Study on the segmentation of the right anterior sector of the liver

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Background. *The segmentation of the right anterior sector of the liver still is debatable due to the lack of an anatomic landmark of the boundary between Couinaud segments V and VIII (cranio-caudal segmentation). Some authors have proposed the concept of a ventro-dorsal segmentation. The aim of this study was to evaluate which concept of segmentation better reflects the anatomy.*
Methods. *Using 3-dimensional computed tomography software, the ramification pattern of the right anterior portal vein was examined in 100 patients. A thick, hepatic, venous branch that passes through Couinaud segment VIII was termed V8, and its course was investigated using a virtual hepatectomy.*
Results. *Regarding the anatomy of the portal vein in the right anterior sector, the cranio-caudal type was found in 53 patients, the ventro-dorsal type in 23 patients, and the trifurcation type in 13 patients. The remaining 11 patients had miscellaneous patterns of ramification. In the cranio-caudal type, the volume of the cranial segment was greater (*$P < .001$*) than that of the caudal segment. In the ventro-dorsal type, the volume of the ventral segment was greater (*$P = .007$*) than that of the dorsal segment. The V8 was identified in 81 of the 89 (91%) patients analyzed. The proportion of cases in which the V8 functioned as a landmark of the border between the ventral and dorsal segments was 63% (56/89 patients).*
Conclusion. *Regarding the segmentation of the right anterior sector of the liver, the cranio-caudal segmentation introduced by Couinaud is dominant (53%), while ventro-dorsal segmentation is less common (23%). Therefore, universalization of the concept of the ventro-dorsal segmentation is unrealistic. (Surgery 2017;161:1536-42.)*

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THE LIVER SEGMENTATION proposed by Couinaud[1] involves dividing the liver into 8 operatively relevant segments based on the anatomy of the portal vein (PV) and hepatic vein and is used in everyday clinical practice. The boundaries between Couinaud segments, however, are not always clear. The boundary between segments V (caudal part of the right anterior sector) and VIII (cranial part of the right anterior sector) often is vague due to the lack of a clear anatomic landmark. Some authors have proposed the right anterior sector should be divided into ventral and dorsal segments.[2-6] In particular, Cho et al[4-6] stressed that this ventro-dorsal segmentation of the anterior sector should be applied universally in all cases and that the "anterior fissure vein" (AFV) is important as its landmark. Some authors have affirmed Couinaud's segmentation,[7,8] while others have supported Cho's classification.[9] Therefore, the method of segmentation still is debatable.

The aims of the present study were to investigate the segmentation of the right anterior sector according to the anatomy of the PV, to evaluate which concept of segmentation, ie, cranio-caudal (Couinaud) or ventro-dorsal (Cho), is most common, and in turn, to enable safe and precise segmentectomy of the right anterior sector of the liver. Therefore, we analyzed the branching pattern of the right anterior PV and evaluated the course of the so-called AFV using a virtual hepatectomy produced by 3-dimensional (3D) image-processing software.

