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Can we delineate preoperatively the right and ventral margins of caudate lobe of the liver?

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Purpose: Complete removal of the caudate lobe, which is sometimes necessary, is accomplished via isolated caudate lobectomy or hepatectomy that includes the caudate lobe. It is impossible, however, to confirm the right and ventral margins of the caudate lobe by preoperative imaging. This study was undertaken to determine whether we could identify the right and ventral margins of the caudate lobe preoperatively using Synapse 3D visualization software.
Methods: Ninety-four preoperative 3-dimensional (3D) computed tomographic images (1-mm slices) of the liver from candidate donors were examined. The images of the caudate lobe were subjected to a counter-staining method according to Synapse 3D to delineate their dimensions. We first examined whether the right margin of the caudate lobe exceeded the plane formed by the root of the right hepatic vein (RHV) and the right side of the inferior vena cava (IVC). Second, we determined whether the ventral margin of the caudate lobe exceeded the plane formed by the root of the middle hepatic vein (MHV) and the root of the RHV.
Results: For the right margin, 17 cases (18%) exceeded the RHV-IVC plane by a mean of 10.2 mm (range, 2.4–27.2 mm). For the ventral margin, 28 cases (30%) exceeded the MHV-RHV plane by a mean of 17.4 mm (range, 1.2–49.1 mm).
Conclusion: Evaluating the anatomy of caudate lobe using Synapse 3D preoperatively could be helpful for more precise anatomical resection of the caudate lobe.
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Key Words: Caudate lobe of liver, Liver anatomy, Preoperative, Three-dimensional imaging

INTRODUCTION

Because hilar cholangiocarcinomas may send metastases to the caudate lobe via minute bile duct branches [1], total caudate lobectomy, along with hepatic resection, is necessary [2,3]. Although the importance of the caudate lobe is being increasingly accepted and a copious amount of research carried out, the anatomy of the caudate lobe lacks consensus.

Couinaud [4] suggested a clinically useful anatomy of the liver, but the concept of caudate lobe anatomy has been changing since then. In 1954, Couinaud defined the caudate lobe as segment I according to its portal ramification. This portion of the liver corresponds to the Spiegel lobe in the Kumon classification, which is currently used worldwide. Kumon classified the caudate lobe into 3 parts: Spiegel's lobe, the paracaval portion, and the caudate process portion [5]. Many researchers have agreed with the Kumon classification, and it is being used clinically.

For the right margin of the caudate lobe, Kogure et al. [6] advocated that the hepatic vein is the boundary between the

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caudate process and the right liver, but it is more important to find the right margin of the paracaval portion when searching for the right border of the caudate lobe. The paracaval portion is located inside the liver parenchyma, in neighboring segments 7 and 8, making it difficult to identify the margin. Kitagawa, of the Murakami group, initially thought that the right hepatic vein (RHV) was the most important landmark of the right margin of the paracaval portion. Later, however, he accepted the concept of the right paracaval plane [7]. Recently, Maki et al. [8] found that the paracaval vein of a branch of the RHV is the boundary between the caudate lobe and segments 7 and 8.

The ventral margin of the caudate lobe was believed to correspond to the route of the middle hepatic vein (MHV). Couinaud [9] opposed this idea, however, and thought that the margin was situated in the vicinity of the confluence of the middle and RHV drainage area into the inferior vena cava (IVC). Later, Kwon et al. [10] reported the existence of the precaudate plane.

The current study focuses on identifying the right and ventral margins of the caudate lobe, which is poorly recognized in the surgical field. So far, there are no reports on the right and ventral margins of the caudate lobe that can be applied clinically. As caudate anatomy has been analyzed by Synapse 3D software (Fujifilm, Tokyo, Japan) to visualize the 3-dimensional (3D) anatomy of the caudate lobe, we set out to delineate the right and ventral margins of the caudate lobe preoperatively using the same system.

