Analysis of the Hepatic Segments on the Isotropic Multi-planar Reformatted CT Images

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Purpose: We wanted to evaluate the diverse distribution and relation of the hepatic segments, as divided by the portal venous territories, on the isotropic multi-planar reformatted (MPR) CT images and we wanted to find their correlation to the intrahepatic venous structures.

Materials and Methods: Fifty adult patients who underwent portal phase CT images and who had the normal liver contours at CT were included in our study. The portal phase images were obtained with a slice collimation and reconstruction interval of 1.25 mm, and they were reformatted in the coronal and sagittal planes with a slab thickness of 3 mm. For analysis of these MPR images, various terms were newly defined according to the portal venous territories (e.g., three vertical planes [right, middle and left] and one transverse plane and their plane angles, the transverse and longitudinal angles). Also, the dominant segments of the right lobe were newly divided into the S7- and S8-dominant types by comparing the transverse angles. The imaging analysis was then conducted for the following: (1) the diversity of the three vertical planes and the one transverse plane and their plane angles, (2) the proportion of the dominant segments of the right lobe and their relation with the plane angles, and (3) the correlation between the dominant segments and the intrahepatic venous structures.

Results: The number of the S7- and the S8-dominant types was 21 and 29, respectively. The vertical and transverse planes were undulating and diverse according to the dominant segments as follows: the plane angles of the right vertical and middle vertical planes were more vertical in the S7-dominant type than in the S8-dominant type ($p < 0.001$). The right transverse plane angle was more horizontal in the S8-dominant type ($p < 0.05$). The left transverse plane angle seemed to be rather vertical than horizontal. For the intrahepatic venous structures, despite of our limited data, the anomalous intrahepatic venous structures might have some correlation with the dominant segments.

Conclusion: According to our results, we suggest that the isotropic MPR images could successfully depict the vertical and transverse planes of the real hepatic segments, as divided by the portal venous territories, which were diverse according to their dominant types.

Index words: Liver, anatomy
Liver, CT
Owing to the segment-oriented approach to performing hepatic resection, the precise segmental localization of hepatic tumor on radiologic studies has become important to radiologists. There have been several radiologic studies during the past ten years to describe the segmental anatomy of the liver upon ultrasonography, computed tomography (CT) and magnetic resonance imaging (1- 10). Needless to say, these studies were accomplished based on the Couinaud classification of the eight segments, which were divided by the three vertical and one transverse scissurae [5]. In this standardized classification, the three vertical scissurae were defined to be the flat planes in the vertical axis that traversed the three hepatic veins, and the transverse plane was defined to be the flat plane that traversed the right and left portal veins. Recently, this classification has been found to be questionable and incompatible with the real segmental anatomy, as defined by the vascular territories that have been proposed by some radiologists (6- 10).

Owing to the advent of 16-slice multi-detector row CT, the axial images of a submillimeter-thickness have been easily reconstructed and reformatted into the coronal and sagittal multi-planar reformatted (MPR) images. The resultant MPR images showed the same image quality as that of the axial images, and they were called the ‘isotropic images’. The isotropic images have recently become widely available and they have emerged as a powerful investigative tool. During our daily practice with the isotropic MPR images, we have found that the vertical and transverse planes, as divided by the vascular territories of the portal vein on the coronal and sagittal MPR images, were not well correlated with those scissurae defined by the Couinaud classification. We also recognized that the dominant hepatic segments seemed to contain more extensive venous supply and drainage. In this respect, the purpose of our study was to evaluate the diverse distribution and relation of the hepatic segments, as divided by the portal venous territories on the isotropic multi-planar reformatted (MPR) CT images, and we evaluated their correlation to the intrahepatic venous structures.