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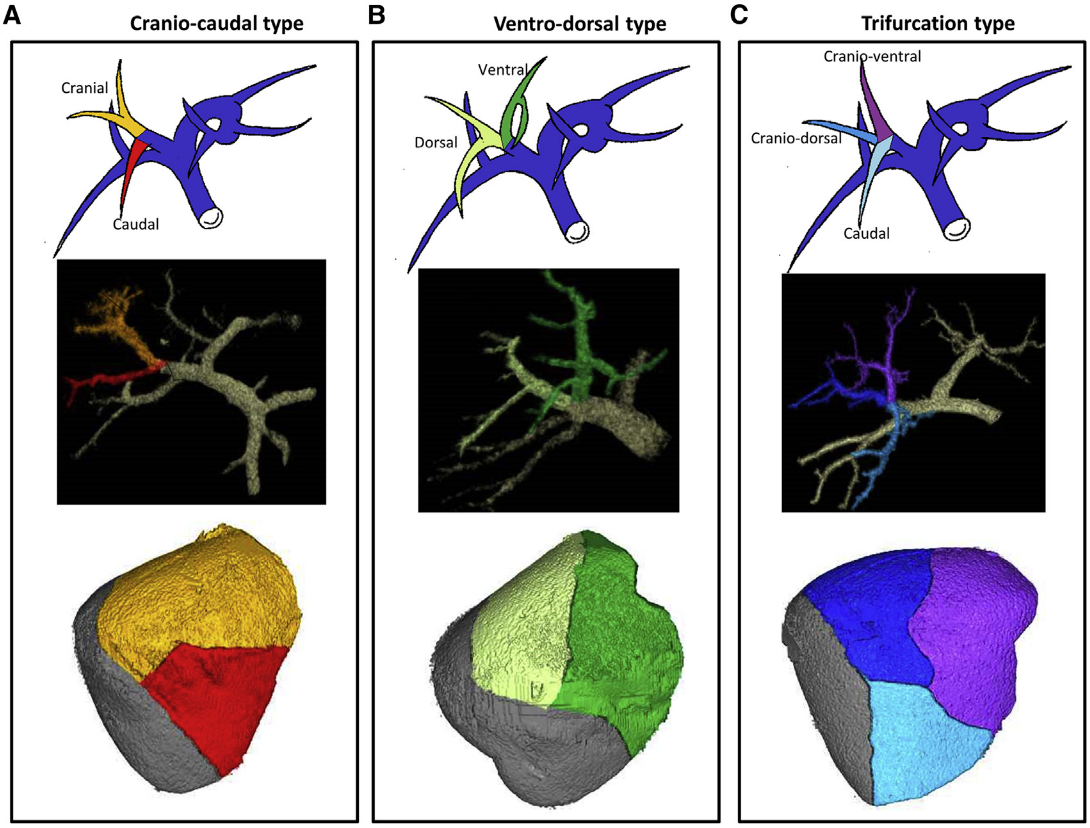

Fig 1. Segmentation of the right anterior sector according to the PV anatomy. A scheme of the anatomy of the PV (top), a 3D-portogram (middle), and the segmentation of the right anterior sector (bottom).

PATIENTS AND METHODS

Among all patients with suspected hepato-biliary-pancreatic disease who underwent multidetector-row computed tomography (MDCT) with dynamic enhancement at Nagoya University Hospital, patients who met all of the following criteria were included for this study: 1) no liver tumor or cirrhosis and 2) no vascular invasion by the tumor.

All MDCT examinations were performed using a scanner with 64 rows of detectors (acquisition 64; Toshiba Medical Systems, Tokyo, Japan). A series of scans without a contrast agent was obtained throughout the liver and biliary tree. Then, 100–150 mL of nonionic contrast material with an iodine content of 300 mg/mL was administered via the antecubital vein at a rate of 0.07–0.08 mL/kg/s for 30 s with a power injector before the second, third, and fourth helical scans (early arterial, late arterial, and portal phases) were obtained (26, 45, and 68 s after contrast injection). The scanning parameters for the portal phase were 16 $\times$ 1.0 mm collimation, 1.0 mm slice thickness, 0.8 mm reconstruction interval, a table advancement of 30 mm/s, a rotation time of 0.5 s, a pitch ratio of 15:1, 120 kV, and 500 mA.

The MDCT data sets were transferred to a workstation for image analysis using specialized software (Synapse Vincent; Fuji Film Co, Tokyo, Japan). The liver parenchyma was extracted semiautomatically from consecutive MDCT images. Three-dimensional, volume-rendered images of the PV and hepatic vein were generated from late arterial or portal phase data using the automatic algorithm of the software. The extracted PV and hepatic vein were overlapped, and the reconstructed images were viewed from several angles on a workstation. The ramification pattern of the right anterior PV was examined, and the volume of the segments according to the right anterior PV anatomy was calculated.