METHODS

Synapse 3D

Contrast-enhanced helical CT examinations of the liver were conducted. After obtaining abdominal multidetector CT images (1-mm slices), 3D image reconstruction was carried out using Synapse 3D. A Digital Imaging and Communication in Medicine file of raw 1-mm CT images was transferred to the Synapse 3D software. After selecting the parenchyma of the whole liver, we traced the portal vein and hepatic vein branches. The caudate lobe was visualized after reconstruction. Although only 15 of 94 cases had portal branches in the caudate lobe, we could delineate the parenchyma of the caudate lobe by electronically clicking on them. Thereafter, we compared it with the parenchyma that remained after staining by clicking on the second-order branches of the portal veins. The directly

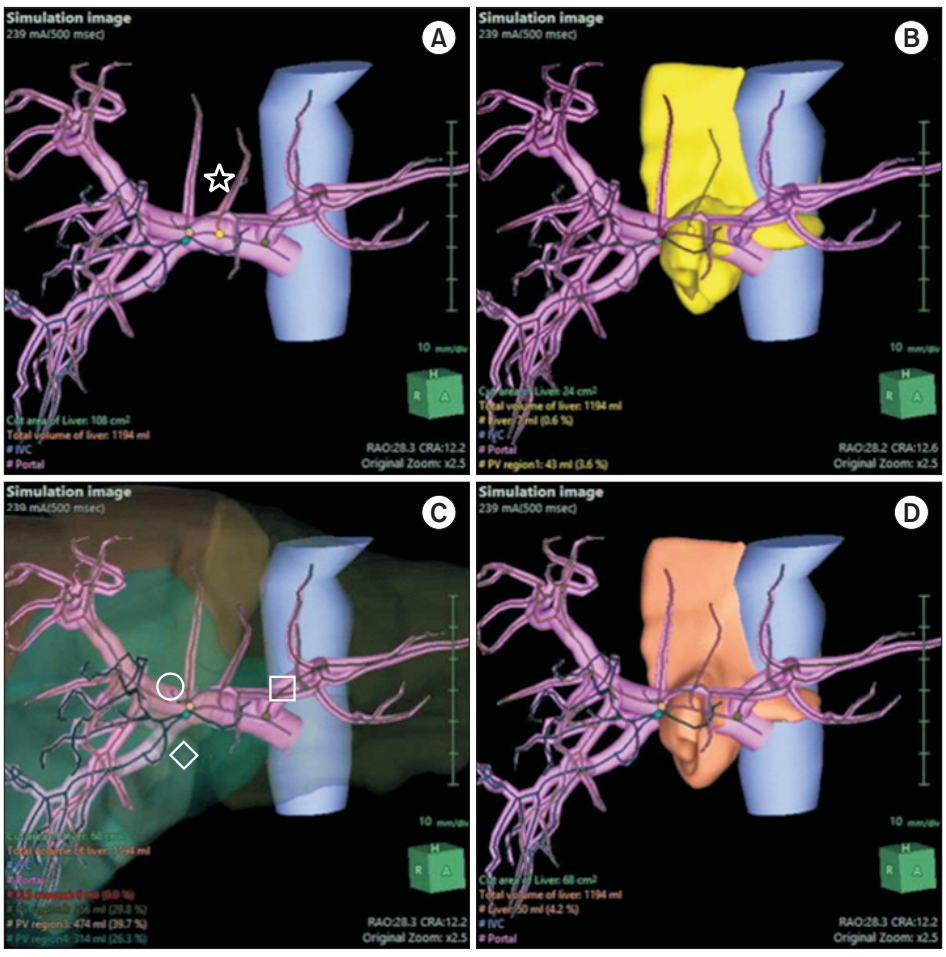

Fig. 1. The caudate parenchyma was delineated using a counterstaining technique. Hepatic veins, hepatic arteries, and bile ducts are hidden to identify images more easily. (A) By hiding the hepatic parenchyma, the portal vein branch of the paracaval portion can be seen (star). (B) By clicking on the portal vein branch of the paracaval portion, the parenchyma of caudate lobe is shown (yellow). (C) In the same case, we clicked on the left portal vein (square), right anterior portal vein (circle), and right posterior portal vein (diamond), respectively, which then showed the corresponding parenchyma of the liver. (D) The shape of the remnant liver parenchyma is the same as in panel B.

