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ORIGINAL ARTICLE

Reliability of hepatic artery configuration in 3D CT angiography compared with conventional angiography – special reference to living-related liver transplant donors

Hisamune Sakai, Koji Okuda, Masafumi Yasunaga, Hisafumi Kinoshita, Shigeaki Aoyagi

Department of Surgery, Kurume University School of Medicine, Kurume, Japan

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Correspondence
Koji Okuda MD, Department of Surgery, Kurume University School of Medicine, 67 Asahimachi, 830-0011 Kurume, Fukuoka, Japan. Tel.: 81-942-31-7567; fax: 81-942-35-8967; e-mail: kook@med.kurume-u.ac.jp

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Summary

Although an accurate anatomical understanding of the hepatic arteries is the most and essential step in living-related liver transplantation (LRLT), the need to reduce the burden place on the donor should be considered in imaging diagnosis. The present study examined the reliability of intravenously enhanced three-dimensional (3D) angiography from multidetector-row computed tomography (MDCT) in evaluating the anatomical configuration of the hepatic arteries comparing with those from conventional angiography by Seldinger method. A total of 109 patients underwent MDCT and 3D images were reconstructed on arterial phase using the volume rendering (VR) method. In the case of 3D angiography, at an infusion rate of 4 ml/s, the extrahepatic hepatic arteries were visualized successfully in all cases (the right, left and middle hepatic artery). The aberrant hepatic arteries were successfully visualized in 23 of 24 cases. The 3D angiography is a reliable method of visualizing the extrahepatic and aberrant hepatic arteries. This minimally invasive examination procedure is useful in individual operative planning and is help to increase the safety of surgery.

Introduction

Accurate preoperative evaluation of the configuration of the hepatic arteries is important in living-related liver transplantation (LRLT) in order to achieve safe and optimal excision from the donor and to ensure optimal arterial anastomosis to maintain graft liver viability [1–5]. If arterial reconstruction is not accomplished properly, critical complications may occur after surgery, possibly leading to graft loss. With regard to arterial configuration, the most important thing to consider is the possibility of the presence of aberrant arteries. Such aberrant arteries are often observed, and when they supplant all the ordinary right or left hepatic arteries they are referred to as 'replaced', whereas if they supplant some part of those arteries they are referred to as 'accessory'. The rate of incidence of aberrant arteries appears to be rather high at about 25–45% [5–8]. Until now, conventional angiography has been only the method of choice for preoperative imaging of hepatic artery configuration. However, improving the safety and reducing the burden placed on donors by preoperative examinations is a matter of fundamental importance, and the use of conventional invasive angiography should clearly be avoided as much as possible.

Recent years have seen significant advances in diagnostic computed tomography (CT) imaging technologies, and the usefulness of multidetector-row (MD) CT-based three-dimensional (3D) visualization in individual preoperative planning has been reported for a number of surgical procedures including liver transplants [9–15]. Reconstruction of 3D images of the hepatic arteries has also become possible, but the visualization has been inadequate, and what is more, there have been few reports comparing the reliability of 3D imaging of hepatic arterial branching with the results of conventional angiography as the standard.

In the present study, we performed MDCT 3D angiography of the hepatic arteries of 109 patients and analyzed the validity of this technique by comparing the results with those obtained from conventional angiography.

Patients and methods

Patients

Subjects of this study were 109 patients with epigastric disorders who received MDCT at our hospital between September 2002 and August 2003. Patients included 49 cases of hepatocellular carcinoma, 12 cases of metastatic liver cancer, four cases of cholangiocellular carcinoma, 10 cases of bile duct cancer, eight cases of gallbladder cancer, 14 cases of cancer of the pancreas, four cases of carcinoma of the ampulla of Vater, one case of gastric cancer, one case of mesenteric tumor, two cases of pancreatic endocrine tumor, three cases of chronic pancreatitis, and one case of cholecystitis. Patient ages ranged from 21 to 88 (mean age 65 years), and there were 76 males and 33 females. Of these patients, three had a history of gastrectomy, one had experienced pancreatoduodenectomy, one had experienced resection of the right hepatic lobe, one had experienced hepatic anterior segmentectomy, and one had experienced hepatic posterior segmentectomy, and the corresponding artery had been removed in these operations. In these latter patients, those arteries that were not susceptible to visualization by conventional angiography were excluded from the present analysis.

