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Relationship of the Presence of the Inferior Right Hepatic Vein with the Right Hepatic Vein Diameter and CT Liver Volumetry

Elif Gündoğdu[1]

[1] Department of Radiology, Faculty of Medicine, Eskişehir Osmangazi University, Eskişehir, Turkey

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Address for correspondence Elif Gündoğdu, MD, Department of Radiology, Faculty of Medicine, Eskişehir Osmangazi University, Meşelik Yerleşkesi 26480, Eskişehir, Turkey (e-mail: elif_basbay@hotmail.com).

Abstract

Background Right hepatic venous anatomy, right lobe volume, and percentage of remnant liver are issues to be considered in preoperative planning especially transplantation.

Objectives The aim of this study was to investigate the relationship of the presence of the inferior right hepatic vein (IRHV) with the right hepatic vein (RHV) diameter, right lobe volume, and percentage of remnant liver.

Materials and Methods In this cross-sectional study, the computed tomography (CT) images of 90 patients who underwent triphasic CT for being living liver donation were evaluated retrospectively. The number and diameter of IRHVs and the diameter of main RHV were recorded. For the liver volume analysis, a deep learning-based automatic liver segmentation (Hepatic VCAR) program was used. A virtual hepatectomy plane was drawn, where the right and left liver volumes were found and the percentage of the left lobe to the total liver volume was calculated. Pearson's correlation analysis was used for correlation analysis and Student's *t*-test was used to compare parameters.

Results A total of 74 IRHVs were detected in 53 (58.88%) of 90 patients. There were no differences in the percentage of remnant left lobe volume, right lobe volume, and RHV diameter between the IRHV (+) and (−) groups. The RHV diameter had a weak negative correlation with the IRHV diameter, and a weak positive correlation with the right lobe volume.

Conclusions The percentage of remnant left lobe volume, right lobe volume, and RHV diameter did not differ in liver donors with and without an IRHV. The RHV diameter had a weak negative correlation with the IRHV diameter and a weak positive correlation with the right lobe volume.

Keywords
- ► CT liver volumetry
- ► deep learning-based automatic liver segmentation
- ► inferior right hepatic vein
- ► living donor liver transplantation

Introduction

Hepatic veins are the main veins that provide the connection between the systemic and portal systems and perform venous drainage of the liver. The left, middle, and right hepatic veins (RHVs) are the main veins draining the liver (►**Fig. 1**). In addition, there are many small veins called accessory or short hepatic veins.[1] The numerical and

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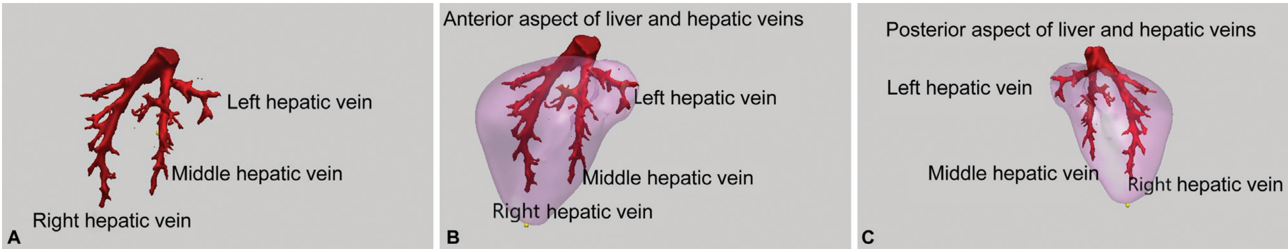

Fig. 1 Hepatic veins (three-dimensional image): (**A**) coronal view, (**B**) anterior aspect of the liver and hepatic veins, and (**C**) posterior aspect of the liver and hepatic veins.