stained caudate parenchyma was the same as the indirectly stained caudate parenchyma. In 79 subjects in whom there were no portal branches of the caudate lobe visualized, we could delineate the caudate parenchyma by Takayama's counter-staining technique (Fig. 1) [11]. The hepatic portal system can be easily identified by hiding the parenchyma of the liver, hepatic veins, hepatic arteries, and bile ducts. When the corresponding parenchyma of the left portal vein, the right anterior portal vein, and the right posterior portal vein is removed, the image of the caudate lobe will be revealed.

We accepted that the RHV-IVC plane is the most reliable landmark of the right margin of the caudate lobe, which contains the RHV from the root + 3 cm and the right border of the IVC. For the ventral margin, the MHV-RHV plane could be regarded as the landmark comprising the MHV from the root + 3 cm and RHV from the root + 3 cm. Where the roots of the MHV and RHV overlapped was considered the MHV-RHV plane (Fig. 2). This study was approved by the Institutional Review Board of Ajou University Hospital (approval number: AJIRB-MED-MDB-19-108).

RESULTS

The characteristics of the caudate lobe in 94 cases are shown in Table 1. For the right margin, 17 subjects (18%) exceeded the RHV-IVC plane by a mean of 10.2 mm (range, 2.4–27.2 mm). Among them, 11 were <10 mm, 3 were 10–20 mm, and 3 were >20 mm (Fig. 3A, B). For the ventral margin, 28 subjects (30%) exceeded the MHV-RHV plane by a mean of 17.4 mm (range,

Table 1. Characteristics of the caudate lobe in 94 cases

Characteristic	Right margin	Ventral margin
No. of cases exceeding the margin	17 (18)	28 (30)
<10 mm	11 (12)	12 (13)
10–20 mm	3 (3)	5 (5)
>20 mm	3 (3)	11 (12)
Mean distance exceeding the margin (mm)	10.2	17.4
Range exceeding the margin (mm)	2.4–27.2	1.2–49.1

Values are presented as number (%) unless otherwise indicated.

