Abdom Imaging 28:668–674 (2003)
DOI: 10.1007/s00261-002-0088-1

Abdominal Imaging

Variations in anatomy of the middle hepatic vein and their impact on formal right hepatectomy

I. R. Kamel, L. P. Lawler, E. K. Fishman

Russell H. Morgan Department of Radiology and Radiological Sciences, Johns Hopkins Hospital, 600 North Wolfe Street, Baltimore, MD 21287, USA

Abstract

Background: We evaluated the incidence of variations of the middle hepatic vein (MHV) branches and their impact on formal right hepatectomy for living-donor liver transplantation.

Methods: Fifty consecutive patients who underwent hepatic multidetector row computed tomography (CT) were evaluated. Three-dimensional volume rendering techniques were used to evaluate the different branching patterns of the MHV. An incision plane was constructed to simulate a formal hepatectomy along Cantlie's line, immediately to the right of the MHV. The number of transected vessels was recorded by consensus of two observers.

Results: In 11 patients (22%) the MHV had no major (>5 mm) branches. In 15 patients (30%) a major branch was seen draining the right lobe, and in 10 patients (20%) a major branch was seen draining each lobe. In five patients (10%) two major branches were seen draining the right lobe and a single branch draining the left lobe. The remaining nine patients (18%) had other variations, including one patient (2%) with the right hepatic vein arising from the MHV. A formal hepatectomy along Cantlie's line was truly avascular in 15 patients (30%).

Conclusion: A formal right hepatectomy can be performed without transecting major branches of the MHV in one-third of patients. In the remaining two-thirds, one or more major branch of the MHV will need be transected. Preoperative knowledge of these variations is critical for surgical planning.

Key words: Computed tomography—Image processing—Liver—Hepatic venous anatomy.

Correspondence to: I. R. Kamel

Living-donor liver transplantation is a new surgical technique that has developed to overcome the shortage of cadaveric livers available for transplantation [1–4]. This procedure allows healthy donors to donate a portion of their livers to a compatible recipient. The larger right lobe is used for the adult patient, and the smaller left lobe is used for the pediatric patient. Graft resection should be accomplished, leaving a sufficient volume of donor liver with adequate vascular supply and drainage to permit regeneration and metabolic function.

The key to successful donor hepatectomy in living-donor liver transplantation is to obtain a graft and maintain the delicate balance between the blood supply and venous drainage [5]. Venous congestion can seriously damage the newly implanted graft, leading to its failure. Therefore, small hepatic venous branches at or near the site of transection should be left intact, or reconstructed if they are along the parenchymal dissection plane.

Anatomic resection of the right lobe of the liver is based on the segmental anatomy originally described by Couinaud [6] and later modified by Bismuth [7]. The liver is divided into two lobes by the main scissura, which is a vertical plane that contains the middle hepatic vein (MHV; Fig. 1). This plane is also along Cantlie's line, between the gallbladder fossa and the inferior vena cava (IVC).

The purpose of this study was to evaluate the incidence of vascular variations of the MHV and their impact on formal right hepatectomy performed along Cantlie's line.

Surgical technique

The donor operation consists of cholecystectomy followed by right hepatectomy, which includes Couinaud segments V–VIII and the right hepatic vein [3]. An extended right hepatectomy may also be performed, to include Couinaud segment IV and the MHV, in addition to