positional variations in venous structures are very important in complex hepatobiliary surgical procedures, especially in liver transplantation from living donors.[2,3] Prevention of acute complications, e.g., necrosis and hepatic failure, and chronic complications, such as atrophy, is only possible with the complete venous drainage of each segment of the liver.[4] The morphological and functional anatomy of the liver differs. Morphologically, it is divided into the right and left lobes by the falciform ligament. The concept of functional anatomy was introduced in 1957 by the French surgeon Couinaud,[5] who suggested that the liver consisted of independent functional segments with their own vascular and biliary drainage. According to this concept of functional anatomy, the liver is divided into eight segments. This classification is used by surgeons because each segment can be surgically resected separately. Although new classifications of functional anatomy have been developed by various researchers, the Federative Committee on Anatomical Terminology still recommends the use of the Couinaud classification for a common terminology.[6]

For adult patients, donor right hepatectomy is performed in right lobe transplantation from a living donor.[7] In the hemihepatectomy plane, the relatively avascular Cantlie line (►**Fig. 2**), which passes approximately 1 cm to the right of the middle hepatic vein and runs in the direction of the gallbladder bed and the inferior vena cava, is preferred.[8] Right hepatic venous anatomy, right lobe volume, and percentage of remnant liver are issues to be considered in preoperative planning.[3,7] Right lobe venous drainage is mainly provided by RHV. The accessory inferior right hepatic vein (IRHV) is the most common venous variation observed at a rate of 6 to 67%, mainly playing a role in the drainage of segment 6.[1,9] The presence and diameter of IRHVs are important for the decision of venous reconstruction. Reconstruction is not required for IRHVs with a diameter of less than 5 mm, while there is a need for surgical reconstruction in those with a diameter of 5 mm or above.[9] It has been reported that there is a negative correlation between the presence of IRHV and the RHV diameter,[1,4] which is even more important considering the possibility of a diameter mismatch in RHV anastomosis.

Although there are a limited number of radiological studies evaluating the relationship between the presence and diameter of IRHV and the diameter of RHV, to our knowledge, no research has investigated the relationship between the presence and diameter of IRHV and the right lobe volume and percentage of remnant liver. Therefore, this study aimed to investigate the relationship between the presence of IRHV and the RHV diameter, right lobe volume, and percentage of remnant liver.

Materials and Methods

The study was undertaken in a tertiary-care hospital. It was approved by the Ethics Committee of the Faculty of Medicine

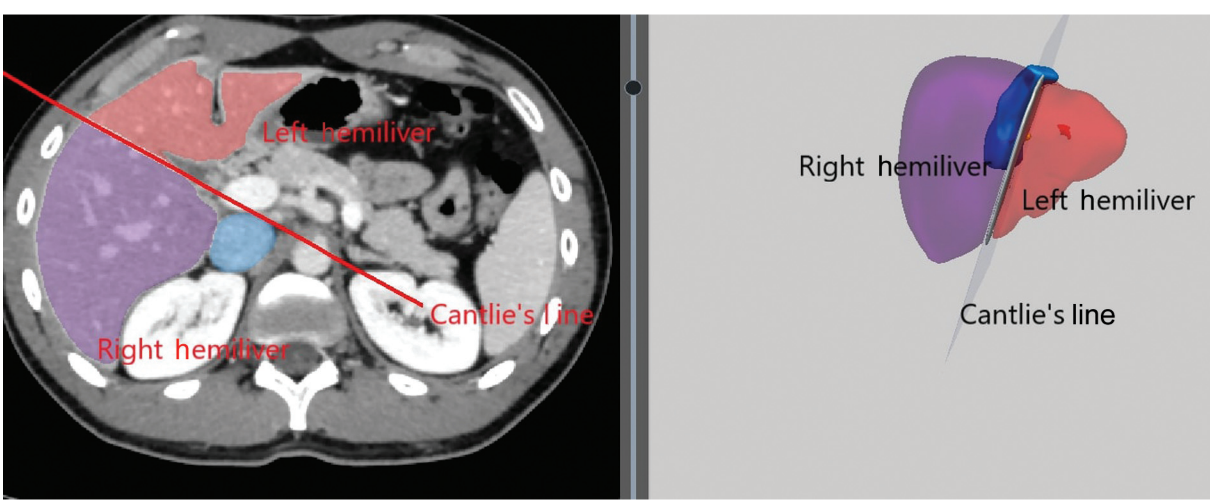

Fig. 2 Cantlie line (extending down from the gallbladder fossa to the left border of the inferior vena cava) dividing the liver into the right and left lobes.

