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ORIGINAL ARTICLE

Preoperative evaluation of biliary anatomy of donor in living donor liver transplantation by conventional nonenhanced magnetic resonance cholangiography

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Summary

Detailed preoperative evaluation of the biliary anatomy of the donor in living donor liver transplantation (LDLT) can minimize postoperative morbidity in the recipient and maximize safety for the donor. We prospectively evaluated the diagnostic accuracy and clinical usefulness of nonenhanced conventional magnetic resonance cholangiography (MRC) for depicting the biliary anatomy of LDLT donors. MRC and intraoperative cholangiography (IOC) examinations of 111 donors were performed between August 2005 and February 2006. We observed the classical branching pattern of the biliary system in 67 subjects (60.4%), with the remaining 44 subjects (39.6%) showing anatomical variations. MRC showed accurate anatomy of the biliary system, using IOC as the reference standard, in 98 (88.3%) subjects. MRC had a sensitivity in differentiating normal from variant anatomy of 95.5%, specificity of 95.2%, a positive predictive value of 96.8% and a negative predictive value of 93.3%. The agreement between MRC and IOC findings, as evaluated by κ-value (0.865) was statistically significant ($P < 0.001$). In conclusion, the diagnostic accuracy of conventional nonenhanced MRC is sufficient for this method to be used for the preoperative evaluation of biliary anatomy in LDLT donor candidates.

Introduction

Biliary reconstruction in living donor liver transplantation (LDLT) has several innate disadvantages, including frequent multiple duct openings of the graft and relatively small-sized graft ducts. As a consequence, most transplantation centers have reported high rates of biliary complication (BC) following LDLT. Despite efforts to reduce the incidence of BC, it remains the most common and intractable problem in LDLT [1].

Biliary complication after LDLT is closely related to the complex anatomy of the biliary tree in the donor. Anomalous biliary anatomy is not uncommon, with the classical branching pattern present only in about 60% of the normal population [2]. Anomalous biliary anatomy frequently involves drainage of the right anterior or posterior sectoral duct. These anomalies uniformly result in multiple graft bile duct openings and require more complicated biliary anastomosis in the recipient. Early anastomotic leaks or stenoses occur in a non-negligible proportion of patients with complex biliary anastomoses.

Preoperative knowledge of the biliary anatomy of the donor can simplify the biliary reconstruction procedure. Information regarding any variation in the biliary anatomy of the donor, especially aberrant accessory ducts, can guide appropriate surgical strategies. In addition, when multiple donor candidates are available, information regarding their biliary anatomy can help in the selection of the optimal donor. Thus, preoperative evaluation of the biliary anatomy of the LDLT donor can minimize postoperative morbidity in the recipient as well as maximize safety for the donor.

Magnetic resonance cholangiography (MRC) has shown promise in the preoperative evaluation of biliary anatomy in LDLT donors. However, conventional MRC using a heavily T2-weighted turbo spin-echo technique has diagnostic limitations in the evaluation of intrahepatic biliary anatomy, especially of the nondilated biliary tree [3]. The introduction of several hepatocyte-specific contrast agents has suggested that contrast-enhanced MRC may counter the limitations of conventional MRC. Contrast-enhanced MRC itself has several limitations including high cost, limited availability, the potential risk of contrast-induced adverse reactions, and long examination times. Recent advances in MRC techniques have improved spatial resolution, and led to renewed interest in the clinical usefulness of conventional nonenhanced MRC in evaluating biliary anatomy. Therefore, we have evaluated the diagnostic accuracy and clinical usefulness of conventional nonenhanced MRC for depicting the biliary anatomy of LDLT donors.

Patients and methods

Patients

From August 2005 to February 2006, we performed 147 liver transplantations including 128 LDLTs and 19 cadaeveric donor liver transplantations. Among the 123 adult-to-adult LDLTs, there were 99 in which preoperative MRC could be performed on the donor. The remaining 24 adult-to-adult LDLTs were urgent or emergent LDLT cases, in which donor MRC could not be performed; these 24 cases were excluded. The 99 included adult-to-adult LDLTs consisted of 87 single-graft LDLTs and 12 dual-graft LDLTs. Thus, there were 111 donors (68 men, 43 women), of mean age 29 ± 9 years (range, 16–52 years).

MRC technique

All magnetic resonance (MR) examinations were performed on a 1.5-T scanner (Magnetom Vision; Siemens, Erlangen, Germany) using a circular, polarized, phased-array body coil with four elements. The entire MR examination was performed under the guidance of a radiologist, to determine the location of the MRC slabs that properly fit the entire length of the common bile duct and intrahepatic duct.