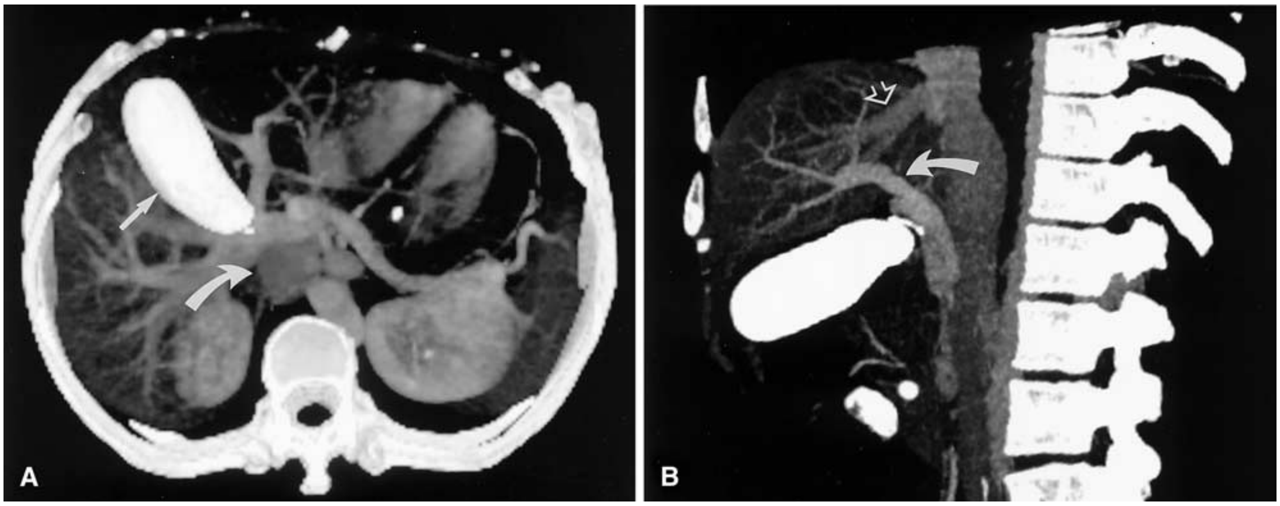

Fig. 1. A 42-year-old woman with a history of pancreatic mass. **A** Axial inferior volume rendered view identifies the gallbladder (*straight arrow*) and inferior vena cava (*curved arrow*), the anatomic landmarks along Cantlie's line. High density of the gallbladder is due to vicarious excretion of contrast. Trapezoid manipulation of the volume rendered image allows for increased transparency of liver parenchyma and conspicuity of the hepatic vascularity. **B** Sagittal MIP along Cantlie's line shows the MHV (*open arrow*), gallbladder, and right portal vein (*curved arrow*).

the right hepatic vein [8]. However, because of the intimate relation of the MHV and left hepatic vein near their drainage into the IVC, surgeons prefer not to dissect the MHV. If the left hepatic vein is injured, it can compromise venous outflow from the remnant left lobe.

Parenchymal dissection can be performed along Cantlie's line by using the MHV as a reference. However, to reduce the risk of serious injury to the MHV, parenchymal dissection is usually performed 1 cm to the right of the MHV. In either case, small hepatic venous branches in the liver graft should be preserved to maintain graft quality and avoid tissue necrosis due to inadequate venous drainage. Intraoperative ultrasonography is used to document the configuration of the MHV as seen by preoperative imaging [9] and to mark on the liver surface the position of the MHV. Parenchymal transection is then performed at the marked plane.

Materials and methods

Image acquisition

Fifty consecutive patients who underwent multidetector row dual phase computed tomography (CT) were evaluated. The indication for CT was to evaluate potential liver donors in 22 patients, evaluate the liver for a possible mass in five patients, and determine resectability of pancreatic neoplasm in the remaining 23 patients. Patients who had liver lesions that affected the branching pattern of the MHV were excluded. Scanning was performed with a variable detector array Volume Zoom unit (Siemens Medical Solutions, Iselin, NJ, USA) using a detector collimation of 2.5 mm, slice thickness of 3 mm, and reconstruction interval of 3–5 mm. All patients received 120 mL of nonionic contrast medium (iohexol, 350 mg/mL; Omnipque, Nycomed Amersham, Princeton, NJ, USA) injected intravenously at a rate of 3 mL/s with a power injector. Portal phase images were acquired 70 s after the start of the contrast injection, with volume data acquisition set during one breath-hold.

Image postprocessing

The CT imaging data was sent from the scanner to a freestanding workstation for postprocessing (3D-Virtuoso, Siemens Medical Solutions). Maximum intensity projection (MIP) and volume rendering techniques were used to evaluate the different branching patterns of the MHV. Initially, clip plane editing was applied to remove slabs of overlying soft tissues (Fig. 2). Histograms of the relative density values were manipulated through trapezoid control of variables such as width, level, opacity, and brightness. In this way visualizations of hepatic veins and surrounding parenchyma was optimized to individual cases. Real-time selection from infinite viewing projections and additional clip planes allowed individual hepatic veins and their branching patterns to be seen (Fig. 3). In certain cases MIP and image rotation techniques were also applied to better define small peripheral branches (Fig. 4). An incision plane was performed with drawing tools on the workstation to simulate a formal right hepatecomy along Cantlie's line (Fig. 5). Real-time cine of