of Eskişehir Osmangazi University (No: E-25403353–050.99–224161 Date: 13.07.2021). The study was conducted in accordance with the principles of the Helsinki Declaration. Datasets were evaluated retrospectively. Therefore, approval and informed consent were not necessary and were waived by our local institutional review board.

Selection of Study Participants

The computed tomography (CT) images of patients who underwent triphasic CT for being living liver donation between January 2018 and July 2021 were evaluated retrospectively. Ethics committee approval was obtained for unrelated donors and related donors were first, second, or third-degree relatives of the recipient. Patients with CT examinations in which it was not possible to evaluate hepatic venous structures due to motion artifacts or an inappropriate contrast phase were not included in the study. In addition, patients with conditions that could affect hepatic hemodynamics (congestive heart failure, tricuspid insufficiency-stenosis, Budd-Chiari syndrome, sinusoidal obstruction syndrome, Osler-Weber-Rendu disease, cirrhosis, solid hepatic mass) were excluded from the study. The CT scans of the remaining 90 patients were included in the study.

Image Acquisition

CT imaging was performed using 64-slice (Aquilion 64; Toshiba Medical Systems, Tokyo, Japan) or 128-slice (GE, Revolution EVO, United States) multidetector CT scanners with the following parameters: 1:1 pitch, 200 to 300 mAs, 120 kVp, and 05 to 0.625 mm isotropic spatial resolution. The subjects were examined in a supine position with their arms extended above their heads.

An iodinated intravenous contrast agent (1.5 mL/kg; iohexol 350, GE Healthcare, United States) was administered through the antecubital veins with an automatic injector at a rate of 4 to 5 mL/s. Saline (20 mL) was injected both prior to and following the injection of the contrast media with the same flow rate. Optimal scan time was detected by the automated bolus tracking method by placing the region of interest over the descending aorta and setting the trigger threshold to 100 HU. Images were obtained in the arterial, portal, and hepatic venous phases.

Image Analysis and Interpretation

The images were evaluated by a single radiologist experienced in transplantation and abdominal radiology using a dedicated workstation (Advantage WorkStation AW 4.7 software, GE Healthcare, Wisconsin, United States). Axial images were reviewed in the first order, then multiplanar reformate images, and thick slab maximum intensity projection images were reviewed to better evaluate the vascular anatomy. The diameter of main RHV draining into inferior vena cava at the level of diaphragm was recorded. All the accessory veins draining segments 6 and 7 of liver, below the level of the diaphragm, were classified as IRHVs. The number and diameter of IRHVs were noted. Axial plane was used for the measurement of diameter in all veins.

For the liver volume analysis, a deep learning-based automatic liver segmentation (Hepatic VCAR, GE Healthcare, United States) program was used. The liver boundary was checked to exclude the surrounding structures/organs, major vessels, and hepatic fissures on every single slice and was corrected manually if present. A virtual hepatectomy plane was drawn on the axial images to the right of the middle hepatic vein (identical to the Cantlie line used during surgery). The right and left liver volumes were found and the percentage of the left lobe to the total liver volume was calculated.

