3D Anatomical Variations of Hepatic Vasculature and Bile Duct for Right Lateral Sector of Liver with Special Reference to Transplantation

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Summary: To achieve a safer living related liver transplantation (LRLT) using the right lateral sector, anatomical variations of the portal vein, hepatic artery and bile duct for the right lateral sector and their three dimensional (3D) relationship were assessed by integrated 3D-CT images. 52 patients who underwent contrast enhanced multi-detector row CT (MD-CT) and MD-CT cholangiography were enrolled. Data from contrast enhanced MD-CT were used to reconstruct the 3D images of the hepatic artery and portal vein. 3D images reconstructed from MD-CT data of the hepatic artery, portal vein and bile duct were integrated into a single image. The dual branching of the right lateral portal vein was observed in 22 (42.3%) patients. Three (5.8%) had dual right lateral ducts and 14 (26.9%) had dual right lateral arteries. Among them, “south-turning” artery and “north-turning” bile duct was observed in 22 (42.3%). “South-turning” artery and “south-turning” bile duct were 3 (5.8%). “North-turning” artery and “north-turning” bile duct were 2 (7.4%). Only 27 (51.9%) had single portal vein, bile duct and artery for the right lateral sector, those were preferable as candidates for right lateral sector graft transplantation. 3D anatomical variations of portal vein, artery and bile duct for the right lateral sector were complexed, and only half of the donor candidates had preferable hepatic structures for right lateral sector graft transplantation. Understanding of the 3D hepatic structures by 3D-CT may contribute to a better definition of anatomical contraindications for LRLT which may further results in more safe and widely applied right lateral sector graft LRLT.

Key words liver transplantation, right lateral sector, MD-CT, 3D image
ceeds 70% of the total liver volume and the right lateral sector has a volumetric advantage than the left lobe.

However, it is obvious that the procurement of the right lateral sector has technical difficulties. Only a few centers are using the right lateral sector graft for transplantation [7,8-10]. The high number of either unrecognized or extemporaneously handled biliary and vascular variants pose high risk both to the donor and the recipient [11]. Preoperative understanding of the anatomical variations of the sectoral and the segmental bile ducts, the hepatic artery and the portal vein is essential to evaluate the feasibility of the right lateral sector transplantation, and to achieve safe transplantation.

Newly developed multi-detector computed tomography (MD-CT) images of the portal vein, the hepatic artery and the bile duct enable us to define the variations of the segmental hepatic structures accurately [12,13] and the three dimension (3D) integrated images contribute to surgical simulation in a better way.

This study was aimed to define the anatomical variations of the portal vein, the hepatic artery and the bile duct for the right lateral sector based on the integrated 3D images in order to help in framing the guidelines for transplantation.

MATERIALS AND METHODS

Patients

Between November 2002 and December 2006, 73 patients underwent contrast enhanced dynamic MD-CT and MD-CT cholangiography in our department, in ordinal clinical schedule for preoperative evaluation. After review these cases, 66 patients who met the following inclusion criteria were selected: age over 20 years, no tumor in the liver/hepatic hilum, no tumor located in peripheral sites in the liver which is more than 30mm in diameter, no previous hepatic or biliary surgery. 3D images of the portal vein, the hepatic artery and the bile duct were reconstructed in all. 14 patients were excluded from the study because of the poor quality of the 3D images. Consequently, 52 patients were enrolled in this study. There were 40 males and 12 females with age ranged from 42-78 (mean 65) years. The pathological diagnosis in these patients were as follows: hepatocellular carcinoma-24, cholangiocellular carcinoma-4, extrahepatic bile duct cancer-7, pancreatic cancer-3, papilla vater carcinoma-1, gall bladder cancer-5, chronic hepatitis-1 and liver hemangioma-1.

MD-CT protocol

All dynamic CT studies were performed with MD-CT (Asteon multi ver. 1.5 Toshiba, Tokyo or LightSpeed Plus, GE Yokogawa, Tokyo). Patients received 100 ml of iopamidol with an iodine concentration of 370 mg/ml (Iopamiron 370; Nihon Schering, Osaka, Japan) as intravenous contrast for vascular imaging. The contrast medium was injected at a rate of 4 ml/sec. with an automatic power injector. Three or four phase scanning was performed with a single breath-hold helical technique at 3 mm collimation, 3.5 helical pitch and 0.75 sec gantry rotation speed. Data from the artery dominant phase and the portal vein dominant phase were used to reconstruct the 3D images.