CT imaging technique

The CT device used was an 8-slice type LightSpeed Ultra (manufactured by General Electric, Tokyo, Japan), and the contrast medium was Iopamidol, 2 ml/kg body weight at a concentration of 370 mgI/ml delivered intravenously from the forearm using an automatic contrast-medium injector. The rate of injection was 4 ml/s in 65 cases, and 2 ml/s in 44 cases. Images on arterial phase were obtained using test injections of 15 ml of contrast medium delivered at 4 ml/s or 2 ml/s; a revisions of interest (ROI) was placed in the aorta and the time–density curves were measured. The time required for optimal visualization was determined and scanning of arterial phase was started 5 s after this time. About 20 s after completing arterial phase imaging, portal venous phase scanning was performed, and after a further delay time of 60 s venous phase scanning were obtained. Images were taken at three phases, however, the images on portal venous phase and venous phase were not evaluated in the present study. Imaging conditions of arterial phase were as follows: slice thickness 1.25 mm, reconstruction pitch 0.63 mm, scan time 0.5/rot, and pitch 10.8.

Conventional angiographic technique

Selective angiography was performed on the celiac and superior mesenteric artery in all 104 patients, using a 4F Shepherd Hook catheter (Medikit Co., Tokyo, Japan) inserted into the femoral artery.

Image assessment

Arterial 3D images were constructed using the volume rendering (VR) method on an INTAGE RV workstation manufactured by KGT Inc. (Osaka, Japan). Visualization of the extrahepatic arteries (celiac, superior mesenteric, common hepatic, gastroduodenal, splenic, left gastric, right, left and middle hepatic), and the segmental hepatic artery by 3D angiography was compared with that from conventional angiography. Definition of the segmental hepatic artery was followed Couinaud's liver segment classification. For example, the arterial branch that distributed to the segment 2 is labeled A2.

Results

Extrahepatic arteries

As shown in Table 1, at an infusion rate of 2 ml/s the visualization rate was 100% for the celiac, superior mesenteric, common hepatic and splenic artery, 95% for the gastroduodenal artery, 80% for the left gastric artery, 89% for the right hepatic artery, 66% for the left hepatic artery, and 42% for the middle hepatic artery (Fig. 1). At an infusion rate of 4 ml/s all the extrahepatic arteries (celiac, superior mesenteric, common hepatic, splenic artery, left gastric, right, left and middle hepatic artery) were successfully visualized in all cases (Fig. 2).

Table 1. Assessment of extrahepatic artery.

Artery	Injection rate (ml/s) 2	4
Celiac	44/44 (100)	65/65 (100)
Superior mesenteric	44/44 (100)	65/65 (100)
Splenic	44/44 (100)	65/65 (100)
Gastroduodenal	42/44 (95)	64/64 (100)
Left gastric	35/44 (80)	62/62 (100)
Common hepatic	44/44 (100)	65/65 (100)
Right hepatic	39/44 (89)	64/64 (100)
Left hepatic	29/44 (66)	64/64 (100)
Middle hepatic	8/19 (42)	27/27 (100)

Data are the number of arteries detected at computed tomographic (CT) angiography/number of arteries detected at conventional angiography. Numbers in parentheses are percentages.