Materials and Methods

Patient Selection

During a five-month-period (from April 2004 to September 2004), we reviewed the medical records of the patients who were referred to our CT unit for performing abdomen CT scans of various protocols, and we selected the patients who had no history of liver disease. A portion of these patients underwent CT scans using a 16-slice MDCT, and 50 adult patients among these patients were consecutively selected as a study population. These 50 patients appeared to have the normal liver contours and intrahepatic venous structures that were sufficiently well depicted on the portal phase CT images of the liver. Their ages ranged from 32 to 86 years (mean age: 56 years), and there were 24 men and 26 women.

Image Acquisition and Post-processing

All patients underwent CT scans with a 16-slice MDCT (Lightspeed Ultra 16, General Electric Medical Systems, Milwaukee, Wis). All the CT scans consisted of either biphasic (the arterial and portal phases) or triphasic (the arterial, portal and equilibrium phases) CT images according to their protocols, of which the portal phase images were obtained 70 seconds after the injection of the contrast material. A total of 120 mL of non-ionic Iopromidol at a concentration of 300 mgI/mL (Ultravist 300; Schering AG, Germany) was intravenously administered at a rate of 4 mL/sec. The scan parameters used for all the CT scans were 1.25-mm slice collimation and a 1.25-mm reconstruction interval with a table speed of 18.75 mm/sec [beam pitch, 0.938]. The axial images of all the phases were reconstructed at every 5 mm thickness to provide contiguous sections, and then the sections were transferred to the Picture Archiving and Communication Systems (PACS, General Electric Medical System). Also, the portal phase image data of the 1.25-mm slice collimation were transferred to a dedicated workstation (Advantage Workstation 4.0, General Electric Medical Systems), and then this was reformatted into the coronal and sagittal MPR images with a slab thickness of 3 mm. These coronal and sagittal images were again transferred to the same PACS.

Image Analysis

Images analysis was done with the axial, coronal and sagittal MPR images of the portal phase by two abdominal radiologists working in consensus on a 2,000 x 2,000 PACS monitor (General Electric Medical System, Milwaukee, Wis) for the following: (1) the diversity of the three vertical planes (i.e., right, middle and left) and the one transverse plane and their plane angles, as defined by the portal venous territories and the corresponding hepatic segments, (2) the proportion of the newly defined dominant segments of the right lobe and their relation with the plane angles, and (3) the correla-
tion between the dominant segments and the intrahepatic venous structures.

To obtain the above-mentioned plane angles, we first defined the three vertical planes and one transverse plane and their plane angles as follows: the right vertical plane was defined as an imaginary plane that traversed the right hepatic vein and the vascular territories that were divided by the tributaries of the anterior and posterior segmental branches of the right portal vein. The middle vertical plane was defined as an imaginary plane that traversed the middle hepatic vein and the vascular territories that were divided by the tributaries of the anterior segmental branch of the right portal vein and the medial segmental branch of the left portal vein. The left vertical plane was defined as an imaginary plane that traversed the left hepatic vein and the vascular territories that were divided by the tributaries of the medial and lateral segmental branches of the left portal vein. The transverse planes were defined as an imaginary plane that traversed the vascular territories that were divided by the tributaries of the portal vein branches of the upper segment (segment 7 and segment 8) and the lower segment (segment 5 and segment 6) in the right lobe, and the vascular territories were divided by the tributaries of the portal vein branches of segment 2 and segment 3 in the left lobe. We then drew the right, middle and left vertical planes and the right and left transverse planes, based on the above-defined portal venous territories, on both the coronal (Fig. 1) and sagittal (Fig. 2) MPR images.

To obtain the vertical plane angles, we drew a straight line that crossed the right or middle vertical plane and it evenly divided both sides of the vascular territories, i.e., the anterior and posterior segments for the right vertical plane (Fig. 2B), and the right and left lobes for the middle vertical plane (Fig. 2G), on the most representative sagittal MPR images. We then separately obtained the right transverse plane angle (Fig. 2D) and left transverse plane angle (Fig. 2L) by measuring the angle between the straight line and the true vertical axis because each transverse plane angle was regarded to have its own significance.