For biliary imaging, in 38 cases, CT scan images were acquired 30 min after the intravenous infusion of 100 ml of biliary contrast agent (Meglumine isotrurate, Biliscopin; Shering, Berlin, Germany) at a rate of 0.1 ml/sec. (DIC-CT). In all 38 cases, DIC-CT and dynamic CT scan were performed on different days. In 14 cases having a percutaneous transhepatic biliary drainage (PTBD) tube, biliary enhanced CT was performed after the administration of 3-15 ml of 6% biliary contrast agent (Meglumine sodium amidotrizoate, Urografin; Shering, Berlin, Germany) through the PTBD tube (PTBD-CT). The adequate volume of the contrast agent was determined by the previously performed PTBD cholangiography.

Image interpretation

Analysis of the image data was performed based on the source images and the 3D postprocessing images on commercially available workstations (Intaverse, KGT, Tokyo and VertualPlace, AZE, Osaka). 3D reconstruction of the hepatic vasculature was made using a volume rendering algorithm. The volume rendered images were obtained in projections selected to depict the course of the hepatic vasculature best. The resulting 3D images of the hepatic artery, the portal vein and the bile duct rendered for each step of the artery dominant phase, the portal vein dominant phase and the DIC-CT/PTBD-CT respectively were carefully reviewed and compared with the axial source images to ensure that no important structure was inadvertently deleted from the 3D images. 3D images of the hepatic artery, the portal vein and the bile duct which were adjusted to position each other focusing at the hepatic hilum on 2D axillary, sagital and coronary
imaging sequences were further integrated into a single image (Fig. 1). To increase the accuracy, 3D images were reconstructed by three surgeons who are experts in hepatico-biliary anatomy and 3D reconstruction (A. Y., H. S and K. O with 8, 12 and 26 years of experience respectively). The study was regarded as diagnostic when both the biliary and the vascular structures were significantly enhanced to allow reliable determination or exclusion of anatomic variants especially in a surgical perspective.

In this study, anatomical variation of each of portal vein, artery and bile duct for the right lateral sector was investigated. Further, as it is important for operation to know the anatomical arrangement of the right hepatic duct/artery, the right paramedian segmental duct/artery and the right lateral segmental duct/artery in the hilar area [17], the 3D relationship of segmental hepatic duct/artery to portal vein was assessed. The segmental artery/bile duct branches which run and course to the dorsal and cranial side of the right paramedian portal vein are termed “north turning” artery/bile duct branch, and those which run and course to the ventral and caudal side of the portal vein are termed “south tuning” branch, as Kawarada et al. [17] named in the previous report. Intrahepatic structures are termed according by the Couinaud’s terminology [14]. Namely, the right paramedian portal vein/artery and bile duct are corresponding to the right anterior portal vein/artery and bile duct in Zollinger’s classification [15,16]. The right lateral portal vein/artery and bile duct are corresponding to the right posterior portal vein/artery and bile duct.

RESULTS

Diagnostic examination

In 52 of the 66 evaluated patients, the MD-CT studies were considered as diagnostic. The study was not diagnostic in the remaining 14 patients because of the poor timing of the contrast and the image acquisition. One patient had poor arterial phase images, 9 had poor biliary images and 4 had both. Portal imaging was satisfactory in all patients.
Analysis of the portal veins

Branching pattern of the right portal vein was defined into 5 types according to Nakamura’s classification (Fig. 2) [18]. Standard anatomy with bifurcation of the main portal vein into left and right was seen in 42 patients (type A, 80.8%). Anatomical variations were observed in 10 patients. Trifurcation of the right paramedian portal vein (RPM), the right lateral portal

Fig. 2. Anatomical variant of portal vein.
Type A: 42 cases (80.8%), Type B: 3 cases (5.8%), Type C: 6 cases (11.5%), Type D: 1 case (1.9%), Type E: 0 cases (0%)
RPM: right paramedian portal vein, RL: right lateral portal branch, R: right portal vein, L: left portal vein, P5: portal vein for the segment 5, P8: portal vein for the segment 8, P4: portal vein for the segment 4, F: right sided round ligament

Fig. 3. Anatomical variant of right lateral portal vein.
Type 1: 30 cases (57.7%), Type 2: 10 cases (19.2%), Type 3: 12 cases (23.1%)
RPM: right paramedian portal vein, RL: right lateral portal branch, M: main portal vein, L: left portal vein

Single ductal pattern

I )
RLD
LHD
RPMD
RLD
RLD
RPMD

II )

III )