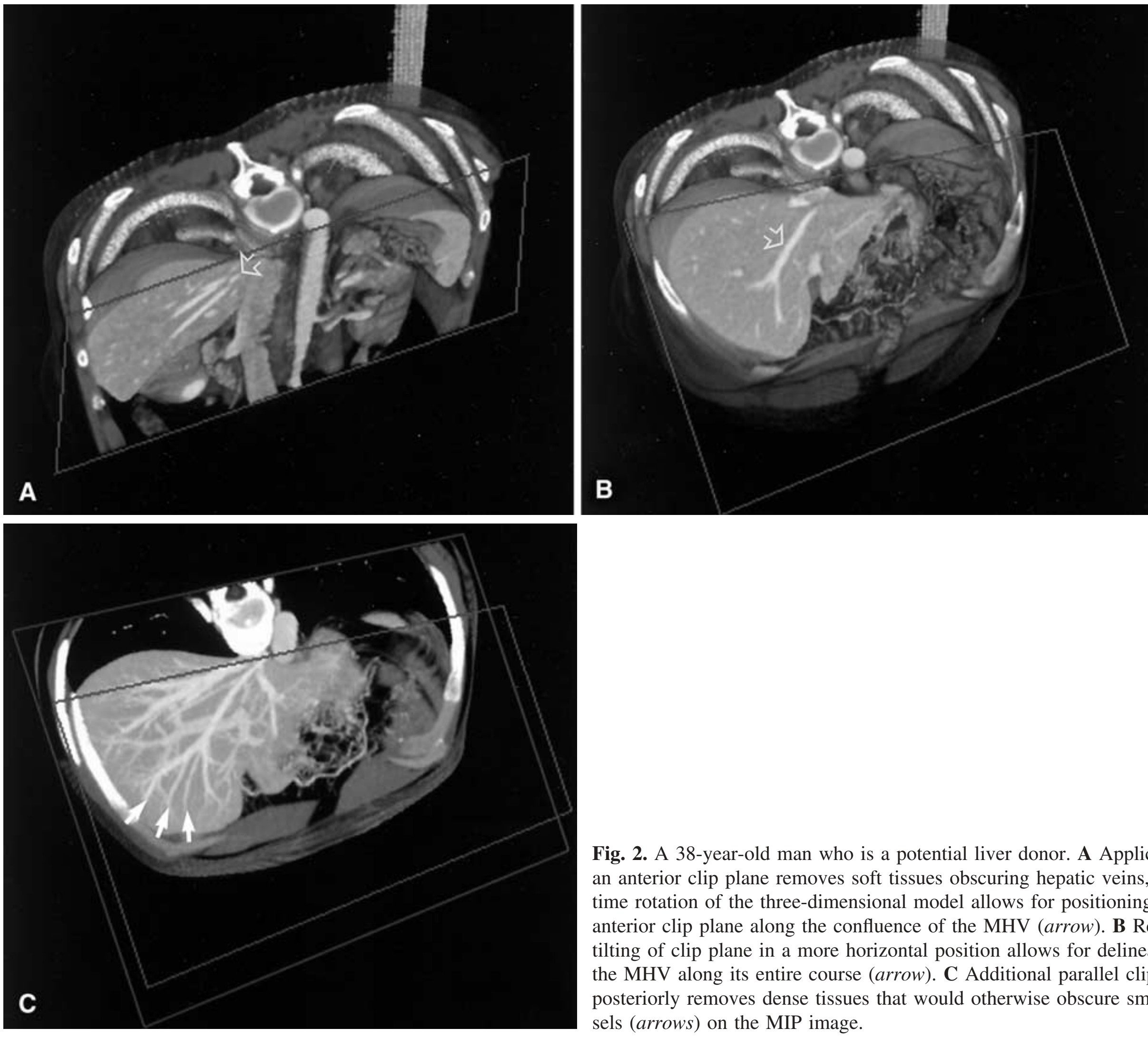

Fig. 2. A 38-year-old man who is a potential liver donor. **A** Application of an anterior clip plane removes soft tissues obscuring hepatic veins, and real-time rotation of the three-dimensional model allows for positioning of the anterior clip plane along the confluence of the MHV (*arrow*). **B** Real-time tilting of clip plane in a more horizontal position allows for delineation of the MHV along its entire course (*arrow*). **C** Additional parallel clip plane posteriorly removes dense tissues that would otherwise obscure small vessels (*arrows*) on the MIP image.

the clip planes along this line was performed, and the vessels and segments traversed by the incision plane were documented and named [10]. The number of transected vessels larger than 5 mm in diameter was recorded. Similarly, a second plane 1 cm to the right of Cantlie's line was drawn, and the number of the transected veins was recorded. In addition, the site of MHV bifurcation was recorded as proximal (<5 cm) or distal (>5 cm) based on the distance between the major bifurcation and the IVC. The average time for image processing was approximately 10 minutes per case.