Statistical Analysis

SPSS software v. 22.0 (IBM Corp.) was used for statistical analysis. The normality analysis was performed with the Shapiro–Wilk test. Descriptive statistics of discrete data are given in the form of n (%). Student's t-test was used to compare parameters. A p-value of less than 0.05 was considered significant. Pearson's correlation analysis was used as a parametric test since the data showed normal distribution for correlation analysis. According to the correlation coefficient, the correlation was evaluated as very poor (0.00–0.25), poor (0.25–0.49), moderate (0.50–0.69), high (0.70–0.89), and very high (0.90–1.0). A receiver operating characteristic (ROC) analysis was undertaken to evaluate the size of RHV in estimation of presence or absence of IRHV. The area under the curve (AUC) was used to determine the cutoff value. The optimal cutoff values were determined according to Youden J index (sensitivity + specificity-1). For the cutoff value of diameter RHV, the sensitivity and specificity values were calculated at the 95% confidence interval.

Results

This study included 90 patients, of whom 34 (37.77%) were female and 56 (62.22%) were male. The mean age of the patients participating in the study was 37.89 ± 10.71 (19–60) years. There was no age difference between the male and female patients ($p = 0.61$).

RHV was not observed in one of the patients included in the study. The mean RHV diameter of the remaining patients was 8.97 ± 2.29 (4.20–15.04) mm. A total of 74 IRHVs were detected in 53 (58.88%) patients (two in 15 patients and three in three patients) (►**Fig. 3**). The mean IRHV diameter was 6.16 ± 4.20 (2–14) mm. There was no difference in age or gender between the IRHV (+) and (−) groups ($p = 0.49$ and $p = 0.37$, respectively).

No significant difference was found between the IRHV (+) and (−) groups in terms of the percentage of remnant left lobe volume and the right lobe volume ($p = 0.592$ and $p = 0.433$, respectively). Among the IRHV (+) patients, the RHV was of finer calibration, but this difference was not statistically significant ($p = 0.19$). The findings are summarized in ►**Table 1**.

The IRHV diameter was more than or equal to 5 mm in 20 (22.22%) patients. There were no significant differences in the remnant left lobe volume percentage, right lobe volume, and RHV diameter between the more than or equal to 5 mm IRHV (+) and (−) groups ($p = 0.432$, $p = 0.599$, and $p = 0.10$, respectively). The findings are summarized in ►**Table 2**.

Fig. 3 Axial and coronal plane computed tomography images showing the inferior right hepatic vein.

Table 1 Comparison of the right hepatic vein diameter, right lobe volume, and percentage of remnant left lobe volume between the IRHV (+) and (−) groups

	IRHV (+) group ($n = 53$)	IRHV (−) group ($n = 37$)	p-Value
Right hepatic vein diameter (mm)	8.59 ± 2.73	9.28 ± 1.98	0.19
Right lobe volume (cm^3)	1,037.38 ± 254.49	996.57 ± 241.53	0.433
Percentage of left lobe volume (%)	33.41 ± 6.25	34.13 ± 6.30	0.592

Abbreviation: IRHV, inferior right hepatic vein.

Table 2 Comparison of the right hepatic vein diameter, right lobe volume, and percentage of remnant left lobe volume between the more than or equal to 5 mm IRHV (+) and (−) groups

	≥5 mm IRHV (+) group ($n = 20$)	≥5 mm IRHV (−) group ($n = 70$)	p-Value
Right hepatic vein diameter (mm)	8.04 ± 2.57	9.11 ± 2.40	0.10
Right lobe volume (cm^3)	1,043.90 ± 210.91	1,013.94 ± 259.46	0.599
Percentage of left lobe volume (%)	32.91 ± 4.58	33.93 ± 6.66	0.432

Abbreviation: IRHV, inferior right hepatic vein.

There was a weak negative correlation between the RHV diameter and the IRHV diameter in IRHV (+) group (correlation coefficient: -0.358, $p = 0.01$). A weak positive correlation was observed between the RHV diameter and the right lobe volume (correlation coefficient: 0.250, $p = 0.05$).

The ROC curve analysis was performed to evaluate the diagnostic efficacy of the RHV diameter in predicting the presence of IRHV (►**Fig. 4**). When the cutoff value was taken as 9.36 mm for the RHV diameter, there was no IRHV in the presence of an RHV with a greater diameter, and the sensitivity and specificity were calculated as 54 and 71.2%, respectively (AUC: 0.593).