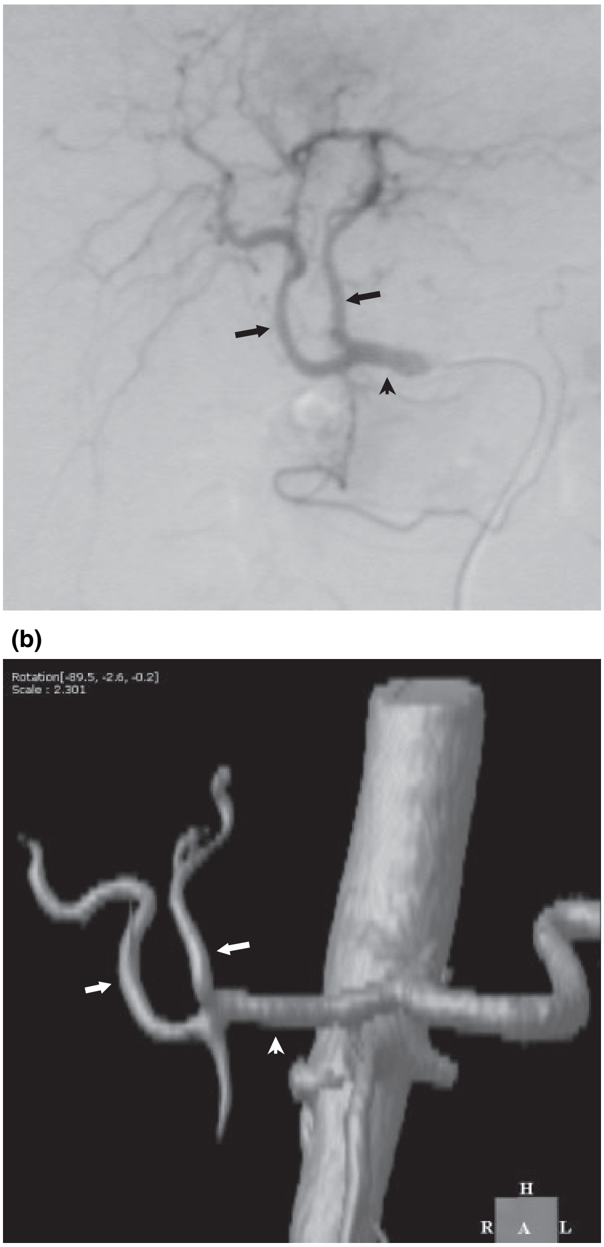

Figure 1 Image (a) is from conventional angiography, while image (b) is from three-dimensional (3D) computed tomographic (CT) angiography at a contrast medium infusion rate of 2 ml/s. Visualization extends only to the right and left hepatic arteries. The arrowhead indicates the common hepatic artery. Arrows indicate the right and left hepatic arteries.