The correlation of the vertical plane angles and the dominant segments of the right lobe.

To obtain the transverse plane angle, we drew a straight line that crossed the right and left transverse planes and it evenly divided both sides of the vascular territories, i.e., the upper and lower segments for the right transverse plane (Fig. 2D) and segment 2 and segment 3 for the left transverse vertical plane (Fig. 2L), on the most representative sagittal MPR images. We then separately obtained the right transverse plane angle (Fig. 2D) and left transverse plane angle (Fig. 2L) by measuring the angle between the straight line and the true horizontal axis because each transverse plane angle was usually measured by adding the right and middle vertical plane angles, which were measured on the different MPR images.

To determine the dominant segment of the right lobe, we measured the angle between the right hepatic vein and the posterior surface of the right lobe to obtain the ‘S7-transverse angle’ (Fig. 3A) and we measured the angle between the right hepatic vein and middle hepatic vein to obtain the ‘S8-transverse angle’ (Fig. 3B) on the most representative axial images. Here the most representative axial image indicated the axial image, which showed the maximum angle of each transverse angle, and this was usually different according to the each reconstructed level. We then decided the dominant segment of the right lobe by comparing both angles, and we defined the ‘S8-dominant type’ when the S8 angle was greater than the S7 angle, and vice versa. Finally, the dominant segments were correlated with all of the vertical and transverse plane angles to present the arrangement of each dominant segment.

The anomalous portal veins (Fig. 4A) and hepatic veins (Fig. 4B) were analyzed to find their relation to the hepatic segments. The statistical analysis was conducted with the use of the independent sample t-tests to verify the statistical significance between the dominant segments of the right lobe and various plane angles. P-values less than 0.05 were considered statistically significant.
Fig. 1. A-J. A series of the isotropic coronal multi-planar reformatted CT images (A-I) and their corresponding levels on the axial images (J). The three vertical planes were oblique to the upward left side. The right transverse plane was upwardly convex. Segments 5 and 8 were located lateral to the middle hepatic vein. The transverse part of the left portal vein divided segments 2 and 3. The numbers indicate the number of the hepatic segment. RAPV = right anterior portal vein, RPPV = right posterior portal vein, LPV = left portal vein, RHV = right hepatic vein, MHV = middle hepatic vein, LHV = left hepatic vein.
Results

In all patients, the right vertical plane was undulating and oblique to the upward right side on the coronal images (Fig. 1), and to the upward posterior side on the sagittal images (Fig. 2); thus, the anterior segments (segment 5 and segment 8) occupied the anterosuperior part of the right lobe. The right vertical plane angle (Fig. 2B) ranged from 13 to 83 degrees (mean: 34 degrees) in the S7-dominant type and from 29 to 77 degrees (mean: 53 degrees) in the S8-dominant type, indicating the right vertical plane angle was more vertical in the S7-dominant type than in the S8-dominant type ($p<0.001$). In all patients, the middle vertical plane was undulating and oblique to the upward right side on the coronal images (Fig. 1) and to the upward anterior side on the sagittal images (Fig. 2); thus, the right lobe was located posterosuperiorly. The middle vertical plane angle (Fig. 2G) ranged from 20 to 89 degrees (mean: 45 degrees) in the S7-dominant type and from 28 to 88 degrees (mean: 55 degrees) in the S8-dominant type, indicating the middle vertical plane angle was more vertical in the S7-dominant type than in the S8-dominant type ($p<0.05$).

In all patients, the right transverse plane was upwardly convex on the coronal and sagittal images (Fig. 1, 2); thus, the lower segments (segment 5 and segment 6) might extend upward over the right portal vein. The right transverse plane angle (Fig. 2D) ranged from 9 to 172 degrees (mean: 41 degrees) in the S8-dominant type and from 6 to 172 degrees (mean: 52 degrees) in the S7-dominant type, indicating the right transverse plane angle was more horizontal in the S8-dominant type than in the S7-dominant type ($p<0.05$). In all patients, the left transverse plane was oblique to the upward posterior side on the sagittal MPR images (Fig. 2); thus the segment 2 occupied the posterosuperior part of the lateral segment. The left transverse plane angle (Fig. 2L) ranged from 53 to 194 degrees (mean: 87 degrees), indicating that the left transverse plane angle was almost vertical.