A thick, hepatic venous branch that passes through Couinaud hepatic segment VIII was termed V8, and its characteristics were investigated. To determine whether V8 runs along the boundary between the ventral and dorsal areas of the right anterior sector (ie, whether V8 functions as a landmark of the boundary), a virtual

Table I. Liver volume of the right anterior sector according to portal vein anatomy

Portal vein anatomy	*Volume (mL)**	*% of total liver volume**	P *value*
Cranio-caudal type ($n = 53$)			
Cranial segment	276 (96–531)	24 (12–32)	<.001
Caudal segment	160 (52–386)	14 (5–26)	
Ventro-dorsal type ($n = 23$)			
Ventral segment	268 (99–392)	22 (8–37)	.007
Dorsal segment	170 (97–418)	15 (1–34)	
Trifurcation type ($n = 13$)			
Cranio-ventral segment	120 (57–282)	12 (7–22)	.381†
Cranio-dorsal segment	104 (42–248)	10 (6–18)	.858‡
Caudal segment	138 (70–225)	12 (7–28)	.696§

*Expressed as median (range).
†Cranio-ventral segment versus cranio-dorsal segment.
‡Cranio-ventral segment versus caudal segment.
§Cranio-dorsal segment versus caudal segment.

Table II. Identification and length of V8 according to portal vein anatomy

Portal vein anatomy	*V8 identified*	*V8 as landmark vein**	*Length of V8 (cm)†*
Cranio-caudal type ($n = 53$)	48 (91%)	34 (64%)	6.1 (3.7–9.3)
Ventro-dorsal type ($n = 23$)	22 (96%)	16 (70%)	6.3 (4.7–8.2)
Trifurcation type ($n = 13$)	11 (85%)	6 (46%)	6.5 (3.7–10.6)
Total ($n = 89$)	81 (91%)	56 (63%)	6.2 (3.7–10.6)

*Indicate that V8 identified runs along the border between ventral and dorsal areas.
†Expressed as median (range).

hepatectomy (left hepatectomy + resection of the ventral area of the right anterior sector) was performed, and exposure of V8 on the virtual transected plane was examined. The virtual hepatectomy was performed by extracting the perfusion area of the target PV followed by its subtraction from the whole liver. The vascular perfusion area was calculated using an algorithm based on the Voronoi tessellation, a calculation method to partition a region into multiple territories. According to the tessellation, a tile corresponding to a given data point is a locus of all points of space closest to this data point.[10,11] The perfusion territory belonging to any selected vessel was bordered by a line located at an equal distance from the surrounding vessels.[12,13]

Statistical analysis. The statistical analysis was performed using the Mann-Whitney *U* test with Tukey's method for multiple comparisons. The analyses were performed using the SPSS statistical package (version 24, SPSS Inc, Chicago, IL).

RESULTS

Between January 2012 and May 2016, 100 patients who met the inclusion criteria were analyzed for this study. The subjects included 68 men and 32 women with an average age of 7 years (range, 30–89 years).

Ramification pattern of the right anterior PV. The anatomy of the PV of the right anterior sector was classified into the following 3 types (Fig 1): the cranio-caudal type where the right anterior PV bifurcates into the cranial and caudal branches, the ventro-dorsal type where the right anterior PV bifurcates into the ventral and dorsal branches, and the and trifurcation type where the right anterior PV diverges into the cranio-ventral, cranio-dorsal, and caudal branches at the same point. The cranio, ventro, and trifurcation types were found in 53 (53%), 23 (23%), and 13 (13%) of patients, respectively. The remaining 11 patients had miscellaneous ramification patterns that did not belong to the above 3 types. After excluding these 11 patients, further analyses were conducted.

Segment volume according to the anatomy of the right anterior PV. Each segment volume of the right anterior sector was evaluated according to the anatomy of the right anterior PV (Table I). In the cranio-caudal type, the volume of the cranial segment was greater ($P < .001$) than that of the caudal segment. In the ventro-dorsal type, the volume of the ventral segment was greater ($P = .007$) than that of the dorsal segment. In the trifurcation type, each segment volume was similar in volume.