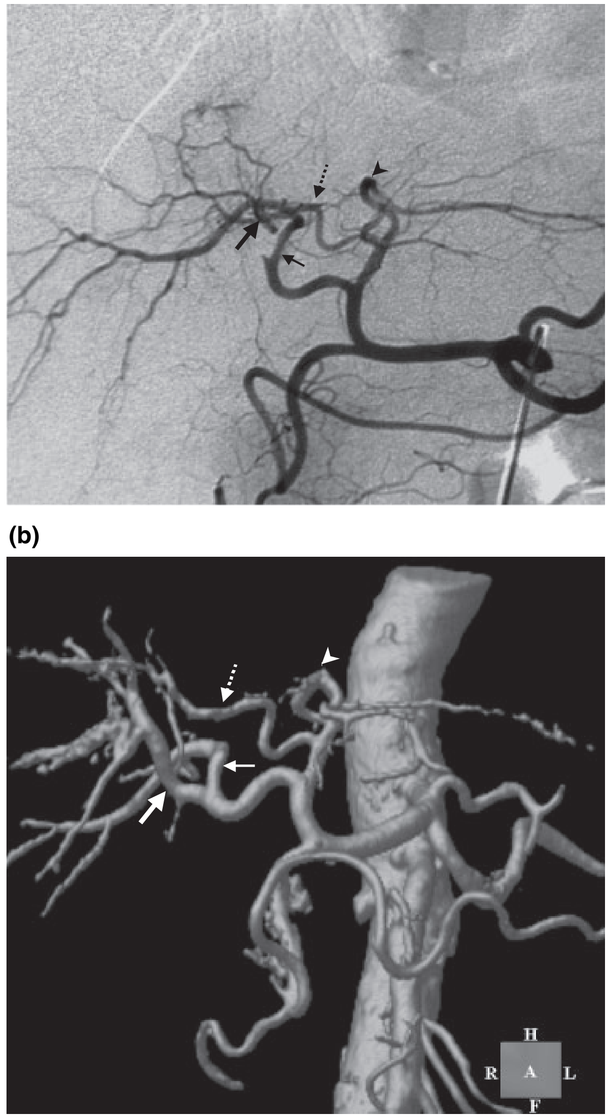

Figure 2 Image (a) is from conventional angiography, while image (b) is from three-dimensional (3D) computed tomographic (CT) angiography at a contrast medium infusion rate of 4 ml/s. Visualization is possible up to the segmental hepatic artery. The thick arrow indicates the anterior branches, thin arrows the posterior branches, dotted arrow the medial branches, and the arrowhead indicates the lateral branches.

Segmental hepatic artery

At an infusion rate of 2 ml/s the visualization rates of A2–A8 ranged from 11 to 34%. At 4 ml/s the visualization rates improved to 76–89%, showing a higher rate of visualization at 4 ml/s (Table 2). Visualization of A1 was generally poor, but identification in this artery is also difficult with conventional angiography, so A1 was excluded from the present analysis.

Aberrant arteries

Aberrant arteries were found in 34 of 109 patients (31.2%) in conventional angiography. At an infusion rate of 2 ml/s the aberrant arteries were successfully visualized in eight of 15 cases. In the group infused at 4 ml/s, aberrant arteries were present in 24 of 65 patients, and they were successfully visualized in 23 of the 24 cases (Table 3). Figure 3 shows a variant case in which a replaced right hepatic artery from the superior mesenteric artery and a replaced left hepatic artery from the left gastric artery. Figure 4 shows another variant case in which the posterior branch of the hepatic artery from the gastroduodenal artery, and the A2 branch from the left gastric artery. The only case that was not successfully visualized was an A6 branching from the superior mesenteric artery.

Table 2. Assessment of segmental hepatic artery.

	Injection rate (ml/s)	
Artery	2	4
A2	5/44 (11)	49/64 (77)
A3	11/44 (25)	57/64 (89)
A4	15/44 (34)	54/64 (84)
A5	5/44 (11)	48/63 (78)
A6	7/44 (16)	51/64 (81)
A7	5/44 (11)	54/64 (84)
A8	7/44 (16)	52/63 (83)

Data are the number of arteries detected at computed tomographic (CT) angiography/number of arteries detected at conventional angiography. Numbers in parentheses are percentages.

Table 3. Assessment of aberrant artery.

	Injection rate (ml/s)	
Anatomic variation	2	4
RHA from SMA	4/4	4/4
RHA from GDA	0/1	1/1
RHA from CA	1/1	1/1
RHA posterior branch from GDA	0/1	2/2
LHA from LGA	1/6	7/7
LHA from CA		1/1
CHA from SMA	1/1	4/4
A6 from SMA	1/1	0/1
A6 from GDA		1/1
A2 from LGA		2/2
Total	8/15	23/24

Data are the number of arteries detected at CT angiography/number of arteries detected at conventional angiography.
RHA, right hepatic artery; LHA, left hepatic artery; CHA, common hepatic artery; SMA, superior mesenteric artery; GDA, gastroduodenal artery; LGA, left gastric artery; CA, celiac artery; CT, computed tomography.