IV )

Dual ductal pattern

V )

VI )

VII )

Fig. 4. Anatomical variants of right lateral duct (RLD).
I: 33 cases (63.5%), II: 8 cases (15.4%), III: 5 cases (9.6%), IV: 3 cases (5.8%), V: 1 cases (1.9%), VI: 1 cases (1.9%), VII: 1 cases (1.9%)
RPMD: right paramedian duct, RLD: right lateral duct, LHD: left hepatic duct
vein (RL) and the left portal vein was seen in one patient (type B: 5.8%). In 6 patients, RPM was arising from the left portal vein extrahepatically (type C: 11.5%). Origin of RPM from the intrahepatic part of the left portal vein was seen in another patient (type D: 1.9%). The anomaly in which multiple RPMs originating from the left portal vein (type E) was not seen in any of our patients.

We have classified the branching pattern of RL into 3 types according to its origin from the right portal vein (Fig. 3). In type 1, RL originated from the right portal vein as a single trunk (n= 30, 57.7%). In type 2, although there were two RLs, they originate from the right portal vein by a common ostia (n=10, 19.2%). Origin of two RLs through separate ostia was defined as type 3 (n=12, 23.1%).

Analysis of the biliary system

The pattern of branching of the biliary system in the right lobe is classified into 7 patterns based on the tributary from the right lateral sector (Fig. 4). Forty-nine cases have single right lateral duct (RLD) (I, II, III and IV) and 3 have dual RLDs (V, VI and VII). I is the
normal anatomy in which RLD and the right paramedian duct (RPMD) join to form the right hepatic duct which further joins the left hepatic duct to form the common hepatic duct. II is trifurcation of the RLD, the RPMD and the left hepatic duct. In III, RLD joins the left hepatic duct (Couinaud’s caudal right paramedian duct) [14]. IV is the joining of the RLD to the common hepatic duct (Couinaud’s caudal right lateral duct) [14]. V is dual RLD insertion into RPMD independently (Fig. 8c). In VI, there are two right hepatic ducts each formed by the joining of separate RPMD and RLD. VII is multiple RLDs and RPMDs. Incidence of each pattern in our series were I, 33 (63.5%) patients; II, 8 (15.4%); III, 5 (9.6%); IV, 3 (5.8%); V, 1 (1.9%); VI, 1 (1.9%) and VII, 1 (1.9%) patient.

Analysis of the arteries

The branching pattern of the right lateral artery (RLA) is demonstrated in Fig. 5. The single RLA was observed in 38 patients (73.1%) and dual RLAs in 14 (26.9%). A single RLA arising from the right hepatic artery was seen in 33 patients (Fig. 5a). RLA was originating from a replaced right hepatic artery from the superior mesenteric artery in 3 patients (Fig. 5b) and from the gastroduodenal artery in one patient (Fig 5c). RLA arising from the middle hepatic artery as an accessory artery was seen in another patient (Fig. 5d). Among patients with dual RLAs, in 9, arteries were

![Diagram of running pattern of right lateral portal vein, artery and bile duct for right lateral sector.](image)

Schemes of the sectional plane of the orifice of the RL are presented at the right inferior corner of each figure.

a) “south-turning” artery and “north-turning” bile duct

![Diagram](image)

b) “south-turning” artery and “south-turning” bile duct

![Diagram](image)

c) “north-turning” artery and “north-turning” bile duct

![Diagram](image)

Fig. 7. Running pattern of right lateral portal vein, artery and bile duct for right lateral sector.

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Fig. 8. A case of the dual arteries and the dual bile ducts.

a) RLs were dual, with separate ostia. RLAs and RLDs also were dual. Both RLAs and RLDs showed “north-turning” and “south-turning”. The portal vein, bile duct and artery for the right paramedian sector show dual branchings as antero-ventral and antero-dorsal pattern.

b) RLAs were dual. RLAs showed “north-turning” and “south-turning”.

c) RLDs were dual. RLDs showed “north-turning” and “south-turning”.

originating independently from the right hepatic artery (Fig. 5e). In 4 patients, dual arteries were taking off independently from the replaced right hepatic artery from the superior mesenteric artery (Fig. 5f). Combined supply from a right lateral branch of the right hepatic artery and a branch of the common hepatic artery was also seen in another patient (Fig. 5g).