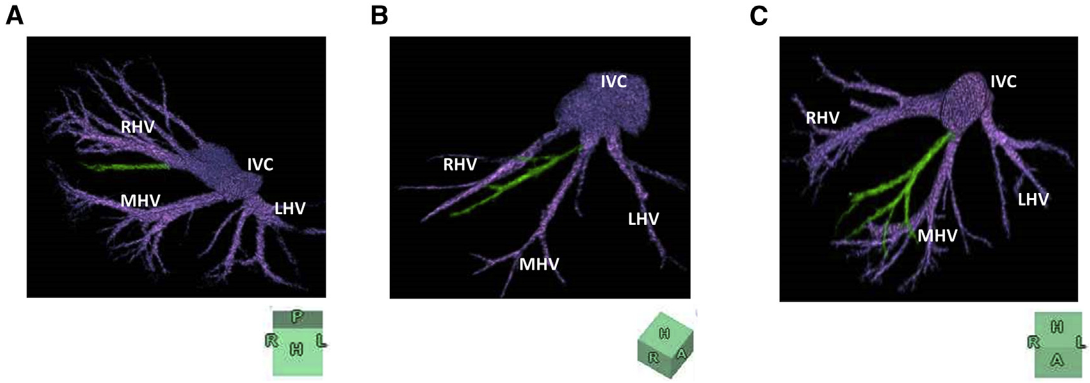

Fig 2. A 3D reconstruction of the hepatic vein. (*A*) The V8 joins the right hepatic vein (RHV). (*B*) The V8 enters the middle hepatic vein (MHV). (*C*) The V8 directly runs into the inferior vena cava (IVC). LHV, left hepatic vein.

Table III. Confluence pattern of V8

	Confluent vein		
Distance from inferior vena cava	*Right hepatic vein* (n = *7*)	*Middle hepatic vein* (n = *68*)	*Inferior vena cava* (n = *6*)
0–3 cm	5	58	—
3–5 cm	2	8	—
<5 cm	0	2	—

Characteristics of the hepatic venous branch termed V8. The V8 was identified in 81 of the 89 (91%) patients analyzed. The incidence of identification was similar among the 3 right anterior PV anatomies, and the length of V8 also was similar among the 3 groups (Table II). Of the 81 V8s identified, 7 entered the right hepatic vein (Fig 2, *A*), 68 joined the middle hepatic vein (Fig 2, *B*), and the remaining 6 entered directly into the inferior vena cava (Fig 2, *C*). Of the 75 V8s that entered the right or middle hepatic vein, 73 (97%) joined the terminal portion of the right or middle hepatic vein, primarily at a point <5 cm away from the inferior vena cava (Table III).

The incidence of exposure of V8s on the virtual transected plane was 64% in the cranio-caudal type, 69% in the ventro-dorsal type, and 46% in the trifurcation type (Fig 3 and Table II). Thus, the proportion of cases in which V8 functioned as a landmark of the boundary between the ventral and dorsal segments was 64% (56/89 patients).

DISCUSSION

Due to recent advances in MDCT and the image analysis workstation, our understanding of liver segmentation has improved and has reached a certain consensus. Nevertheless, segmentation of the right anterior sector still is debatable due to the lack of a clear anatomic landmark for the boundary between Couinaud segments V and VIII. Instead of the cranio-caudal segmentation introduced by Couinaud, some authors have proposed the concept of ventro-dorsal segmentation.[2-6] Cho et al reported that "in all 60 patients examined, the right anterior portal vein bifurcated into ventral and dorsal branches"[5] and stressed that the right anterior sector should be divided into 2 segments, ie, the ventral and dorsal segments.[4-6] In contrast, the present study demonstrated that the cranio-caudal segmentation was dominant, accounting for approximately half of the study patients, and the ventro-dorsal segmentation was minor (23%). Kurimoto et al also studied the ramification pattern of the right anterior PV and reported results similar to our findings. Specifically, in their series, the cranio-caudal type (Couinaud's segmentation) was observed in 50% of the study patients, the ventro-dorsal type (Cho's segmentation) was observed in 26% of the patients, and the multiple (trifurcation) type was observed in 24% of the patients.[14] Although it is difficult to explain such a large disparity among the studies, we acknowledge the observations by Cho et al, in which all of the patients had the ventro-dorsal pattern, but we think that pattern is not dominant.[4-6]