The number of the S7-dominant type and the S8-dominant type were 21 and 29, respectively. The S7-transverse angle (Fig. 3A) ranged from 39 to 73 degrees (mean: 51 degrees) in the S7-dominant type, and from 18 to 46 degrees (mean angle: 32 degrees) in the S8-dominant type ($p<0.001$). The S8-transverse angle (Fig. 3B) ranged from 19 to 68 degrees (mean: 40 degrees) in the S7-dominant type, and from 22 to 75 degrees (mean: 51 degrees) in the S8-dominant type ($p<0.001$). These results indicated that the S7-transverse angle was significantly greater in the S7-dominant type than in the S8-dominant type, and vice versa. The S8-longitudinal angle (Fig. 2B and 2G) ranged from 56 to 137 degrees (mean: 78 degrees) in the S7-dominant type and from 73 to 140 degrees (mean: 108 degrees) in the S8-dominant type ($p<0.001$), indicating that the S8-longitudinal angle was significantly greater in the S8-dominant type than in the S7-dominant type.

For the anomalous supply of the portal vein, the anterior branch of the right portal vein that arose from the left portal vein was seen in four patients of the S7-dominant type (Fig. 4A). The left portal vein that arose from the anterior branch of the right portal vein was seen in one patient of the S7-dominant type. In the S8-dominant type, the anterior branch of the right portal vein that arose from the left portal vein was seen in two patients, while the posterior branch of the right portal vein that arose from the anterior branch of the right portal vein was seen in one patient. For the anomalous drainage of the hepatic vein, one or two prominent inferior right hepatic veins greater than 5 mm in diameter were present in all of the S7-dominant type (Fig. 4B), whereas they were present in nine of the S8-dominant type (38%) ($p=0.035$).
Fig. 2. A-M. A series of the isotropic sagittal multi-planar reformatted CT images (A-L) and their corresponding levels on the axial images (M). The right vertical plane was oblique to the upward posterior side. Thus, the anterior segments (segment 5 and segment 8) occupied the anterosuperior part of the right lobe. The right vertical plane angle was obtained by measuring the angle between the straight line crossing the right vertical plane and the true vertical axis (B). The straight line was drawn to evenly divide the vascular territories of the anterior and posterior segments. The middle vertical plane was oblique to the upward anterior side. Thus, the right lobe was located posterolaterally. The middle vertical plane angle was obtained by measuring the angle between the straight line drawn in the same manner like Fig. 2B and the true vertical axis (G). The S8-longitudinal angle was obtained by adding the right and middle vertical plane angles, which are shown in Fig. 2B and Fig. 2G, respectively. The right transverse plane was upwardly convex. The right transverse plane angle was obtained by measuring the angle between the straight line that was drawn in the same manner like Fig. 2B and the horizontal axis (D). Segment 5 and segment 6 were located between the right and middle hepatic veins. The left transverse plane was upwardly oblique to the posterior side. Thus, segment 2 occupied the posterolateral part of the lateral segment. The left transverse plane angle was obtained by measuring the angle between the straight line drawn in the same manner like Fig. 2B and the horizontal axis (L). The numbers indicate the number of the hepatic segment. RAPV = right anterior portal vein, RPPV = right posterior portal vein, LPV = left portal vein, RHV = right hepatic vein, MHV = middle hepatic vein, LHV = left hepatic vein, RVP = right vertical plane, RVPA = right vertical plane angle, MVP = middle vertical plane, MVPA = middle vertical plane angle, RTP = right transverse plane, RTPA = right transverse plane angle, LTP = left transverse plane, LTPA = left transverse plane angle, SL = straight line, VA = vertical axis, HA = horizontal axis.
Discussion