Two MRC techniques were utilized; single-slab rapid acquisition with relaxation enhancement (RARE) and multislice half-Fourier acquisition single-shot turbo spin-echo (HASTE). The slabs of a single-shot RARE sequence were obtained at various angles to allow optimal visualization of the bile ducts. Images with coronal, oblique coronal (20–35° to the coronal plane), and sagittal planes were routinely obtained. The number of thick-slab acquisitions per patient ranged from 5 to 10 (mean, 7). Multislice HASTE images were subsequently obtained in the coronal plane. Each examination was performed during a single breath-hold. Fat saturation was used to reduce strong fat signals during image acquisition. The total acquisition time for all imaging steps in the MR imaging sequence was <15 min. No intravenous contrast was administered. Thin section images were used to create maximum-intensity-projection (MIP) reconstruction images of bile ducts.

Image interpretation

All MRC images were interpreted by two radiologists with subspecialty in abdominal imaging and interventional radiology at a picture archiving and communication system (PACS, Petavision II, Hyundai Information Technology Co, Seoul, Korea). The classification system of the biliary tract was similar to that of Huang *et al* [4]. As we identified several minor variations that could not be included in this system, we therefore added Type VI (unclassified group). The details of our classification system were:

Type I Normal branching pattern

Type II Trifurcation of the right anterior duct (RAD) and right posterior duct (RPD) and the left hepatic duct (LHD)

Type III RAD or RPD draining into the common hepatic duct (CHD)

Type IV RAD or RPD draining into LHD

Type V RPD draining into the cystic duct (CD)

Type VI unclassified

All MRC images were compared with intraoperative cholangiography (IOC) images and verified by intraoperative findings.

Surgical technique

IOC and division of the graft bile duct

Immediately after cholecystectomy, IOC was performed by injecting 15 ml radiocontrast (meglumine ioxitalamate) through the cystic duct stump. Just before bile duct division, we again performed IOC using the method of radio-opaque marker tagging, to identify the optimal site of bile duct division. Although preoperative planning was performed using MRC, IOC was used for final determination of the site of bile duct division. Following near-complete transection of the liver parenchyma, the first-order bile duct was sharply transected, allowing us to minimize the number of graft duct openings and to minimize the risk of stricture of the remnant duct of the donor.

Selection of the biliary anastomosis method

The method of bile duct anastomosis was selected intraoperatively by matching the size and number of the graft bile ducts and the recipient bile duct stumps. When suitable recipient duct was available, a single duct-to-duct (DD) anastomosis was preferentially performed to the single or snout graft duct. If the recipient hepatic duct was not suitable for anastomosis (e.g., it was larger than the donor duct, there was extensive dissection around the recipient duct, or biliary disease was the primary cause of transplantation), single hepaticojejunostomy (HJ) was performed. For multiple separate graft duct openings, double DDs, double HJs, or a combination of DD and HJ was selected. In all cases of dual donor LDLT, the biliary anastomosis of the right-sided graft was DD and the biliary anastomosis of the left-sided graft was HJ.

Statistical analysis

Agreement between preoperative MRC and IOC was determined using κ statistics.

Results

For the 87 single-graft LDLTs, we used 83 modified right lobes (MRL), two extended left lobes (ELL) and two right posterior segments (RPS). For the 12 dual-graft LDLTs, we used two ELLs for nine, MRL and ELL for two and ELL and RPS for one. Two of the 111 donors developed symptomatic pleural effusions and required percutaneous drainage. Postoperative bleeding occurred in one donor leading to re-exploration. All donors were discharged without physical or psychological sequelae and are doing well to date.

Among the 99 recipients, three (3.0%) died during the immediate postoperative period. The causes of deaths were intracranial hemorrhage, sepsis, and pneumonia, respectively. Among the 96 living recipients, 14 (14.6%) experienced biliary complications. Four patients experienced minor leakage from the anastomosis and three experienced bile leakage from the resection margin of the graft; all were resolved by conservative management. Seven patients developed anastomosis stenoses, four of which were treated via percutaneous transhepatic biliary drainage (PTBD) tubes and three of which were treated via endoscopic retrograde biliary drainage (ERBD) tubes. In two patients, stenoses were resolved, with the other five patients still undergoing treatment.

Table 1. Biliary anatomy of 111 LDLT donors on conventional nonenhanced MRC and IOC.

