branches 1-1.5 cm caudal to the diaphragm on the right side of the inferior vena cava. They have conducted a range of analyses of the branching configuration by examining the combination of branching positions of the superior right hepatic vein that drains S7 and the hepatic vein that drains S8.

2) Middle/left hepatic vein

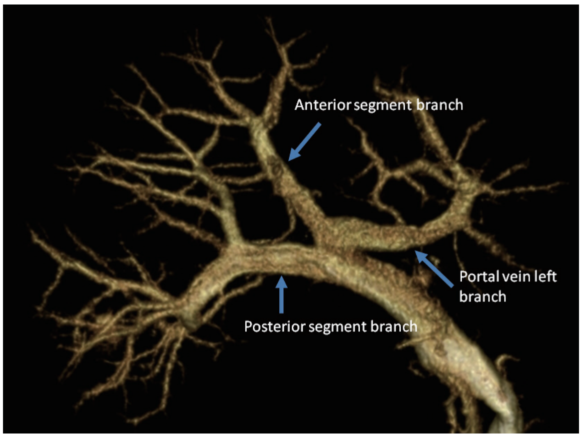
According to Nakamura et al. [7], the middle and left hepatic veins formed a common vessel of 0.2-1.7cm in length in 84% of a total of 83 cases they analysed. The middle hepatic vein essentially drains S5, S8 and S4. However, it is thought that a portion of the caudate lobe vein and the S6 vein also flow into the middle hepatic vein in some cases[8]. The left hepatic vein drains S2 and S3.



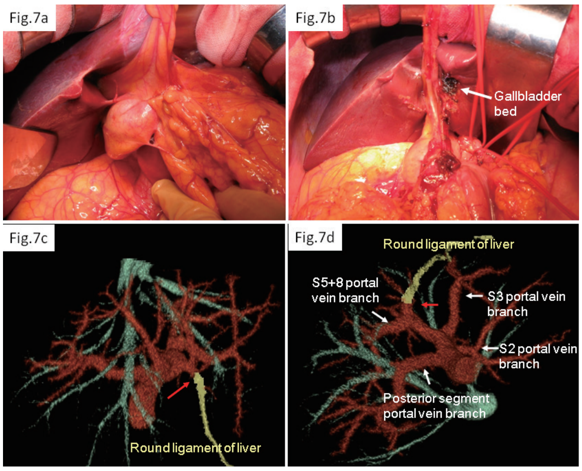
(Figure 5) Portal vein variation (cited from reference 1)

a. Normal anatomy, no notes; b. portal vein trifurcation; c. independent bifurcation of the right lateral portal vein branch; d. right anterior segment branch originates from the left portal vein; e. overlapping type of right anterior segment branch and right posterior segment branch; f. portal vein right and left forks not formed. LP: left portal vein, RPM: right paramedian sector branch, RL: right lateral portal vein branch.

Large vein tributaries of the hepatic vein, other than the middle/left hepatic vein, include the superficial vein that drains S2 and the umbilical fissural vein [1], which flows between the left and middle hepatic veins. According to Couinaud's Surgical Anatomy, the superficial vein runs along the posterior margin of the lateral segment and was present in 67% of a total of 97 cases. The fissural vein runs along the cranial side of the portal vein umbilical portion and was present in 51.5% of a total of 97 cases(1). On examination by CT before liver transplantation, Sano et al. [9] have reported that an umbilical fissural vein was observed in all cases and its root drained into the left hepatic vein in 81% of a total of 21 cases.



(Figure 6) 3DCT of posterior segment independent divergence type (case study)
Segmental branches divide independently, and then divided into the left portal branch and the anterior segment portal branch.

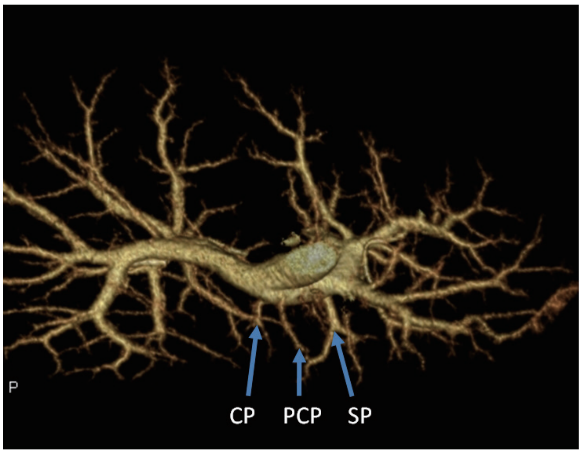


(Figure 7) Right-sided round ligament of liver from a case study
a, b: Laparotomy field showing the round ligament of liver to the right of the gallbladder bed (a: before cholecystectomy, b: after cholecystectomy).
c, d: On 3DCT, the round ligament of liver (yellow) is not connected to the umbilical portion but to the right portal vein branch (red arrow) (c: image viewed from the right side, d: image viewed from the caudal side).