Results

The MHV was identified in all 50 patients (100%). The superior oblique volume rendered and MIP views along the plane of the MHV were best in demonstrating major branches on both sides of the MHV. The sagittal oblique views were very useful in visualizing small branches extending superiorly and inferiorly from the MHV, which were poorly represented on the axial and coronal oblique planes (Fig. 3). In 11 patients (22%) the MHV had no major (>5 mm) branches (Fig. 5). In 15 patients (30%) a major branch was seen draining the right lobe (Fig. 6), and in 10 patients (20%) a major branch was seen draining each lobe. In five patients (10%) two major branches were seen draining the right lobe and a single branch draining the left lobe. The remaining nine patients (18%) had other variations, including one patient (2%) with the right hepatic vein arising from the MHV. In 45 patients (90%) the MHV had distal (>5 cm from the IVC) confluence, and in four patients (8%) the confluence was proximal (Fig. 7). In one patient (2%) the MHV was very

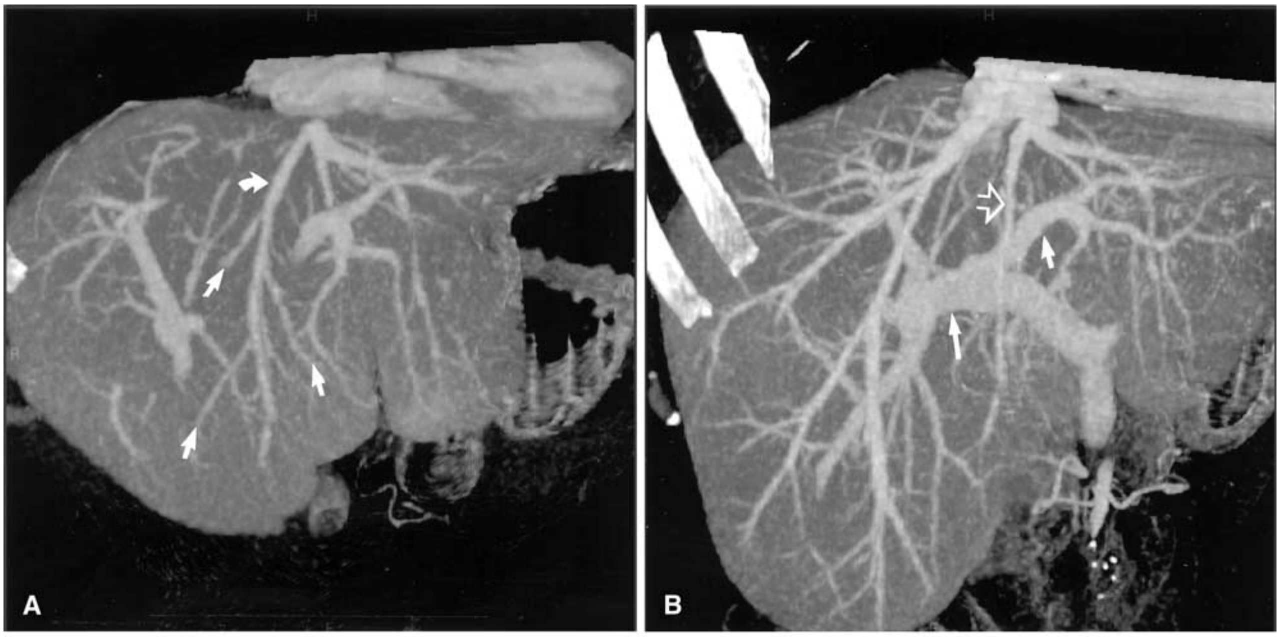

Fig. 3. A 54-year-old woman imaged for possible liver mass. MIP images in the (**A**) superior oblique, (**B**) Right anterior oblique (RAO), and (**C**) sagittal positions. Superior oblique view allows for adequate visualization of the MHV (*curved arrow*) and its side branches (*straight arrows*). RAO view demonstrates the complex relation of the MHV (*open arrow*) and the right (*long arrow*) and left (*short arrow*) portal veins. Sagittal plane allows for visualization of the entire course of the MHV (*curved arrow*) and small branches draining the dome of the liver (*straight arrows*).

small and did not branch. A formal hepatectomy along Cantlie's line was truly avascular in 11 patients (22%), with no major branches arising from the MHV. Hepatectomy performed 1 cm to the right of Cantlie's line was avascular in 15 patients (30%). In 19 patients (38%) the plane transected one major branch of the MHV; in the remaining 16 patients (32%) two or more major branches of the MHV were transected.