	Intraoperative Cholangiography						
MRC	I	II	III	IV	V	VI	Total
NI*	4	0	0	0	0	0	4
I	60	0	2	0	0	0	62
II	2	9	1	0	0	1	13
III	1	0	17	0	0	0	18
IV	0	0	2	8	0	0	10
V	0	0	0	0	2	0	2
VI	0	0	0	0	0	2	2
Total	67	9	22	8	2	3	111

NI* = not interpretable.

Branching patterns of bile duct in LDLT donors

Of the 111 donors, only 67 (60.4%) had classical branching patterns of the biliary system. The remaining 44 subjects had anatomical variants: 9 (8.1%) had Type II, 22 (19.8%) had Type III, 8 (7.2%) had Type IV, 2 (1.8%) had Type V, and 3 (2.7%) had Type VI.

Diagnostic accuracy of MRC: comparing with IOC

Compared with IOC as the reference standard, MRC revealed the accurate and detailed anatomy of the biliary system in 98 (88.3%) of 111 subjects (Table 1). In four subjects, MRC findings were not interpretable due to artifacts evoked by patient motion. In three subjects, MRC results showed anomalous anatomy, whereas IOC revealed normal anatomy. In two subjects, MRC results showed normal anatomy but IOC showed Type III anomalies. In four subjects, MRC and IOC, both showed anomalous but different anatomy. MRC revealed RPD draining into CHD (Fig. 1) in 17 subjects, and RAD or RPD draining into LHD in eight subjects (Fig. 2). In two subjects, MRC clearly demonstrated RPD draining into the CD (Fig. 3), and examination of one subject showed the accessory duct of segment seven draining into CHD (Fig. 4).

The overall sensitivity of MRC in differentiating normal and variant anatomy was 95.5%, its specificity was 95.2%, and its positive and negative predictive values were 96.8% and 93.3%, respectively. The agreement between MRC and IOC, evaluated by κ-value (0.865) was statistically significant ($P < 0.001$).

Donor selection according to the MRC findings

During the study period, a total of 151 donor candidates were evaluated and 40 were excluded due to inadequate right-to-left volume proportion, severe fatty change, abnormal liver function or anomalous vascular or biliary

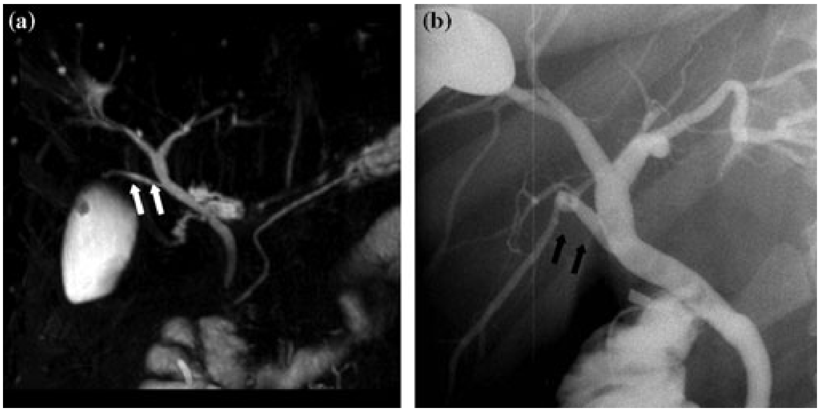

Figure 1 A 31-year-old female patient underwent right hemihepatectomy. Magnetic resonance cholangiography (a) clearly demonstrated right posterior duct (white and black arrows) draining into common hepatic duct and confirmed by intraoperative cholangiography. (b). Two openings of bile duct were present on graft and two duct-to-duct anastomoses were performed in recipient.