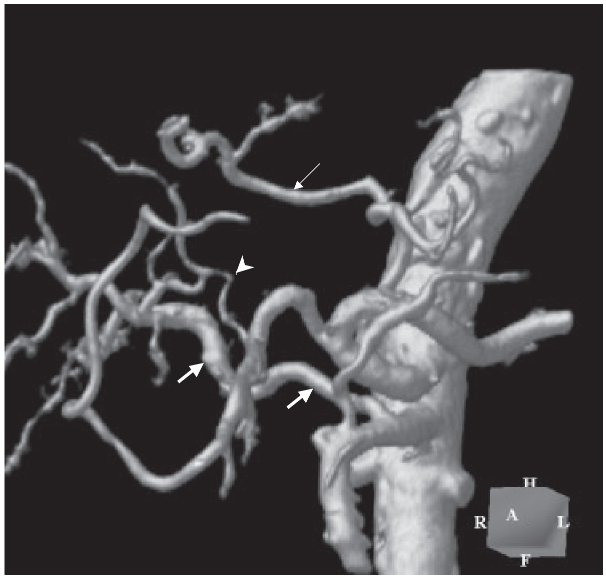

Figure 3 Image from three-dimensional (3D) computed tomographic (CT) angiography at a contrast medium infusion rate of 4 ml/s. The right hepatic artery branching from the superior mesenteric artery (thick arrows) and the left hepatic artery branching from the left gastric artery (thin arrow) were visualized. The arrowhead indicates the visualized the middle hepatic artery.

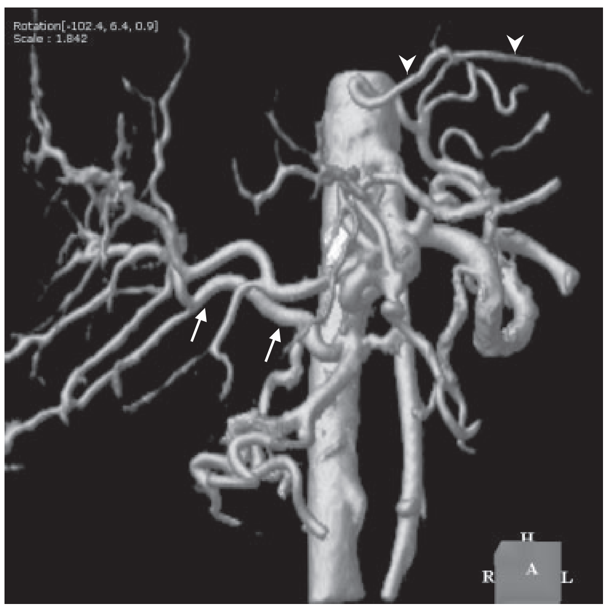

Figure 4 Image from three-dimensional (3D) computed tomographic (CT) angiography at a contrast medium infusion rate of 4 ml/s. The posterior branch of the right hepatic artery from the gastroduodenal artery (arrows) and A2 from the left gastric artery (arrowheads) were visualized.

Discussion

Of conventional methods available for confirming arterial configuration, standard angiography is considered to be superior, and we adopted the visualization rate form conventional angiography as the gold standard in this study. We found that visualization of the segmental hepatic artery in 3D CT angiography is inferior to that with conventional angiography. However, for preoperative use in LRLT for clarification of the configuration of the extrahepatic arteries, and for determining the presence and configuration of aberrant arteries, it was concluded that 3D CT angiography is a highly reliable diagnostic imaging modality. The extrahepatic arteries including right, middle and left hepatic artery was visualized in all cases when the contrast medium infusion rate was 4 ml/s. Further, the present study did identify a weakness in the ability of two-dimensional (2D) imaging of conventional angiography to confirm the configuration of the arterial branching in the left lobe. In the case in question, the 2D image from conventional angiography indicated that the left hepatic artery had a short trunk with branches A2, A3 and A4. The 3D images, however, revealed clearly that actually A3 and A4 branched from the proper hepatic artery and that A2 branched alone from another periphery of the proper hepatic artery (Fig. 5). Misjudgment of this kind with regard to arterial configuration can lead to difficulties during operation and may prevent the application of appropriate measures in transplant surgery. This was a case demonstrating the superior of 3D CT angiography over conventional angiography in confirming 3D arterial configuration. With regard to aberrant arterial configurations, the success rate was 23 of 24 cases in 4 ml/s of infusion rate. Visualization was unsuccessful in only one case, in which A6 branches from the superior mesenteric artery. In this case, the visualization from the CT data was poor for the origin from the superior mesenteric artery, and this artery was deleted in the process of constructing the 3D image because of interruption of the continuous arterial enhancement. However, in this case the point of origin was also poorly visualized, showing smooth stenosis, by conventional angiography. The problem here may have been related to the low native