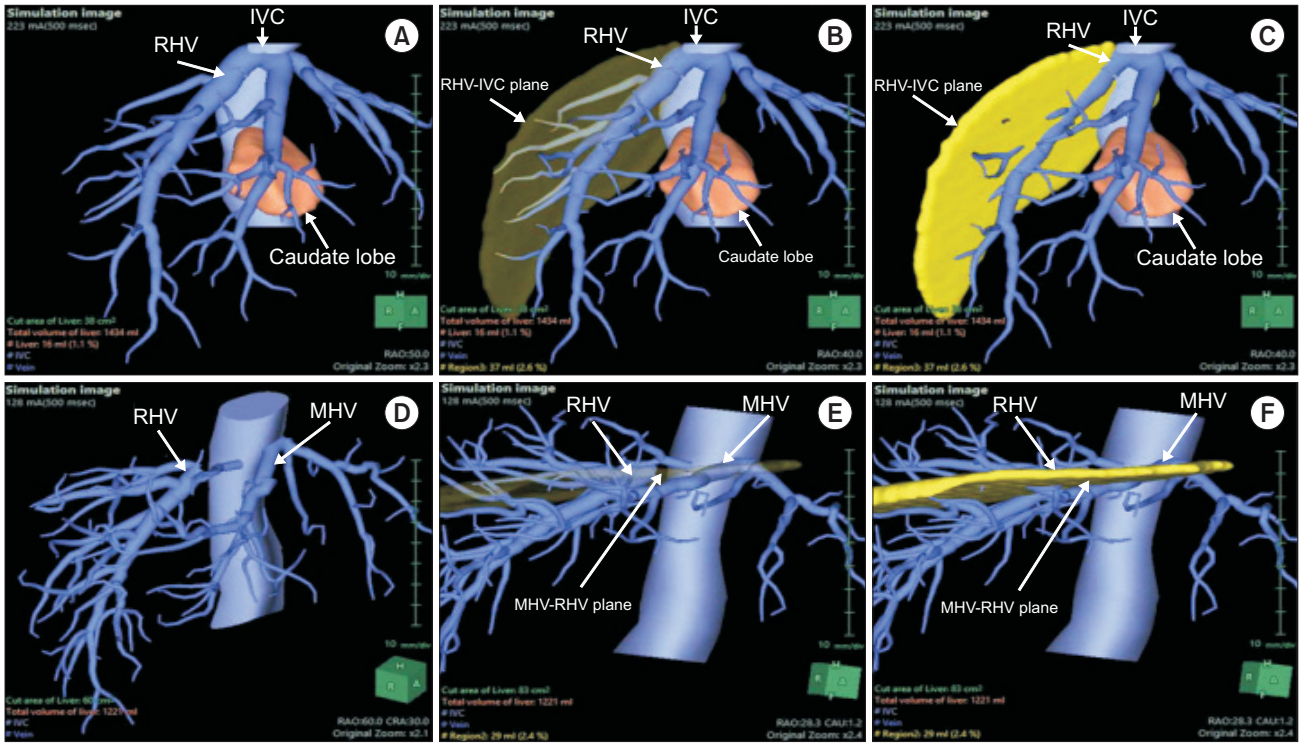

Fig. 2. The methods to define the right and ventral margins are shown. (A) IVC and RHV can be identified after hiding the hepatic parenchyma other than the caudate lobe. (B) RHV-IVC plane can be seen (translucent brown) by connecting the RHV from the root + 3 cm and the right border of the IVC. (C) RHV-IVC plane can be seen (yellow) by connecting the RHV from the root + 3 cm and the right border of the IVC. (D) MHV and RHV can be identified after hiding the hepatic parenchyma. (E) MHV-RHV plane can be seen (translucent yellow) by connecting the MHV from the root + 3 cm and RHV from the root + 3 cm. (F) MHV-RHV plane can be seen (yellow) by connecting the MHV from the root + 3 cm and RHV from the root + 3 cm. IVC, inferior vena cava; RHV, right hepatic vein; MHV, middle hepatic vein.