Next, we examined the so-called AFV. Cho et al named the hepatic venous branch that crossed between the ventral and dorsal segments of the right anterior sector the AFV,[6] which is called V8 in the present study. We used the term V8 purposely, because "anterior fissure" is insubstantial and unsuitable for use as medical term. Cho et al reported that the AFV (=V8) was identified in "all" 44 patients examined: 28 (64%) AFVs joined the

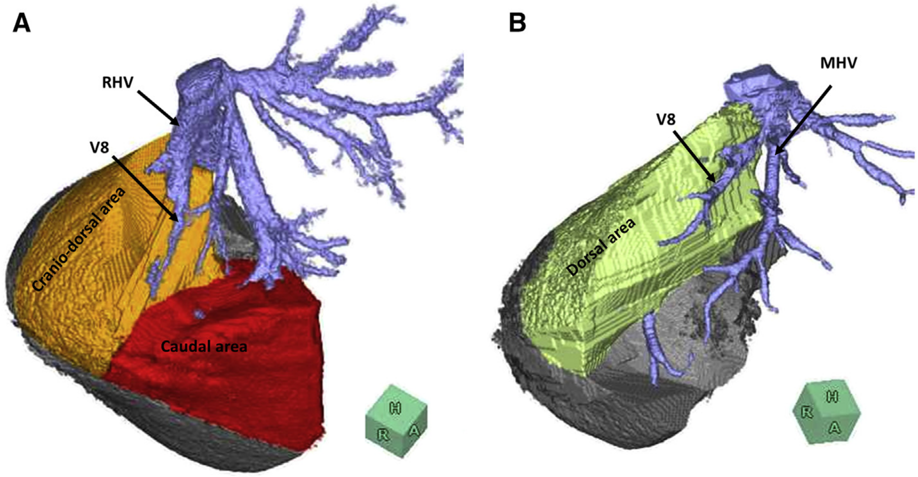

Fig 3. Virtual hepatectomy. (*A*) The cranio-caudal type. The left liver and the cranio-ventral segment of the right anterior sector are resected. V8, which enters the terminal portion of the right hepatic vein, is exposed on the virtual transected plane. (*B*) The ventro-dorsal type. The left liver and the ventral segment of the right anterior sector are resected. V8, which enters the terminal portion of the middle hepatic vein, is exposed on the virtual transected plane.

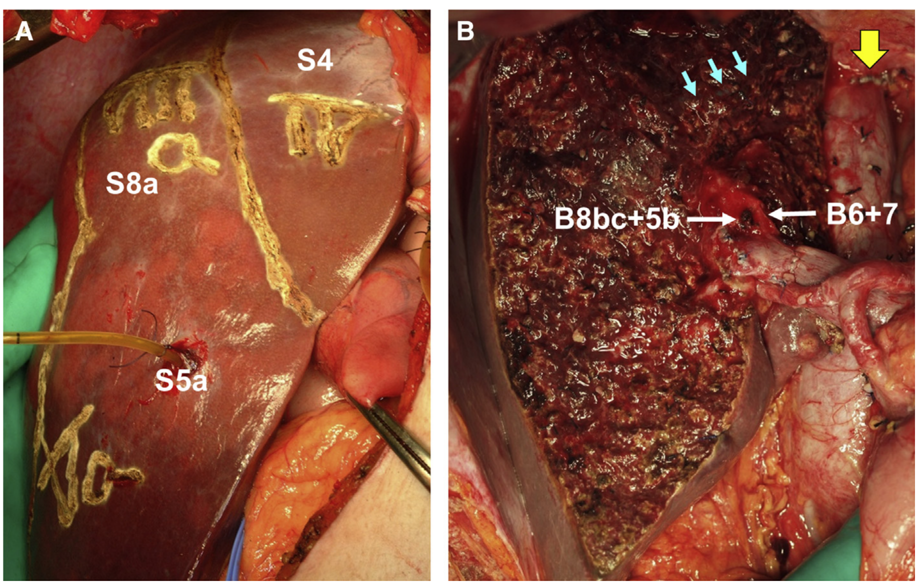

Fig 4. Operative views of a patient with a predominantly left-sided perihilar cholangiocarcinoma who had the ventro-dorsal segmentation of the right anterior sector. (*A*) The patient underwent embolization of the left portal vein and the ventral branches of the right anterior portal vein. Therefore, the demarcation line between the ventral and dorsal areas appeared after dividing the ventral branches of the right anterior hepatic artery. (*B*) A left hepatectomy and caudate lobectomy combined resection of the ventral segment of the right anterior sector was completed. Portal vein also was resected and reconstructed. The middle and left hepatic veins were resected at their origin (yellow arrow). Blue arrows indicate V8 entering the right hepatic vein. B6+7, the right posterior bile duct; B8bc+5b, the cranio- and caudal-dorsal branches of the right anterior bile duct. (Color version of this figure is available online.)