3D relationship of the artery, the bile duct and the portal vein

3D relationship of the artery and the bile duct to the right lateral sector with reference to the portal vein branches were studied. As showing Fig. 6, we defined the right lateral sector with reference to the portal vein (3D relationship of the artery and the bile duct to the portal vein) [17]. In 49 patients with single RLD, 44 had the “north-turning” duct (Fig. 6a) and 5 had the “south-turning” duct (Fig. 6b). In 3 patients with multiple RLDs, one had both of the “south-turning” variety and the other two showed a combination of the “north-turning” and “south-turning” ducts (Fig. 8c). Among 38 cases of single RLA, 8 had “north-turning” artery and 30 had “south-turning” artery. Out of 14 dual RLA cases, in 6, a combination of “north-turning” and “south-turning” (Fig. 6b) were observed. In the remaining 8 cases, all had “south turning” arteries.

3D reconstruction of the single artery-bile duct-portal vein combination for the right lateral sector which was observed in 27 patients is shown in Fig.7. A combination of “south turning” artery and “north turning” duct was the most frequent pattern (22 cases). In all of them, the artery was running cranial or ventral to the bile duct and the portal vein at the sectional plane of origin of RL. The bile duct was sited cranial to the portal vein in 20 cases and dorsal in 2. The “south turning” artery- “south turning” bile duct combination was observed in 3 cases and the “north turning” artery-“south turning’ duct combination in one. Among patients with these two patterns, 4 had the artery sited dorsally or cranially to the bile duct.

Case presentation (Fig. 8, a, b, c)

RLs were dual, with separate ostia. The dual arteries show “north-turning” and “south-turning”, and the dual bile ducts also show “north-turning” and “south-turning”. The portal vein, bile duct and artery for the right paramedian sector show dual branchings as antero-ventral and antero-dorsal pattern [19].

DISCUSSION

Reliability of the 3D MD-CT on the anatomical evaluation of the living liver donors has been reported in several articles [12,13,20-23]. The advantages of MD-CT are mainly faster scanning capability, improved temporal resolution, improved spatial resolution and increased effectiveness of the intravascular contrast agent. Sakai et al. [12] reported that, comparing with conventional angiography, 3D CT angiography depicted the extra hepatic arteries and the aberrant arteries successfully and also depicted the intrahepatic segmental arteries with a high detection rate. These results are comparable with the other published literature [13,21]. The portal venous system was also clearly visualized by MD-CT with a high accuracy rate [13]. However, a problem is that 3D reconstruction imaging does not protect against potential misinterpretation during post-processing. As authors did in this study, to increase the reliability of 3D vascular images, it is important to check and pick up the missing branches on sequential 2D images after automatic reconstruction of 3D vascular images by the surgeon himself who is an expert in the anatomy of the hepatic structures.

Contrast enhanced CT was used in this study for the biliary system. Chen et al. [24] reported that CT cholangiography had a good correlation with the images from the endoscopic retrograde cholangiography and the intra-operative cholangiography, and it depicted the tertiary and the quarternary branches of the biliary tree in 99.6% of cases. Accurate depiction of the biliary tree by excretory MR cholangiography using biliary contrast agent Mangafodipir trisodium is reported recently [25,26]. However, Yeh et al. [22] indicated that the biliary enhanced CT cholangiography enabled significantly better biliary tract visualization than the conventional or excretory MR cholangiography either alone or in combination. IV contrast enhanced CT cholangiography is rarely performed in North America partly because of the perceived high risk of the contrast agent [27,28]. However, adverse contrast agent reactions of the biliary enhanced CT can be decreased to 1-3% (similar to the conventional IV contrast enhanced CT) using slow infusion of the contrast agent and premedication with intravenous diphenhydramine [29-32]. Severe side effects which resulted in death were reported to be 0.01% [30,33].

For the understanding of the 3D anatomical relations, integration of the images of the artery, the portal vein and the bile duct will be extremely useful. Dynamic enhanced CT and biliary enhanced CT were
performed at different times in this study because of the possible accelerated adverse effects of the vascular and the biliary contrast media. Each scan was performed with the same focus of view and in post-processing, the 3D position of each image was adjusted accurately on sequential 2D images of axial, sagittal and coronal view, focusing the hepatic hilum especially the right portal vein.

Ramification of the first branch of the portal vein has a few anomalies compared with the bile duct and the artery [13]. Nevertheless, as to RL, the single portal vein cases were only 57.7% and others had a common ostia at origin or dual branches without a common right branch. Kyoto team reported that dual portal branches can be reconstructed safely using technical modifications with or without interposed venous graft when the bifurcation is extraparenchymal [18]. However, in institutions with a few experience of LRLT reconstruction of multiple portal branches should be risky and challenging.