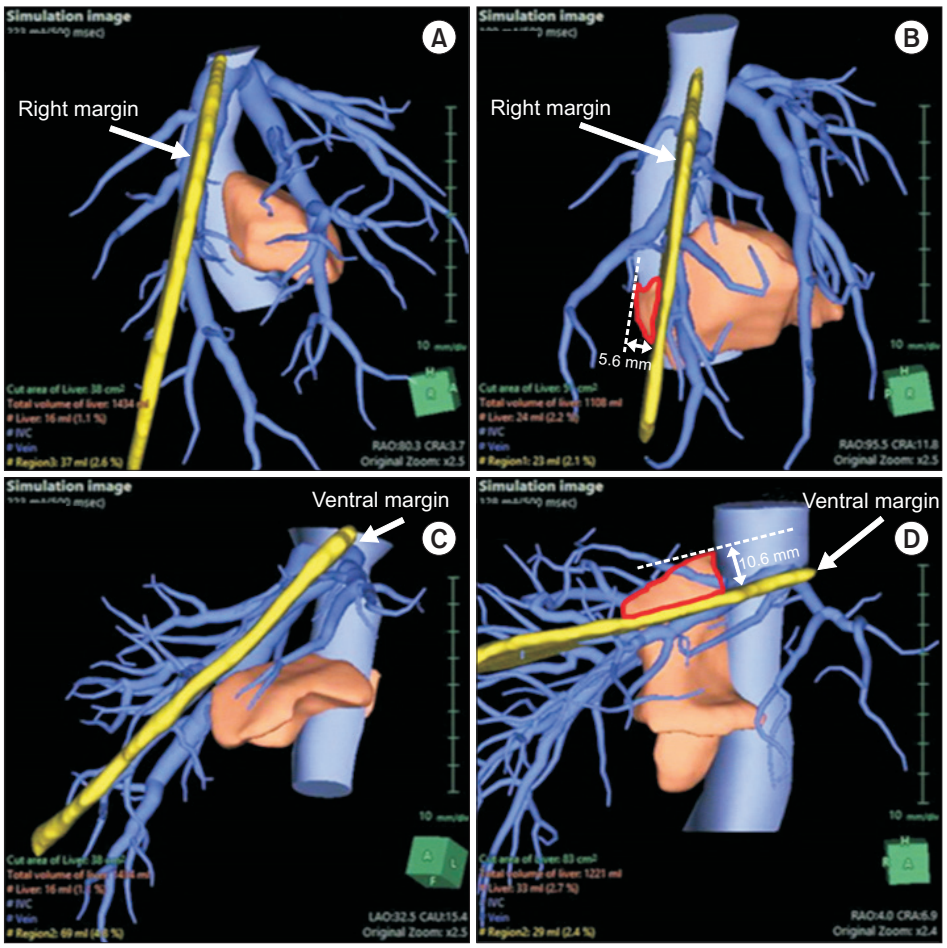

Fig. 3. Right and ventral margins of the caudate lobe are shown. The relations between the caudate lobe and right hepatic vein and inferior vena cava (RHV-IVC) plane and the middle and right hepatic veins (MHV-RHV) plane is shown in Synapse 3-dimensional images. (A) Caudate lobe is located on the right side of the RHV-IVC plane (yellow). (B) The parenchyma of the caudate lobe exceeds the RHV-IVC plane (yellow) is outlined in red. We calculated that the distance exceeds the right margin is 5.6 mm in this case. (C) Caudate lobe is ventrally located in the MHV-RHV plane (yellow). (D) The parenchyma of the caudate lobe exceeds the MHV-RHV plane (yellow) is outlined in red. We calculated that the distance exceeds the ventral margin is 10.6 mm. IVC, inferior vena cava; RHV, right hepatic vein; MHV, middle hepatic vein.

1.2–49.1 mm). Among them, 12 were <10 mm, 5 were 10–20 mm, and 11 were >20 mm (Fig. 3C, D). In all, 10 subjects were found to exceed both the MHV-RHV and RHV-IVC planes.

DISCUSSION

Hilar cholangiocarcinoma is known to invade the parenchyma and bile duct of the caudate lobe rapidly during early stages of the disease. In the literature, microscopic tumor involvement in caudate lobe branches was found in 42% of patients at the time of surgery [1]. Thus, caudate anatomy is of great importance when performing total caudate lobectomy in patients with hilar cholangiocarcinoma. Prognosis reportedly improved in cholangiocarcinoma patients when caudate lobectomy was performed [12]. In cases of caudate lobe tumor, isolated caudate lobectomy can be performed, as introduced by Lerut et al. [13] in 1990. Surgery included partial or total caudate lobectomy. Partial caudate lobectomy was performed by resecting Spiegel's lobe or the caudate process only, each of which was easily identified intraoperatively [14]. In other previous research, total isolated caudate lobectomy was performed by approaching the caudate lobe from the right side of the liver, using the right posterior Glisson pedicle as the anterior border plane of the caudate lobe and reaching the dorsal plane by transecting the parenchyma between the MHV and RHV. There was no mention of the right margin of the caudate lobe [15,16]. Although it is known that the anatomy of the caudate lobe is important when performing total caudate lobectomy, the exact locations of the right and ventral margins remain obscure.

