Identification of the anterior sectoral trunk with particular reference to the hepatic hilar plate and its clinical importance

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Short title: Anterior sectoral trunk and portal vein ramification
**Key words:** liver, portal vein, anterior sector, hilar plate, right-sided round ligament

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None
ABSTRACT

Background. At the hilum of the liver, there is a structure called hilar plate, which is of great surgical importance because all variations in the bile ducts and blood vessels occur within this region. The Rex-Cantlie line does not always pass the point of portal bifurcation. Classifying portal vein (PV) variations based on the shape and origin of anterior sectoral trunk (AST) within the hepatic plate system will be of higher anatomical and surgical value than the conventional method based on PV ramification.

Methods. We investigated PV variations in the hilar plate in terms of combinations of four hepatic sectoral trunks rather than successive ramification of the PV. The combination patterns of each sectoral trunk were analyzed using data from adult cadaver liver dissection (n = 64) and multi-detector computed tomography (n = 216) of human livers.

Results. The AST root position on the hilar plate is varying in contrast to the other sectoral trunks, which are relatively constant in their root position. Three types of PV variations were identified based on the AST root position. In addition, four similar but different shapes (I, Y, V, and U) of AST were identified.

Conclusion. Not only the root position in the hepatic hilar plate but also the shape of AST can be considered as the major determinants of PV variations.
Abbreviations

AS, anterior sector, anterior section; AST, anterior sectoral trunk; LPS, left paramedian sector; LS, lateral sector; LST, lateral sectoral trunk; MDCT, multi-detector computed tomography; MIP, maximum intensity projection; PS, posterior sector; PST, posterior sectoral trunk; PV, portal vein; RPS, right paramedian sector; RSRL, right-sided round ligament; UP, umbilical portion, a short segment of PV where the round ligament is attached; UT, umbilical trunk; UV umbilical vein
There are four anatomical sections or sectors of the liver according to the International Hepato-Pancreato-Biliary Association Brisbane 2000 Terminology.¹ This most widely accepted liver anatomy nomenclature is based on Couinaud’s² description of four sectors and eight anatomic segments. The terms sections and sectors are neither synonymous nor interchangeable in the left liver, but they become synonymous in the right liver. The liver is largely divided into the right and left hemi-livers by the Rex-Cantlie line, an imaginary plane connecting the gallbladder bed to the inferior vena cava, and the middle hepatic vein lies in this principal plane. The right hemi-liver is further divided into the anterior sector (AS) and posterior sector (PS) by the right hepatic vein, and the left hemi-liver into the left paramedian sector (LPS) and lateral sector (LS) by the left hepatic vein. According to Couinaud,³ the hemi-livers, sectors, and segments are supplied by the first-order, second-order, and third-order portal branches, respectively. In practice, however, the orders of the branches are not always easy to identify because the portal vein (PV) does not follow a hierarchical binary ramification.

The different vascular and parenchymal compartments of the adult liver have different embryological origins. All the intrahepatic PVs are differentiated from the sinusoids of the septum transversum. The extrahepatic PVs and two lateral sectors are derived from the omphalomesenteric (vitelline) veins, whereas the right paramedian sector (RPS) and LPS from the ventral sector along the gallbladder. The umbilical vein enters the LPS and supplies two segments (left medial and left lateral). During the period of developmental chaos, blood vessels supplying the liver (e.g., vitelline and umbilical veins) are selected from paired sets of their veins. While every sector and its trunk are uniquely
positioned within the liver, the root position of the anterior sectoral trunk (AST) on the hilar plate varies. Therefore, when reading multi-detector computed tomography (MDCT) images, a designated sector should be examined first, followed by its vascular connection.

According to Couinaud’s concept,\(^3\) types 1, 2, and 3 primary PV variations correspond to ASTs stemming from the posterior sectoral trunk (PST) (Type 1), from the confluence of the posterior and lateral sectoral trunks (Type 2), and from the lateral sectoral trunk (LST) (Type 3) (Fig 1). In other words, the AST root position is unstable while the other sectoral trunks are stable in their root position. However, Ryu & Cho\(^4\) suggested that the types 1, 2 and 3 variations of primary PV ramification could be determined by the position of the left PV located between the right and left hemi-livers. In the early stage of embryo, the right and left hemi-livers are supplied dominantly by the PV (vitelline vein) and umbilical vein (UV), respectively, and these two hemi-livers are connected by the left PV. However, Ryu & Cho’s concept\(^4\) is also not applicable to some types of PV variations.