Discussion

IRHV was found in 53 (58.88%) of the 90 patients included in our study, and it was more than or equal to 5 mm in 20 (22.22%) of these patients. There were no significant differences in the remnant left lobe volume percentage, right lobe volume, and RHV diameter between the IRHV (+) and (−) groups or between the more than or equal to 5 mm IRHV (+) and (−) groups. A weak negative correlation was found between the RHV diameter and the IRHV diameter in the IRHV (+) patients. There was also a weak positive correlation between the RHV diameter and the right lobe volume. The cutoff value for the RHV diameter was 9.36 mm in predicting the presence of IRHV.

The prevalence of IRHV has been reported as 6 to 67% in previous studies.[1] One of the main reasons why prevalence rates vary is due to technical parameters. Makuuchi et al evaluated the presence of IRHV with ultrasonography (USG) and reported the prevalence of IRHV to be 10%.[10] This low rate can be explained by USG being operator-dependent, affected by gas artifacts, and unable to adequately evaluate especially posterior body regions in obese patients. In addition, the authors conducted that study back in 1983, and

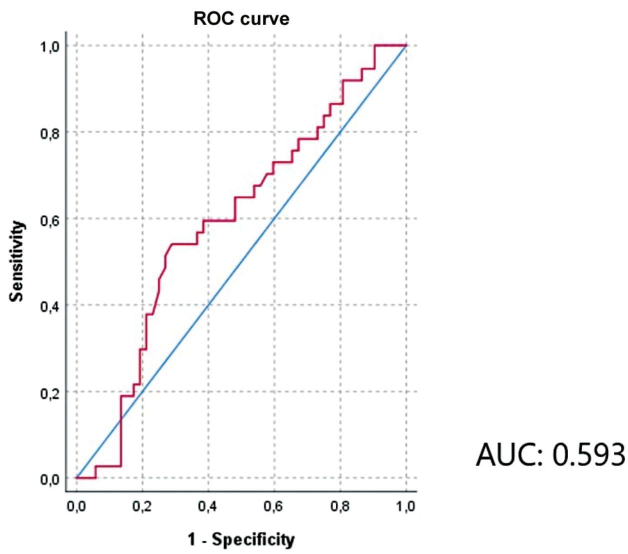

Fig. 4 Receiver operating characteristic analysis for the evaluation of the size of right hepatic vein in the estimation of the presence or absence of the inferior right hepatic vein.

since then technological developments have increased USG image resolution. Another study reporting a low prevalence rate was Soyer et al.[11] In that study, the prevalence of IRHV was determined as 8.6% based on CT. The authors performed CT examinations with 8 mm collimation, 8 mm per second table speed, and 4 mm reconstruction interval and obtained images only in the axial plane, and the CT device was of the helical type. These factors can result in small IRHVs not being visualized. Therefore, their low prevalence value is considered to be due to technical reasons. In other studies with a relatively low prevalence, there was a bias due to patient selection.[3,12] The prevalence of IRHV was reported as 21% by Fang et al, who evaluated patients with chronic hepatitis of a certain age range and 19% by Sahani et al, who evaluated patients with hepatic tumors scheduled for surgery.[3,12] In contrast, in studies conducted with liver donor candidates in the literature, higher prevalence rates, such as 40 to 67.5%, have been reported.[2,7,13–16] In this study, we found the prevalence of IRHV to be 58.88% in hepatic donor candidates, which is similar to the literature. Performing a multiphasic examination that includes hepatic and portal phases separately in liver donor candidates can increase the detectability of IRHV. Especially small IRHVs can be overlooked in routine portal phase imaging; therefore, we consider that higher rates are reported in donor candidates who undergo a multiphasic examination. IRHVs of 5 mm and larger require separate anastomosis to prevent venous congestion at the graft.[2,9,17] In the literature, the prevalence of IRHVs greater than 5 mm has been reported to vary between 6 and 56.7%.[17,18] Consistent with the literature, we found the prevalence of more than or equal to 5 mm IRHV as 22.22%.