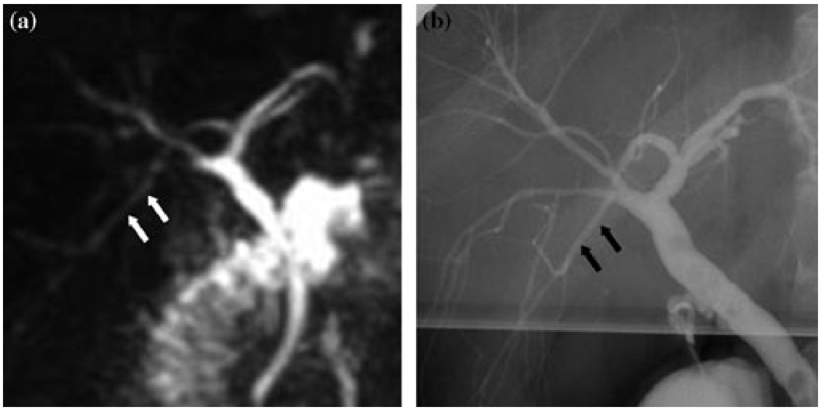

Figure 2 A 19-year-old male patient underwent right hemihepatectomy. Magnetic resonance cholangiography (a) clearly demonstrated right posterior duct (white and black arrows) draining into left hepatic duct and confirmed by intraoperative cholangiography. (b). Two openings of bile duct were present on graft and combination of duct-to-duct anastomosis and hepaticojejunostomy was performed in recipient.

anatomy. Of these, 40 excluded donor candidates, six were excluded due to anomalous biliary anatomy, as revealed by preoperative MRC (Table 2).

Discussion

Anatomical variation of the biliary tree of an LDLT donor are not contraindication for donor hepatectomy. Rather, these difficulties can be overcome by meticulous and precise surgical techniques. If a recipient has only one donor candidate who fulfills other indications for donor hepatectomy, such as age, steatosis, volume proportion, and liver function profile, this candicate would be chosen despite anomalous biliary anatomy. In this study, most recipients had only one donor candidate, with preoperative MRC results used to choose donors for only four recipients. Therefore, the practical usefulness of preoperative evaluation of biliary anatomy in LDLT donor may be limited. Intraoperative evaluation by IOC and direct bile duct probing can provide enough information for donor hepatectomy.

Biliary anomalies in the donor uniformly result in multiple graft bile duct openings, thus requiring more complicated biliary anastomoses in the recipient. Early anastomotic leaks or stenoses occur in a non-negligible proportion of patients with complex biliary anastomoses. Most transplantation surgeons want to acquire grafts with simple biliary anatomy. Thus, if multiple donor candidates are available, the optimal donor can be selected according to biliary anatomy. Furthermore, preoperative information about any variation in the biliary anatomy of donor, especially aberrant accessory ducts, can optimize the surgical strategy. Preoperative information can lessen the burden on the donor surgeon and prevent accidental biliary injury to the donor. Thus, preoperative evaluation of LDLT donor biliary anatomy can minimize postoperative morbidity in the recipient as well as enhance donor safety.

When estimating the clinical usefulness of diagnostic modalities for donor evaluation, two aspects should be considered: noninvasiveness and precision. Endoscopic retrograde cholangiography (ERC) has been found to provide the best quality for precise evaluation of the biliary tree. ERC, however, is associated with substantial risks in otherwise healthy donors, including post-ERC pancreatitis, bile duct injury and duodenal perforation [5]. Therefore, most transplantation centers do not perform ERC routinely in LDLT donors.