Discussion

A major role of imaging in the evaluation of potential liver donors is to assist surgeons in the preoperative determination of the feasibility and safety of hepatic resection and to plan the surgical approach. Multidetector row CT [11–14] and magnetic resonance imaging [15–17] have been used in preoperative donor evaluation. However, to our knowledge, none of the prior studies evaluated the incidence of a truly avascular plane along Cantlie's resection line, along which a formal hepatectomy is typically performed. Although the MHV anatomy can be displayed by intraoperative ultrasonography, knowledge of the exact anatomy before surgery is nonetheless required. Preoperative visualization of intrahepatic venous structures greatly affects surgical decision making because it may dictate the site of parenchymal dissection

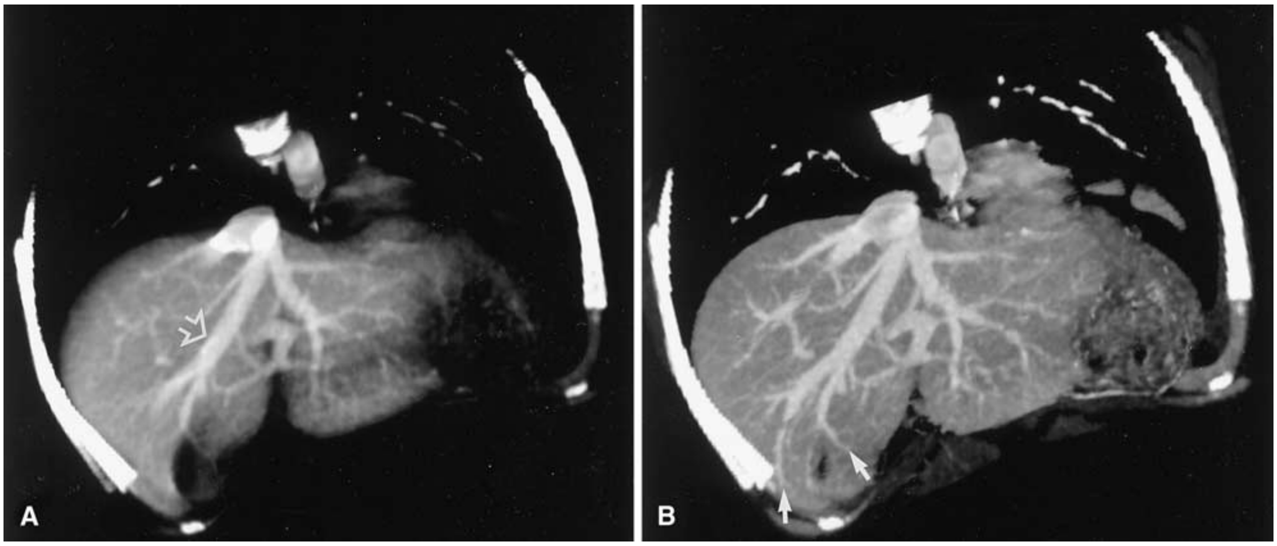

Fig. 4. A 36-year-old woman who is a potential liver donor. **A** Volume rendering allows for visualization of the complete volumetric data between two clip planes. The course of the MHV (*arrow*) is well delineated. **B** MIP allows for better visualization of terminal branch vessels (*arrows*) not seen on volume rendered images.