3) Short hepatic veins

The veins, other than the right, middle and left hepatic veins, which drain directly into the inferior vena cava are called short hepatic veins. The inferior right hepatic vein (IRHV) that drains S6 and S7 [10] and the middle right hepatic vein (MRHV) are typical examples (Figure 9). In Couinaud's Surgical Anatomy [1], one or two IRHV were observed in 68.6% of a total of 102 cases. One or two MRHV were observed in 33.3% of the 102 cases. Makuuchi et al. [10] reported a new hepatic resection method in which the preservation of region drained by IRHV in an S7 resection combined with the resection RHV-drained region enabled the preservation of S6.

There are a number of reports demonstrating the distribution of short hepatic vein openings in the



(Figure 8) 3DCT of caudate lobe portal branch (case study)
In this case, three caudate lobe portal branches can be confirmed dividing in a posterior direction from the portal vein stem to the left portal vein. The three branches were draining into the Spiegel lobe (SP), the paracaval portion (PCP) and the caudate process (CP).

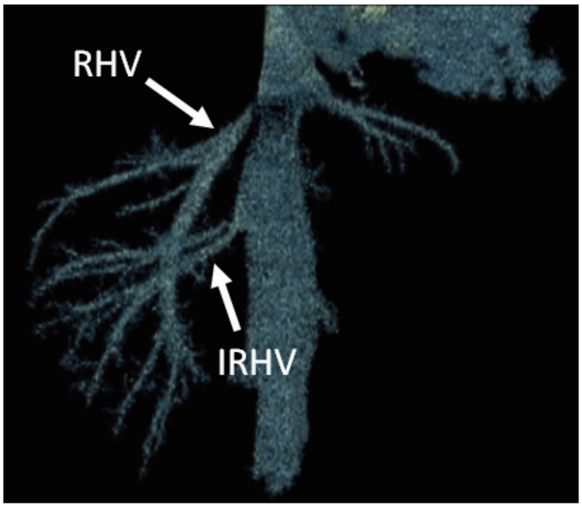
hepatic portion of the inferior vena cava. During an examination of short hepatic veins opening into the inferior vena cava, 1291 short hepatic veins were observed in 176 livers [11]. The breakdown of these was as follows: inflow vein from the caudate lobe (1124 veins), IRHV (104 veins) and MRHV (63 veins). Looking at these inflow veins originating from the caudate lobe, short hepatic veins of ≥1 mm draining from the paracaval portion were designated as S9 veins, while short hepatic veins of ≥3 mm draining from the Spiegel lobe were designated as caudate veins. There were 279 caudate veins and 845 S9 veins in the 176 livers (Figure 10).

Apart from draining into the inferior vena cava, the superior part of the Spiegel lobe can also drain to the middle hepatic vein [12].

Nakamura et al. [7] classify the hepatic veins in the right liver into three types according to the combination of right, middle and short hepatic veins. According to this classification, they reported that 38.6% of the 102 cases either had no IRHV or had extremely narrow one.

4) Hepatic portion of the inferior vena cava

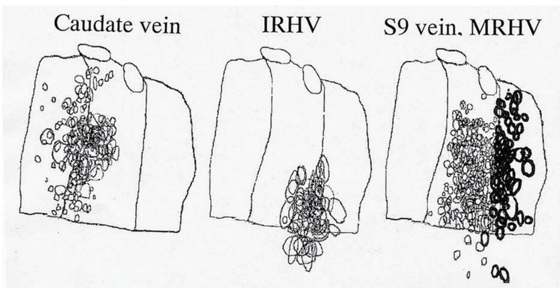
Nakamura et al. [7] reported the length of the posterior vena cava in the posterior liver to be 69 ± 11mm. Furthermore, they stated that the right suprarenal vein drains into the right wall of the inferior vena cava 14 ± 11 mm cranial to the IRHV and that in 24.4% of 83 cases, after draining into a short hepatic vein, the right suprarenal vein merged with the inferior vena cava. Great care should be taken when resection of the right liver in these cases, as they are prone to venous injury.



(Figure 9) 3DCT of hepatic vein (case study)
Two IRHV can be confirmed. No thick MRHV is present.

Summary

The present study provided an overview of the Couinaud's segmentation system of the portal and hepatic veins, the controversies surrounding it and the typical variations the anatomy of the portal and hepatic veins. Even with the advent of three-dimensional CT (3DCT), it goes without saying that a basic knowledge of Couinaud's classification is essential. Future advances in technology are expected to enable the superimposition of preoperative 3D images and intraoperative real-time ultrasound images. Looking forward, a secure knowledge of the fundamentals of liver anatomy is necessary for patient safety during liver transplantation or R0 resection, in which the tumour is not exposed. [13]



(Figure 10) Distribution of short hepatic veins (cited from reference 11)
The longitudinal incision was made on the inferior vena cava from the posterior side and the short hepatic vein openings were traced. The caudate veins were at the central part of the hepatic portion of the inferior vena cava and tended to have openings towards the inner left side of the inferior vena cava. IRHV had openings to the caudal side or the central part of the inferior vena cava. MRHV had openings between the level of the right hepatic vein and IRHV, but further towards the right (lateral) side than IRHV. The distribution of S9 veins did not show any particular trends.

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