As described above, the current concept that we utilized for the segment-oriented hepatic resection is based on the Couinaud classification [5]. Several radiologic studies for the segmentation method of the liver have been done to meet the growing need for accurate preoperative localization of a focal hepatic lesion [1-4]. In these studies, the liver on the cross-sectional images was divided into eight segments by means of three vertical and one transverse scissurae, as defined by the Couinaud classification. Several radiologists have recently reported observations that called into question this conventional segmentation method. Fasel et al [6] confirmed that the vertical planes that intersected the trunks of the hepatic veins did not correspond to the real segmental boundaries, as divided by vascular territories. Nelson et al [7] evaluated the preoperative segmental localization of a focal hepatic lesion with the use of CT during arterial portography, and they concluded that the CT localization of a focal hepatic lesion disagreed with the extent of the lesion observed upon surgical resection in 11 of 36 lesions (31%). Von Leeuwen et al [8] described the oblique right vertical plane by using two- and three-dimensional MR imaging, and they concluded that the preoperative delineation of the resection planes required consideration of the anatomic variations that exist for the segmental anatomy of the liver. Another report by von Leeuwen et al [9] clarified that the right vertical plane was tilted posteriorly, and the right hepatic vein and transverse plane did not seem to be clear landmarks. These radiologic observations were in good accordance with the results obtained in our study. In this respect, we observed that the correlation of the conventional radiologic segmentation method with the real anatomic segments, as defined by the portal venous territories, was poor because the shape and size of the segments varied greatly according to the portal venous supply, and their territorial boundaries were not flat planes, but rather, they were undulating. Moreover, in our results, the discrepancy between them was more pronounced in the transverse plane than in the vertical plane.

For the vertical planes, we found that they were not in the true vertical axis, but they showed undulating and oblique planes with variable vertical plane angles. Moreover, the right and middle vertical plane angles correlated very closely with the dominant type of the right lobe. According to our results, the right and middle vertical plane angles correlated very closely with the dominant type of the right lobe. According to our results, the right and middle vertical plane angles and the S8-longitudinal angle in the S8-dominant type was more oblique and wider than in the S7-dominant type, indicating the dominant segment of the dome area of the right lobe was segment 8 in the S8-dominant type. This observation corresponded well to the findings described by Ohashi et al [10]. Fasel et al [1] have described that the discrepancy of the segmental boundaries between the conventional segmentation method and the real segmental anatomy, as divided by the portal venous supply, on the axial images varied and this discrepancy was as large as 40 mm maximally. This suggested that a hepatic tumor with a diameter of up to 4 cm could be attributed to an incorrect segment by the
conventional segmentation method. We also recognized this assumption to be realistic for a hepatic tumor located in the dome area because, as mentioned above, the segment in the dome area, as determined by the conventional segmentation method, was quite different from the real anatomic segment, and particularly in the cases of the S8-dominant type. We could eventually observe that this conventional segmentation method was sometimes unsatisfactory to determine the true segmental anatomy of the liver, and the conventional vertical scissurae were an oversimplification that was not in agree with the anatomic reality.

The discrepancy that existed for the transverse plane between the conventional segmentation method and the real segmental anatomy, as divided by the portal venous territories in our study, was greater than that for the vertical plane. The right transverse plane was usually upwardly convex instead of being a flat plane. The right transverse plane angle of the S8-dominant type was proved to be more horizontal. This might be due to the dominant volume of segment 8 that occupied more of the anterosuperior part of the right lobe as compared to the S7-dominant type. The transverse plane angles of the right and left lobes were so different that the right and left transverse plane angles had to be described separately in our results. Contrary to its name, the left transverse plane angle was rather vertical than transverse; thus, segment 2 and segment 3 were located at the posterosuperior and anteroinferior aspects of the lateral segment, respectively.