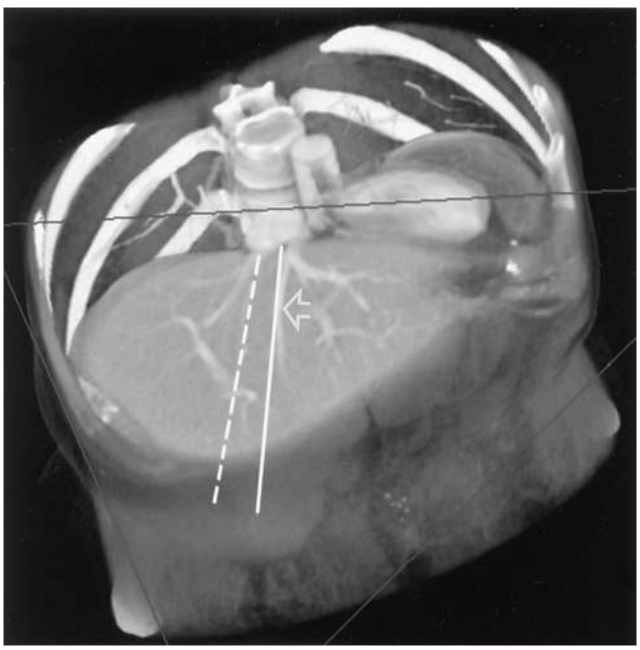

Fig. 5. A 54-year-old woman imaged for possible liver mass. Volume rendered image in the superior oblique plane shows Cantlie's resection line (*solid line*) immediately to the right of the MHV (*arrow*). A second resection line (*dashed line*) is drawn 1 cm to right of Cantlie's line. Both resection planes in this case are truly avascular.

and allow preoperative prediction of the postoperative liver volume [11, 12]. Variations in intrahepatic venous anatomy are common [18] and may influence the surgical approach. For example, knowledge of the presence of a large branch of the MHV draining the right lobe is critical because it may require an additional anastomosis into the recipient's IVC. According to one study, 8% of cadavers had major portions of the right lobe drained by branches of the MHV and accessory inferior right hepatic vein [19]. Our results demonstrated that no major branches arise from the MHV in 22% of patients, similar to that reported by a prior study using spiral CT with volume rendering in 26 patients [20]. In our study, approximately two-thirds of the patients had at least one major branch of the MHV that would be transected if a formal hepatectomy was performed. These facts reinforce the need for careful analysis of venous anatomy with preoperative imaging. Valuable preoperative information can be provided to the surgeon to ensure safer hepatic surgery.

Since the advent of slip ring technology, spiral CT has allowed the growth of true volume scanning. Multidetector row CT has been used to improve these techniques with more detector rows and faster gantry rotation times [21]. Most four-detector scanners in use today, such as ours, can achieve volume coverage on average eight times faster than their single detector predecessors. For hepatic vasculature imaging, this has meant faster *z*-axis coverage of the organ and smaller collimation to increase resolution of smaller vessels. Volume rendering can harness the potential of the isotropic and near-isotropic data sets obtained and provides a means to handle the increasingly large number of slices produced. The high fidelity of volume rendering harnesses the high-quality CT data and preserves vascular and parenchymal detail. Thus, the true volume acquisition and subsequent rendering of the liver and its vessels provide a more intuitive understanding of the anatomy in health and disease that defies isolated conventional two-dimensional axial