Left-lobe grafts are usually not sufficient except for pediatric cases, and therefore right lobe transplantation is preferred in adult patients.[2,7] Preoperative knowledge of the right and left lobe volumes is essential to provide adequate metabolic function until regeneration in the donor and ensure donor-recipient volume compatibility to prevent graft failure in the recipient.[7] For the safety of the donor, the volume of the remnant left lobe should be more than 30%.[19] To calculate the adequate liver volume for the recipient, the graft-to-recipient body weight ratio (GRWR) is calculated, in which the estimated graft volume rather than the actual graft weight is used (estimated GRWR = graft volume/recipient body weight × 100), and for most centers, the minimum acceptable GRWR is 0.6 to 0.8.[20] In this study, we evaluated the relationship between the remnant left lobe volume percentage and the right lobe volume. We investigated the usability of the presence of IRHV in volume estimation. Both in all patients with an IRHV and in those with a more than or equal to 5 mm IRHV, the right lobe volume was greater and the remnant left lobe volume was smaller compared with the remaining patients. It is expected that a greater volume results in the need for more venous drainage, and we also observed this situation in our study. However, the volume difference we found was not statistically significant, and accordingly we concluded that the presence and diameter of IRHV could not be used in the estimation of volume. We detected a weak positive correlation between the RHV diameter and the right lobe volume. In light of this information, it can be predicted that the right lobe volume will be greater in donors with greater RHV diameters. To our knowledge, there is no study on this subject in the literature, and thus we consider that our results make a valuable contribution to the literature and should be supported by further studies involving more patients.

The RHV diameter is important for donor-recipient diameter compatibility. Since both RHV and IRHV drain the same liver lobe and there are intersections between drainage areas, we tested whether the RHV diameter would be smaller in the presence of IRHV and in thick IRHVs. In both the IRHV (+) and more than or equal to 5 mm IRHV (+) groups, the RHV was of finer calibration, but the differences were not statistically significant compared with the remaining patients. Nevertheless, we did find a weak negative correlation between the RHV diameter and the IRHV diameter in the IRHV (+) patients. Similarly, Yang et al reported a weak negative correlation between the RHV diameter and the IRHV diameter.[4] According to our results, the presence of an RHV greater than 9.36 mm in diameter detected the absence of IRHV at a sensitivity of 54% and specificity of 71.2%. Therefore, a thin RHV should alert clinicians to the presence of IRHV.

According to the results of our study, although there is no significant relationship between the presence of IRHV and remnant left lobe volume percentage, right lobe volume, and RHV diameter, it may be necessary to be more sensitive in the evaluation of volumetric measurements in this patient group, since the remnant left lobe volume percentage decreases in the presence of IRHV. In the current donor evaluation, there are different methods for hepatic volume (manual, semiautomatic, automatic liver segmentation), especially in radiology departments with limited experience in transplantation, their combined use can be thought. Internal validation can be achieved by looking at the intraobserver and interobserver correlations in patients with IRHV.

The main limitation of our study is the small number of patients. Our results need to be supported by further studies involving a larger number of patients. In addition, CT examinations being evaluated by a single radiologist can be seen as a limitation, but we consider that the evaluator's experience in transplantation radiology invalidates this limitation.

Conclusion

The remnant left lobe volume percentage, right lobe volume, and RHV diameter did not differ in liver donors with and without an IRHV. There was a weak negative correlation between the RHV diameter and the IRHV diameter and a weak positive correlation between the RHV diameter and the right lobe volume. A thin RHV diameter should alert clinicians to the presence of IRHV. It can be predicted that the right lobe volume will be greater in patients with a thick RHV.

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Conflict of Interest
None declared.

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