It is possible to suppose that the PV variations are determined by the combination of the four sectoral trunks rather than by a successive hierarchical ramification of the PV. In this context, the direct connection of the first short segments of the PST and LST could be considered as a platform for the AST root. On this platform where the PV variations occur, there is a thick layer of fibrous tissue called hilar plate. The present study examined livers from cadavers and radiological liver images in order to explore a new method of classifying PV variations.
METHODS

This study of PV variations involved three major procedures: dissection of cadaver livers (n = 64), analysis of MDCT images of human livers (n = 216), and literature survey to identify published PV variations. PV variations were assessed within the portal platform by considering four combined hepatic sectoral trunks rather than successive ramification of the PV.

Cadaver livers were recovered from adult human bodies donated to the Chonbuk National University Medical School. Each donation was reviewed by the Medical Ethics Committee of the University, and its use for the present study was approved by the Internal Review Board at the Medical School. The cadaver livers were preserved in 10% formalin solution. Dissection commenced from the perihilar area of the liver by following the ramifications of the right and left portal pedicles as far as they were traceable.

MDCT liver images of 200 gastric cancer patients (age = 30 to 65) without liver lesions and 16 potential donors (age = 19 to 39) for living donor liver transplantation were examined. The MDCT liver images were captured every 1 mm using Sensation 16 (Siemens Medical Solutions, Forchheim, Germany). The volume-rendered images and maximum intensity projection (MIP) images of PV were reconstructed by following the post-processing procedure of Rapidia (INFINITT, Seoul, Republic of Korea).

A comprehensive literature review was conducted to survey PV variations and AST shapes. PV ramification patterns were then analyzed in terms of AST migration within the hepatic plate rather than binary ramification of the main PV. One radiologist and two surgeons examined the MDCT liver images
and cadaver specimens and reached consensus on the classifications of PV variation types and AST shapes.
RESULTS

**AST origin points within the portal platform**

The liver dissection study identified three known types of PV variation in terms of the sites of AST origin from the hilar plate. The AST always ran 1-2 cm deep in the narrow space between Rouviere’s groove and the thin posterior part of the cystic plate. However, the space was somewhat wider for type 3 PV variation. The hilar plate was considered in the present study as the thick layer of connective tissue on the first short segments of the two lateral trunks (PST and LST). The connection of the two lateral trunks provides the portal platform from where the two paramedian trunks (RPS and LPS) stem. The three common patterns of PV variation can be explained by the variations of the AST root on the portal platform. In dissected specimens, the AST was found stemming from the PST in most cases (87.5%), from the union of the PST and LST (7.8%), and from the LST (4.7%). (Table 1). We excluded the MDCT image data of four livers because the point which the AST stemmed from was not clear. While the dissected specimens showed less than 5% of ASTs stemmed from the LST, the MDCT liver image analysis indicated that about 11% of ASTs stemmed from the LST.

**Right-sided round ligament (RSRL) anomaly**

The MDCT liver image analysis revealed two RSRL cases (Fig 2). The locations of the gallbladders in these two anomalies were left-sided (left side of the round ligament). These anomalies revealed no normal looking umbilical portion of PV system as well as LPS. These were considered as the counterpart...
of type 3 PV variation.

**Analysis of the AST according to shape and ramification pattern**

The dissection study showed that each sector had its own specific position within the liver and its unique form of ramification of Glisson’s sheath. While the paramedian sectors revealed a short stout trunk and multiple radiating branches (6 - 8 branches), the LSs (right posterior and left lateral) showed long trunks with few side branches. Additionally, we found that only the AST tended to be further divided into two parts (ventral and dorsal parts). We classified AST shapes into four categories according to the degree of further division: I, Y, V, and U types (Fig 3). We also analyzed the MDCT images in terms of AST shape (Fig 4). I, Y, and V types were thought to be equivalent to those of Kogure’s single tip type, Y-shaped type, and two-branch type, respectively. Type U, a very rare anomaly, had two separate trunks which ramified to several branches into the AS and a horizontal portion between the trunks when compared to type V. We considered this variation as a deep-rooted form of the trunk.