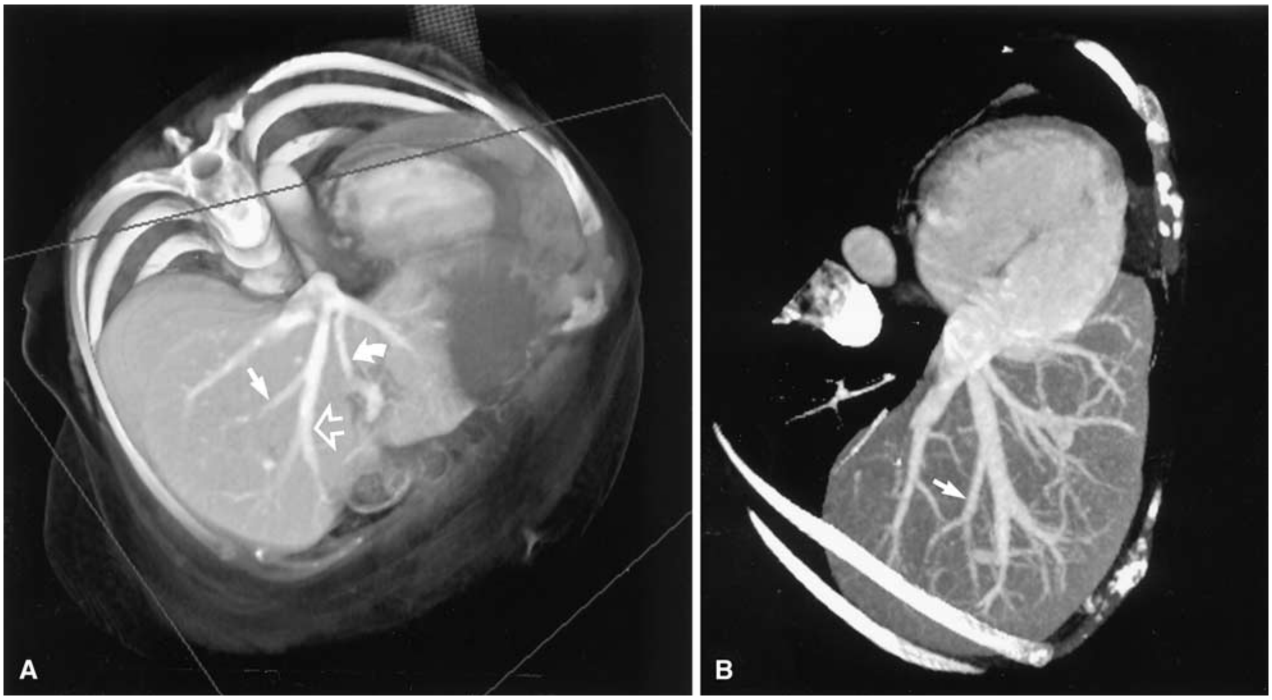

Fig. 6. A 76-year-old woman with a pancreatic mass. MHV has one side branch to the right. **A** Volume rendered image in the superior oblique position demonstrates a large branch (*solid straight arrow*) of the MHV (*open arrow*) draining the right lobe. Note the proximity of a large left hepatic vein branch to the MHV (*curved arrow*). **B** MIP images with a slight degree of tilt allows for better demonstration of drainage of the side branch vessel (*arrow*) into the MHV.

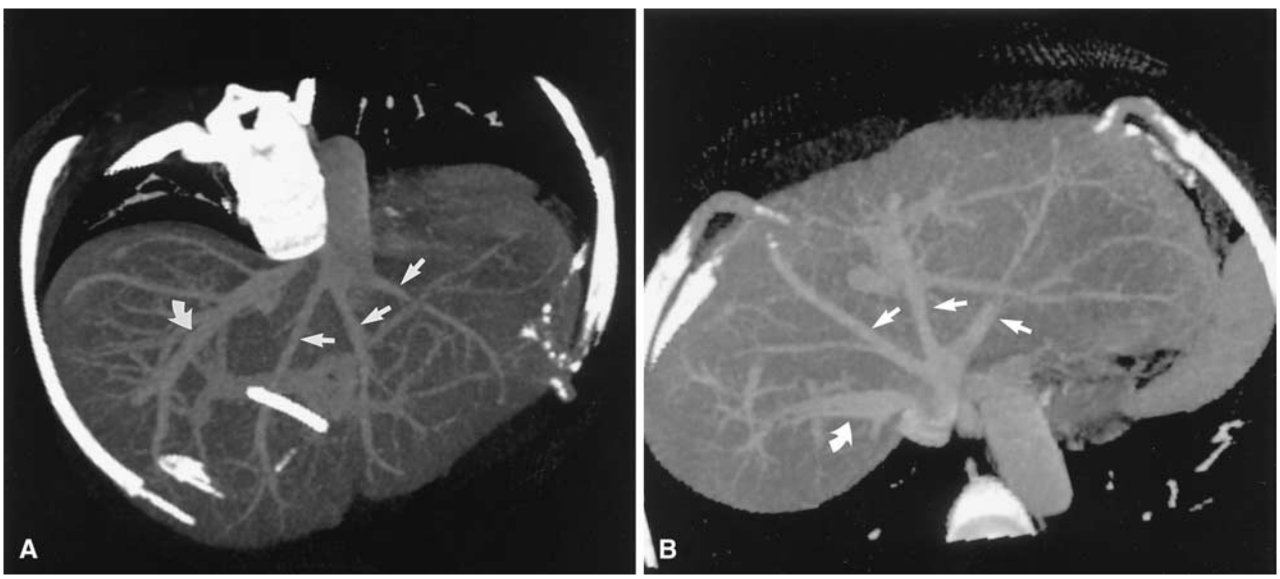

Fig. 7. A 53-year-old woman with a pancreatic mass. **A** MIP in the superior oblique plane demonstrates complex venous anatomy of the liver. The middle and left hepatic vein trunks are absent. Instead, there is confluence of three large branches at the inferior vena cava (*straight arrows*). The right hepatic vein (*curved arrow*) is also seen. An incidental biliary stent is noted. **B** Similar findings are seen in the inferior oblique position.

planes. This not only facilitates our interpretation but also allows interactive real-time processing during clinician consultations. The precise three-dimensional relation between vascular anatomy and liver parenchyma is clearly defined, providing close harmony between the CT images and basic segmental anatomy and eliminating a large number of potentially confusing sectional images. In addition, three-dimensional images from designated projections can show anatomic features to their best advantage.