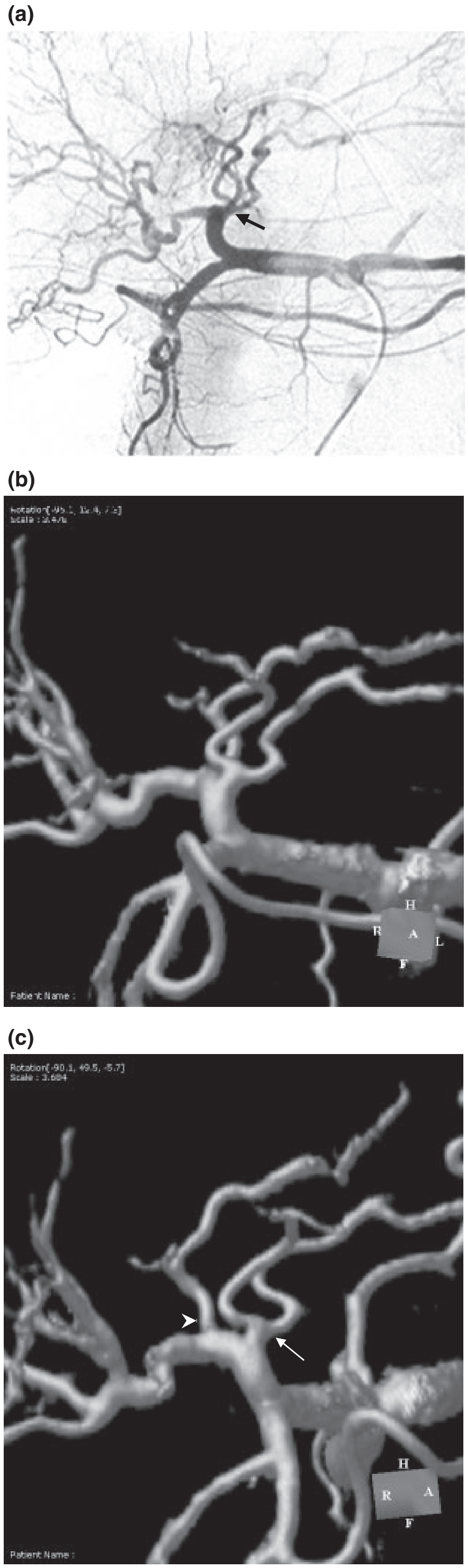

Figure 5 Image (a) is from conventional angiography, while image (b, c) is from three-dimensional (3D) computed tomographic (CT) angiography at a contrast medium infusion rate of 4 ml/s. With conventional angiography it was concluded that the left hepatic artery had a short trunk with branches A2, A3 and A4 (thick arrow). Under 3D CT angiography, however, it was clearly shown that in fact A3 and A4 branched from the proper hepatic artery (thin arrow), while A2 branched alone from another periphery of the proper hepatic artery (arrowhead).

flow of this accessory artery with or without localized pathological lesion at the origin of this artery, but this result points out the possibility that this type of aberrant artery might be deleted as an unnecessary artifact during the process of reconstruction of the 3D image, and therefore one key to improving the visualization rates will be to ensure that the 3D images are reconstructed by an expert in hepato-biliary morphology with a thorough knowledge of aberrant arteries. With regard to the effect of infusion rates are associated with improved arterial images [16]. The results of our study showed that when contrast medium was infused at 2 ml/s, visualization of A2–A8 ranged from 11 to 34%, whereas the visualization rate improved to 76–89% when the infusion rate was increased to 4 ml/s, demonstrating that an infusion rate of 4 ml/s produced superior results. Further studies of infusion rates and image timing will be required to achieve additional improvement in visualization rates.