Type Y was the most common AST variant (51.8%) and was characterized by a few branches spreading radially from each top into the upper three quarters of the AS. Type I was the second-most common variant (43.2%), and was characterized by an I-shaped single top trunk and many branches spreading radially from the top into the upper three quarters of the AS. Types U and V were rare (5%), and were characterized by each top having a few branches spreading radially like type Y (Table II).
DISCUSSION

Couinaud originally presented five PV variations based on the concept of a missing right PV, but then later described these variations based on the concept of right PV duplication. The right PV missing concept was replaced because it could falsely indicate the absence of the right hemi-liver, which receives a blood supply from the right PV. However, the right PV duplication concept, which literally means having two right PVs, causes another misconception that the right hemi-liver can be duplicated by right PV duplication. Since Couinaud’s concepts (right PV missing and right PV duplication) may confuse understanding of the complex liver anatomy, the present study classified PV variations based on two major anatomical criteria: the site of AST root and the shape of AST.

Although the first-order portal branch is not always the pedicle of the right liver (22.5% according to Couinaud), a sector of the right liver almost always has its own sectoral trunk. To avoid confusion resulting from the order of ramification, we prefer to use horticultural terms such as trunk and branch rather than second-order and third-order branches.

PV variations can also be classified based on the pattern of the four portal trunks, which have their own unique shape and orientation. Based on Couinaud’s concept that the two lateral sectors originate from the vitelline veins, we suppose that the PST and LST may lead the fundamental pattern of primary PV ramification to be bifurcate. We then infer that the variations of the primary PV ramification can be explained by the variations of the AST root on the hilar platform.

Cho et al divided the anterior segment into the ventral (right anterior) and dorsal (right middle)
segments. They also noted that the ventral segment may correspond to segment 4, the dorsal segment to segment 3, the posterior segment to segment 2, and the right anterior portal trunk to the UP of the left PV. This was the first report on segment-to-segment correspondence, which was based on the idea of bilateral symmetry. Our dissection study identified that the branches of the AS were comparable in terms of total number and thickness with those of the LPS. However, if an apoplexy took place within the left UV during the very early stages of development, the LPS would have disappeared, as indicated in Fig 4. Nagai\textsuperscript{10} named these types of PV variation RSRL anomaly. By reviewing the RSRL anomalies series\textsuperscript{4, 8-10} we found that the AST also showed the same wandering pattern in its root stemming from the PST to the LST, and we designated the patterns as types 1R (Nagai’s bifurcation type), 2R and 3R (Nagai’s trifurcation type) PV variations (Fig. 5). Fusion of liver planes is inevitable in RSRL anomalies. Sabiers et al\textsuperscript{9} described that the RSRL, gallbladder and Rex’s recessus occurred in the same plane. The lack of hepatic parenchyma between the Rex-Cantlie’s line and the umbilical fissure can be confusing for radiologists.

Ryu & Cho’s hypothesis is not applicable to Couinaud’s type d in which the AST is connected to the left portal vein and a quadruplicate PV case (equivalent to Couinaud’s type e) in which the ventral and dorsal branches of the AST are not combined into one but separately connected to the main portal trunk. When type V of the AST takes its root from the main PV, the primary PV ramification looks like quadruplicating branches.\textsuperscript{11} Couinaud insisted that right PV duplication is a rather common and most important feature of liver anatomy.\textsuperscript{12}
There are four plates in the hilar area: hilar, cystic, Arantian, and umbilical plates. The hilar plate is located in the central part of the hilar area and is continuous with the umbilical plate on the left. The hilar and umbilical plates contain not only a large number of lymphatics and nerves but also major and minor bile ducts and hepatic arteries; therefore, knowing the exact location of the AST before surgery is important in liver surgery. In major liver resection or living donor liver transplantation, the type of PV variation needs to be identified at the planning stage to prevent an anatomical complication. The present study presented classification systems for various types of PV variations and AST shapes, which can contribute to resolution of the hepatic Babel discussed by Strasberg. In addition, the proposed classification system in the present study can be of use in training hepatic surgeons. The original paper by Launois described a blunt technique called extrafascial approach. However, we emphasize the need for careful preoperative planning and imaging if one plans on using such an approach. The detailed knowledge of the segmental anatomy of the liver based on the ramification pattern of the AST in the hilar plate is essential in not only doing donor hepatectomy but also various oncological settings. For example, knowing the origin and ramification of the AST is crucial in planning an extended left resection including the ventral segment of the right anterior sector for hilar cholangiocarcinoma.