It is difficult for us to define the right margin of the caudate lobe of the liver because the paracaval portion is located anterior to the IVC, to the right of the ligamentum venosum, and cranial to the hilar plate. The right and ventral margins were not identifiable from the exterior as their locations vary [17]. Couinaud [18] suggested that the right portion of the caudate lobe was a neighbor of segments 7 and 8, lying adjacent to the end point of the RHV. Kitagawa et al. [7] firstly thought that the RHV is the most important landmark of the right margin of the paracaval portion. Later, however, they suggested the concept of the right paracaval plane. These investigators suggested that the right paracaval plane may serve as an imaginary right margin of the caudate lobe. In fact, the right margin of the paracaval portion was located on the left side of the right paracaval plane

in 65.4% (36 of 55) of cases. Therefore, if hepatic resection was carried out in this plane, total caudate lobectomy was complete with 60% anatomical reliability; if carried out at 10 mm to the right of this plane, 80% reliability was guaranteed; and if performed at 30 mm to the right of this plane, there was 100% reliability. This report was a milestone in the search for a definition of the right margin of the caudate lobe—which is poorly visualized from the exterior. Nevertheless, the concept had little effect on identifying the right margin during surgery. Recently, Maki et al. [8] identified the paracaval vein as the landmark for establishing the boundary between the caudate lobe and segments 7 and 8. The paracaval vein, however, cannot be found by intraoperative ultrasonography. In the current study, 17 cases (18%) exceeded the RHV-IVC plane. As landmarks, the RHV and IVC are easily found in the surgical field as well as with intraoperative ultrasonography.

The need to identify the individualized right margin of the caudate lobe is indisputable. The use of Synapse 3D is more likely to enable surgeons to perform total caudate lobectomy based on each patient's unique liver anatomy.

Regarding the ventral margin of the caudate lobe, in 2002 Kwon et al. [10] reported the existence of a precaudate plane. This plane, which they described as flat or slightly curved, was a continuum of the ligamentum venosum and the ventral margin of the hilar plate. According to this report, the ventral margin of the caudate lobe was restricted within the dorsal side of the precaudate line in 63.2% (48 of 76) of the liver specimens. In 36.8% of the cases where ventral extension of the caudate lobe was found, the ventral margin was extended to the dome-like area under the terminals of the RHV, MHV, and the left hepatic vein. The authors suggested that the precaudate plane could serve as an imaginary ventral margin of the caudate lobe, which was a milestone in the definition of the ventral margin of the caudate lobe. However, it is an illusory plane that could not be used as the foundation on which to base surgical decisions. In the current study, we used the MHV-RHV plane to facilitate identifying the ventral margin of the caudate lobe. The RHV and MHV could be easily identified during surgery because their locations were relatively fixed, allowing them to serve as landmarks. Traditionally, the caudate lobe was thought to be confined within the RHV and MHV. Based on this belief, surgeons performed total caudate lobectomy. Our results showed, however, that 28 cases (30%) exceeded the MHV-RHV plane. Kumon [5] noted that the paracaval portion reached the liver surface underneath the diaphragm in 53% of corrosion liver casts. Kwon et al. [10] found the same results in 50% of cadaveric studies, and Maki et al. [8] reported the same results in 30% of images of living patients. In this type of caudate lobe, it is impossible to perform total caudate lobectomy from the dorsal side of the liver.

Although our research has limitations—e.g., that small branches (<1-mm diameter) could not be easily identified on CT images—we learned that preoperative analysis of the caudate lobe using Synapse 3D is necessary to evaluate the anatomy of the caudate lobe. Synapse 3D provides the margins of the caudate lobe that 2-dimensional CT cannot.

In conclusion, regarding the right margin, 18% exceeded the RHV-IVC plane, whereas 30% exceeded the MHV-RHV plane for the ventral margin. Evaluating the anatomy of the caudate lobe using Synapse 3D preoperatively could be helpful in achieving more precise anatomical resection of the caudate lobe.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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