Biliary reconstruction is the most challenging part in liver transplantation. Failure to recognize even minor intrahepatic branches crossing the dissection line can result in severe postoperative bile leak and other complications. The incidence of biliary complications in right lobe LRLT is reported to be 10.8-17.5% [18,34] and this is high compared to left-sided liver graft. Nakamura et al. [18] reported that, among 120 right lobe grafts, 43 had dual bile ducts and 4 had triple orifices. Surgical options in multiple ducts can be double reconstructions or reconstruction as a single orifice with or without duct-plasty. They reported that all the biliary variants were successfully reconstructed with an acceptable complication rate (9.3% bile leaks and 8.5% stenosis) in grafts with multiple biliary orifices and concluded that there are no definite contraindications in the biliary anatomy which can preclude a transplantation. However, in right lateral sector LRLT, biliary variants are more complicated. The duct which runs along the ventral side of RPM is relatively easy to dissect and reconstruct. However, in our series, in 43 cases, RLD showed a ‘north turning’ pattern-RLD runs along the dorsal side of RPM. The ‘north turning’ duct is difficult to dissect while procuring the graft because the right paramedian portal vein interferes the dissection. According to Sugawara et al. [35], when the bile duct was sited dorsally to RPM, they pulled the dissected right portal vein and RPM cranially and after that they were able to dissect the bile duct from the surrounding connective tissues. They described that there are no anatomical variations of the bile duct which contraindicate a right lateral sector procuring. Even though, in dual duct cases especially when one duct runs dorsally to the right lateral portal vein and the other ventrally, reconstruction of dual ducts partitioned by the portal vein should be unacceptably difficult. We observed 2 cases with this anomaly.

Because hepatic arterial thrombosis is one of the serious complications after transplantation, arterial anomaly is also a critical consideration in right lateral graft transplantation. The incidence of hepatic artery injury in procurement was significantly higher in grafts with aberrant arterial anomaly and arterial injury was associated with an increased risk of arterial thrombosis [36]. One of our cases had an aberrant RLA arising from the middle hepatic artery. As this anomaly is very rare, accurate anatomical understanding of this artery during the graft procurement is difficult if preoperative imaging of the segmental arterial anatomy is not clearly revealed. This study also revealed that 73.1% of cases had a single RLA and 26.9% had dual RLAs. Among the 38 single artery cases, 8 had ‘north turning’ right lateral artery. In 6 among the 14 dual artery cases, both or one of the dual arteries was ‘north turning’. These ‘north-turning’ arteries are also difficult to dissect. Further, the arterial branch or branches for the right lateral sector are thinner and shorter than those of the right lobe graft or left-sided graft. Reconstruction of all dual arteries may be difficult in right lateral sector transplant. Whether the presence of multiple arterial branches increases the incidence of hepatic arterial thrombosis remains controversial. Soin et al. [39] recommended that livers with aberrant right hepatic arteries should not to be used because these grafts require multiple arterial reconstructions with a high incidence of postoperative arterial thrombosis. Some institutions are not using left liver grafts with multiple arteries because of the technical difficulties of reconstruction [40,41]. On the other hand, Ikegami et al. [42] recommended to reconstruct only the thickest artery if intraoperative doppler shows pulsatile arterial flow and arterial signal in the corresponding segment of the non-anastomosed arteries. The Tokyo team [43] proposed a simple test on the back table for the selection of single hepatic arterial reconstruction in grafts with multiple arteries. Even though, preoperative precise identification of the hepatic arterial variants by imaging and the accurate assessment of the feasibility are essential components of a successful right lateral graft LRLT.

According to some studies [4,7], in 9-18% of potential donors, the right lateral sector has volumetric advantages compared to the left lobe. However, anomalies of the hepatic vasculature cause further limitations for the feasibility of transplantation. The indica-
tions for the right lateral sector transplantation should have been deliberate at least in institutions which have only a few experiences. In our study, cases having single portal vein, single artery and single bile duct are only 27 among 52 (Fig. 9). Therefore, to increase safe right lateral sector LRLT and to overcome donor shortage, accurate preoperative anatomical evaluation and excellent surgical technique coping with the particular anatomical variant is required. Anatomical understanding based on the 2D images may not be sufficient at operation. The understanding of the 3D vascular and biliary anatomy revealed by this study will contribute to a better definition of the anatomical contraindications for transplantation which may further results in more safe and widely applied right lateral graft LRLT.

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