The percentage discrepancies of three PV variations between the two study groups may result from the difference in sample size and partly the misinterpretation of the MDCT images using Rapidia. Therefore, a further study can be planned in the future which analyzes vessels by exact 3D segmentation from DICOM images.
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FIGURE LEGENDS:

**Fig 1.** Schematic representation of three types of primary portal vein (PV) variation according to the location of the anterior sectoral trunk (AST) on the portal platform. These PV variations can be considered to be determined by the AST root position, which was confirmed in a comparative anatomy study by Couinaud.\(^1\) Redrawn from Couinaud.\(^2\)

PV, portal vein; AST, anterior sectoral trunk; PST, posterior sectoral trunk; LST, lateral sectoral trunk; UP, umbilical portion; LT, ligamentum teres; P, portal veins with Arabic numerals of corresponding Couinaud’s segments

**Fig 2.** A series of MDCT images (a) and an MIP image (b) of the portal venous phase illustrating a RSRL anomaly variation. The round ligament (white triangle) joined with the top of the AST (white arrow) forms a new umbilical fissure. The gallbladder (G) is on the left side of the umbilical fissure. A black arrow indicates the LST.

AST, anterior sectoral trunk; LST, lateral sectoral trunk; MDCT, multi-detector computed tomography; MIP, maximum intensity projection; RSRL, right-sided round ligament.

**Fig 3.** Schematic presentation of four anterior sectoral trunk types observed in the anatomic and MDCT studies.

AST, anterior sectoral trunk; PST, posterior sectoral trunk.
**Fig 4.** AST variations. (A) type I, (B) type Y, (C) type V, and (D) type U. All AST variations are shown as VR images (left side of each pair of images) and MIP images (right side of each pair of images).

AST, anterior sectoral trunk; v, ventral branch of the AST; d, dorsal branch of the AST; VR, volume rendered; MIP, maximum intensity projection.

**Fig. 5.** Illustrations of three types of primary PV variation according to Couinaud’s concept in the upper figures and a proposal of new nomenclature for the corresponding counterpart of three known RSRL anomalies in the lower figures. A black star (★) indicates the normal distal attachment of the round ligament and a white star (☆) the distal attachment of the right–sided round ligament.

AST, anterior sectoral trunk; LST, lateral sectoral trunk; PST, posterior sectoral trunk; PV, portal vein; RSRL, right-sided round ligament; UP, umbilical portion.
Table 1. Ramification patterns of the portal venous system

<table>
<thead>
<tr>
<th>Types</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadaver dissection (n = 64)</td>
<td>56 (87.5%)</td>
<td>5 (7.8%)</td>
<td>3 (4.7%)</td>
</tr>
<tr>
<td>MDCT (n = 212)</td>
<td>172 (81.1%)</td>
<td>17 (8.0%)</td>
<td>23 (10.9%)</td>
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<tr>
<td>Total (n = 276)</td>
<td>228 (82.6%)</td>
<td>22 (8.0%)</td>
<td>26 (9.4%)</td>
</tr>
</tbody>
</table>
**Table II.** Shapes of anterior sectoral trunk

<table>
<thead>
<tr>
<th>Shapes</th>
<th>Type I</th>
<th>Type Y</th>
<th>Type V</th>
<th>Type U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadaver dissection (n = 64)</td>
<td>23</td>
<td>36</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>MDCT (n = 216)</td>
<td>98</td>
<td>109</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Total (n = 280)</td>
<td>121 (43.2%)</td>
<td>145 (51.8%)</td>
<td>9 (3.2%)</td>
<td>5 (1.8%)</td>
</tr>
</tbody>
</table>

MDCT, multi-detector computed tomography.
REFERENCES


Fig 1.
Fig 2.
Fig 3.
Fig 4.
Fig 5.