It is interesting that we found that the portal venous supply and the hepatic venous drainage had some correlation with the dominant type of the right lobe. For the anomalous supply of the portal vein, the less dominant segments were found to have an anomalous portal vein. For example, four patients of the S7-dominant type had an anomalous right anterior branch arising from the left portal vein, and one patient of the S8-dominant type had
an anomalous right posterior branch arising from the anterior branch of the right portal vein. This suggested that the segments supplied by the anomalous portal vein might be less developed and so they became less dominant due to the insufficient blood supply. For example, one patient with the S7-dominant type had an anomalous left portal vein arising from the anterior branch of the right portal vein, which might reduce the portal venous supply to the anterior segment. Regarding these patients, we could suggest that there was a tendency to have a smaller portal supply in the less dominant segments. On the other hand, there were some patients who had anatomy contrary to our ideas. For example, two patients of the S8-dominant type had an anomalous right anterior branch arising from the left portal vein. Regarding these anomalies, the small number of patients in our study seemed insufficient to draw a conclusion about the correlation between the anomalous portal venous supply and the dominant type of the right lobe. For the hepatic venous drainage, we found that all of the S7-dominant types had the inferior right hepatic vein, indicating that the volume of segment 6 was also sufficiently great that it required additional draining veins. Despite of our limited data, we think that the anomalous intrahepatic venous structures might have some correlation with the dominant segments, which further suggests that there might be correlation between the volume of each segment and the intrahepatic venous structures.

Precise localization of a hepatic tumor and depiction of complex intrahepatic vascular structures and their relationships are essential for planning surgical treatment. As is shown in our study, the development of isotropic MPR images allowed us to trace the tributaries of the portal and hepatic veins, and the results enabled us to demarcate the boundaries of the portal venous segments. Moreover, our results revealed that the conventional segmentation method did not always reflect the real segmental anatomy. In this respect, it seems necessary to establish a more accurate radiologic method for localizing the segmental anatomy of the liver, and our study suggested that the MPR images are believed to be helpful for this purpose when comparing them with the information obtained from both the axial and MPR images.

Our study had several limitations. First, the vertical planes were not obtained on the axial images in our study. These planes on the axial images might be also undulate like those seen planes on the MPR images, and they could easily be obtained. Also, these vertical planes were not correlated with the MPR and axial images for clarifying that these planes were completely in accordance with each other. However, it seemed to be sufficient only to analyze the coronal and sagittal MPR images to demonstrate the diversity of the vertical and transverse planes, and to compare the planes angles and the dominant segments. Second, many parameters that included the vertical and transverse planes and the plane angles, as well as the S8-longitudinal angle, were all measured on the sagittal MPR images. As was expected, the two-dimensional sagittal images could not completely show the real, three-dimensional vertical and transverse planes and the plane angles. However, we thought that the sagittal images could indirectly reflect on the tendency for the obliqueness of each plane and the plane angle, and they were better than the coronal images for this purpose, as is shown in Fig. 2. Third, the measurement of all the angles might be subjective because it was sometimes difficult to determine the most representative sagittal image and to draw the straight line crossing the vertical or transverse plane that equally divided both sides of vascular territories. To reduce this limitation, two abdominal radiologists tried to meticulously measure the plane angles of all the sagittal images and the areas of both vascular territories, as divided by the straight line on the most representative images on the PACS monitor. Finally, all of our results were not surgically correlated. In reality, the surgical correlation was not available, and furthermore, we think that the isotropic MPR images were sufficiently good to identify the segmental boundaries according to the portal venous territories.

Despite of these limitations, we might conclude that the isotropic MPR images could successfully depict the real hepatic segments, as divided by the portal venous territories, and these were not well correlated to the conventional segmentation method. On the isotropic MPR images, the hepatic segments were diverse in their distribution and their relationships, according to their dominant types. We additionally found that there might be some correlation between the volume of each segment and the intrahepatic venous structures.

References

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