Conclusion

Multidetector liver CT with volume rendering and supplemental MIP provides excellent delineation of the MHV and its branches and identifies important venous variants. A right hepatectomy with an alternative resection margin 1 cm to the right of the MHV could be performed without transecting its major branches in one-third of patients. In the remaining two-thirds, one or more major branch of the MHV might need to be transected and will require additional anastomosis. Preoperative knowledge of these variations is helpful for surgical planning and may reduce postoperative complications.

References

1. Shaked A, Lucey MR. Transplantation of liver grafts from living donors into adults. *N Engl J Med* 2001;345:923–924
2. Seaman DS. Adult living donor liver transplantation: current status. *J Clin Gastroenterol* 2001;33:97–106
3. Pomfret EA, Pomposelli JJ, Jenkins RL. Live donor liver transplantation. *J Hepatol* 2001;34:613–624
4. Pomfret EA, Pomposelli JJ, Lewis WD, et al. Live donor adult liver transplantation using right lobe grafts: donor evaluation and surgical outcome. *Arch Surg* 2001;136:425–433
5. Kawasaki S, Makuuchi M, Miyagawa S, et al. Extended lateral segmentectomy using intraoperative ultrasound to obtain a partial liver graft. *Am J Surg* 1996;171:286
6. Couinaud C. *Le foie: etudes anatomiques et chirurgicales.* Paris: Masson, 1957
7. Bismuth H. Surgical anatomy and anatomical surgery of the liver. *World J Surg* 1982;6:3–9
8. Lo CM, Fan ST, Liu CL, et al. Adult-to-adult living donor liver transplantation using extended right lobe grafts. *Ann Surg* 1997; 226:261–270
9. Fan ST, Lo CM, Liu CL. Technical refinement in adult-to-adult living donor liver transplantation using right lobe graft. *Ann Surg* 2000;231:126–131
10. Calhoun PS, Kuszyk BS, Heath DG, et al. Three-dimensional volume rendering of spiral CT data: theory and method. *Radiographics* 1999;19:745–764
11. Kamel IR, Raptopoulos V, Pomfret EA, et al. Living adult right lobe liver transplantation: imaging before surgery with multidetector multiphase CT. *AJR* 2000;175:1141–1143
12. Kamel IR, Kruskal JB, Pomfret EA, et al. Impact of multidetector CT on donor selection and surgical planning before living adult right lobe liver transplantation. *AJR* 2001;176:193–200
13. Pannu HK, Maley WR, Fishman EK. Liver transplantation: preoperative CT evaluation. *Radiographics* 2001;21:S133–S146
14. Bogetti JD, Herts BR, Sands MJ, et al. Accuracy and utility of 3-dimensional computed tomography in evaluating donors for adult living related liver transplants. *Liver Transplant* 2001;7:687–692
15. Fan Cheng Y, Long Chen C, Liang Huang T, et al. Single imaging modality evaluation of living donors in liver transplantation: magnetic resonance imaging. *Transplantation* 2001;72:1527–1533
16. Fulcher AS, Szucs RA, Bassignani MJ, Marcos A. Right lobe living donor liver transplantation: preoperative evaluation of the donor with MR imaging. *AJR* 2001;176:1483–1491
17. Lee VS, Morgan GR, Teperman LW, et al. MR imaging as the sole preoperative imaging modality for right hepatectomy: a prospective study of living adult-to-adult liver donor candidates. *AJR* 2001;176: 1475–1482
18. Soyer P, Bluemke DA, Choti MA, Fishman EK. Variations in the intrahepatic portions of the hepatic and portal veins: finding on helical CT scans during arterial portography. *AJR* 1995;164:103–108
19. Masselot R, Leborgne J. Anatomical study of the hepatic veins. *Anat Clin* 1978;1:109–125
20. van Leeuwen MS, Noordzij J, Fernandez MA, et al. Portal venous and segmental anatomy of the right hemiliver: observations based on three-dimensional spiral CT rendering. *AJR* 1994;163:1395–1404
21. Rubin GD. Data explosion: the challenge of multidetector-row CT. *Eur J Radiol* 2000;36:74–80