terminal portion of the middle hepatic vein, 4 (9%) joined the terminal portion of the right hepatic vein, and the remaining 12 (27%) joined the proximal portion of the middle hepatic vein.[4,6] They stressed that the AFV always functions as a landmark for the boundary between the ventral and dorsal segments. In the present study, the V8 (=AFV) was identified in 91% of the study patients, but the proportion of cases in which V8 functioned as a landmark was only 63%. Kaneko et al evaluated the AFV using MDCT and found that this vein was identified in 85% of patients examined.[7] They observed that the boundary between the ventral and dorsal segments could not be determined even after identifying the AFV in some cases, and thus, they determined that the AFV lacks universality as an anatomic landmark.[7] In short, the V8 (AFV) can be identified in most, but not all, patients; however, this vein can function as landmark only in some patients.

Regarding the volume of each segment of the right anterior sector, 2 studies reported that the volumes of the ventral and dorsal segments were approximately equal.[15,16] According to a study by Tanaka et al, the volume of the ventral segment was 230 mL, while the volume of the dorsal segment was 227 mL.[16] Conversely, we found that the volume of the ventral segment was significantly greater than that of the dorsal segment in the ventro-dorsal type (268 mL vs 170 mL). Differences in volumes also were observed between the cranial and caudal segments in the cranio-caudal type (276 mL vs 160 mL). These values are compatible with the study by Kurimoto et al in which the volume of the ventral segment was significantly greater than that of the dorsal segment in the ventro-dorsal type, and the cranial segment was significantly greater than that of the caudal segment in the cranio-caudal type.[14] The present study included patients with suspected hepato-biliary-pancreatic disease. Although the disease may have affected the results of the liver volume, the volume of the right anterior sector in the present study was similar to the previous report involving donner patients with a normal liver.[17] Therefore, we think that the effect of the disease was minimal or lacking.

Several authors have reported a resectional procedure for the right anterior sector based on its segmentation, especially in the ventro-dorsal type.[6,14,16,18,19] To find the demarcation line between the ventral and dorsal area, the right pedicle is encircled and clamped temporarily, then the demarcation line appears. Liver transection is performed along the line, leaving the trunk of the middle hepatic vein, and the branches draining from the ventral area are ligated and divided. Then, the ventral and dorsal pedicles of the right anterior sector appear somewhat cranially to the hepatic hilum and can be encircled separately.[18] Tanaka et al proposed a right hemihepatectomy that preserved the ventral right anterior sector.[16] Fujimoto et al demonstrated that a resection of the ventral or dorsal segment alone is feasible without radically impairing selected patients with hepatocellular carcinoma.[18] We have performed a left hepatectomy and caudate lobectomy combined with resection of the ventral segment of the right anterior sector in eight patients with perihilar cholangiocarcinoma (Fig 4).[19] This procedure could substitute for left hepatic trisectionectomy in patients with a predominantly left-sided perihilar cholangiocarcinoma who have ventro-dorsal segmentation of the right anterior sector. When a parenchyma-preserving hepatectomy based on the ventro-dorsal segmentation is planned, a preoperative virtual hepatectomy can prove very useful, especially to assess whether the V8 functions as landmark of the boundary.

In conclusion, the cranio-caudal segmentation as introduced by Couinaud is the prevailing segmentation of the right anterior sector. Although some patients have the ventro-dorsal segmentation type, this type is minor. Therefore, universalization of the concept of the ventro-dorsal segmentation, stressed by Cho et al,[4-6] does not seem to be accurate.

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