Thanks to recent advances in diagnostic CT imaging technology, especially the development of MDCT, it has become possible to obtain detailed helical data from the hepato-biliary region in only 5–10 s [17]. By infusing a contrast medium and making images at the optimum times, clear and detailed 3D images can be reconstructed on each vascular phase [18]. In comparison with conventional 2D images, which can only be read effectively by experts with a great deal of knowledge and experience, 3D images can be understood much more intuitively and can be manipulated to permit visualization from any desired angle, so they are considered to be extremely useful for accurate anatomical understanding and preoperative navigation. Increased interest in 3D imaging has also been shown in the field of liver transplant, and several reports have been published on the usefulness of this technique in obtaining 3D images of the liver [9–15]. Winter *et al.* have reported the usefulness of 3D CT angiography in evaluating aberrant hepatic arteries in transplant candidates [10,17]. However, none of these previous reports included comparisons with conventional angiography as a standard, and therefore it cannot be said that the reliability of 3D CT angiography has been adequately confirmed. Takahashi *et al.* [18] compared 3D CT angiography using a contrast medium infusion rate of 5 ml/s with conventional angiography and reported that 3D CT angiography was 98% successful in identifying hepatic artery type, but their evaluation was based primarily on maximum intensity projection (MIP) images. The 3D visualization based on MIP are inferior to those reconstructed using the VR method, and further, with MIP it is not possible to obtain composite images of the portal vein, bile duct, arteries, etc. In the present study, we compared the results of 3D imaging using the VR method alone with those obtained from conventional angiography.

In LRLT, the most basic and essential step is to gain an accurate understanding of the ramification pattern of the hepatic arteries in order to determine the most appropriate operative procedures [3–5]. The analysis of aberrant arteries is considered especially critical to maintaining maximum graft viability. Kostelic *et al.* [19] reported that hepatic artery reconstruction in 50% of the living donors with aberrant arteries was unsatisfactory or difficult when using donor selection criteria based on conventional angiography. Recently, there are a number of reports indicating that fine anastomosis using microsurgical techniques can successfully treat even complex hepatic arterial anomalies [20,21]. Even with these advances in surgical technique, however, it is obvious that preoperative clarification of the arterial configuration will lead to improved clinical results. In some cases, where multiple hepatic artery branches are supplying the graft liver, all branches may not be necessarily reconstructed because of collateral blood flow after reconstruction of one of the branches [22,23]. However, it is generally impossible to assess the presence of collateral circulation by preoperative imaging modality. Therefore, a second arterial reconstruction is usually performed where there are two hepatic arteries with identical diameters, or when backflow from the stump is weak after completion of the first reconstruction. In the situation, an accurate preoperative understanding of the arterial configuration will be great valid in terms of optimizing operative procedures.

Conventional angiography is invasive and should be avoided in preoperative examination of living donors. The 3D CT with intravenous infusion of contrast medium does not require hospitalization, can performed on an outpatient basis, and reduces the burden place on living donors. In addition, data converted to 3D images can be manipulated for 3D viewing from various angles, making it easy to confirm various relationships with other vasculatures and organs. Our results showed that visualization of the extrahepatic arteries (celiac, superior mesenteric, common hepatic, gastroduodenal, splenic, left gastric, right, left and middle hepatic) using 3D CT angiography with 4 ml/s of contrast medium infusion rate was equivalent to that obtained in conventional angiography, and visualization of the aberrant arteries was similarly equivalent except one special case. Although not demonstrated in the present study, it is possible with MDCT examination to measure segmental liver volume and to confirm the arterial configuration based on integrated 3D images of arteries, portal vein, and hepatic veins. Therefore, intravenously enhanced 3D CT angiography is extremely useful, comprehensive and minimally invasive preoperative examination for LRLT donors.

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