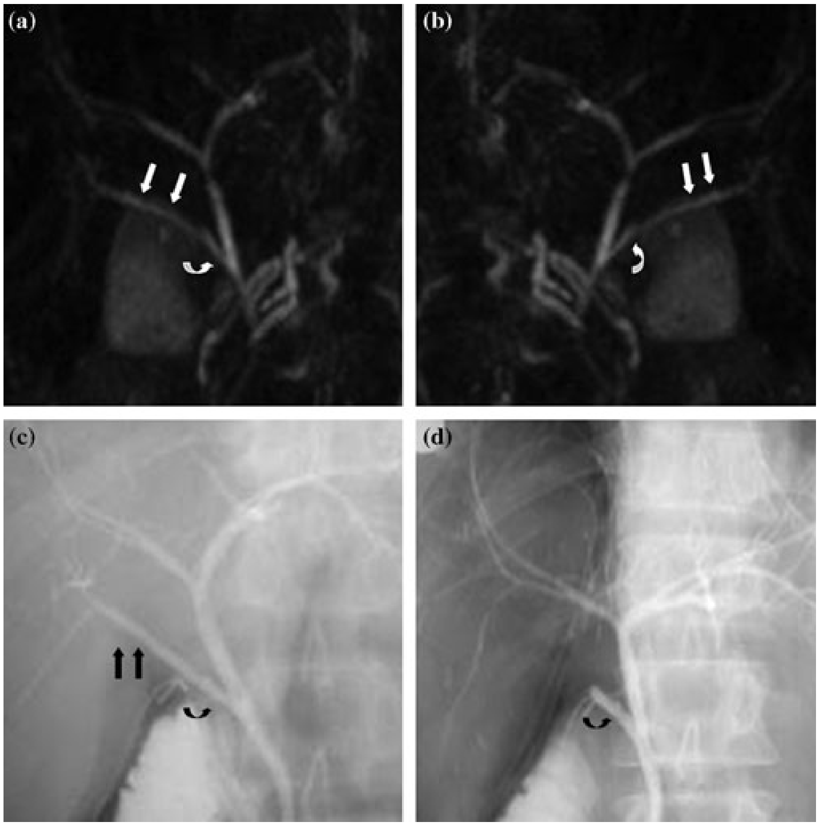

Figure 3 A 24-year-old female patient underwent right hemihepatectomy. Magnetic resonance cholangiography (a) demonstrated right posterior duct (white arrows) draining into cystic duct (white curved arrow). It looked like right posterior duct draining into common hepatic duct (b). However, rotational view could help to discriminate cystic duct. The preoperative magnetic resonance cholangiography finding was confirmed by intraoperative cholangiography (c) and (d). After division of right posterior duct (black arrow), the cystic duct stump (curved black arrow) was still visualized. Two openings of the bile duct were present on the graft and a combination of duct-to-duct anastomosis and hepaticojejunostomy was performed in the recipient.

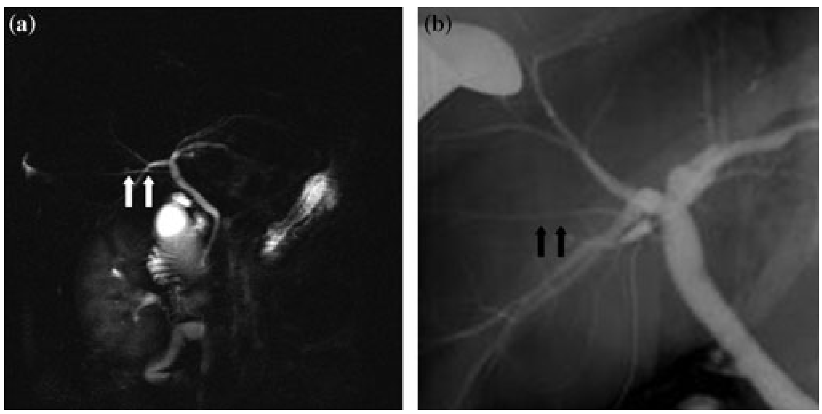

Figure 4 A 34-year-old male patient underwent extended left hemihepatectomy for dual-graft living donar liver transplantation (a). Magnetic resonance cholangiography revealed accessory bile duct draining segment seven (white arrows) joined with common hepatic duct (b). Intraoperative cholangiography verified this finding (black arrows).

The usefulness of computed tomographic cholangiography (CTC) using intravenous injection of radiocontrast agent (10.3% iodipamide meglumine) has been shown to provide much better spatial resolution than other imaging tools [6–8]. Multi-detector raw CT scans, with thinner sections and shorter scanning time, can provide consistently good visualization of the biliary system, including in the preoperative evaluation of LDLT donors. Due in part to adverse reactions to the radiocontrast agent, however, CTC is not used routinely in LDLT donor evaluation. The potential risk of allergic reactions can be reduced by diphenhydramine premedication and very slow infusion (over 30 min) of the radiocontrast agent. This, however, lengthens the examination time and causes greater inconvenience to the donor.

Magnetic Resonance Cholangiography has potential as a noninvasive, nonbiohazardous diagnostic modality for evaluating LDLT donors. The basic concept is that heavily T2-weighted images demonstrate high signal intensity from static fluid structures while background signal is suppressed. This conventional MRC technique, however, has several limitations for detailed depiction of the biliary

Table 2. Six donor candidates excluded due to biliary anomaly revealed on preoperative MRC.

	Donor Candidates*		
	Selected Candidate	Excluded Candidate 1	Excluded Candidate 2
Recipient 1	Type I	Type III	Type III
Recipient 2	Type I	Type II	–
Recipient 3	Type II	Type IV	–
Recipient 4	Type I	Type IV	Type V

Donor Candidates* = all donor candidates were similar to their respective recipient in another indications for donor hepatectomy, such as age, steatosis, volume proportion, and liver function profile.
MRC, magnetic resonance cholangiography.

tree, especially in nondilated ducts. The introduction of various hepatobiliary contrast agents, which are excreted into the biliary system, has led to renewed interest in contrast-enhanced MRC, with mangafodipir trisodium (Mn-DPDP)-enhanced MRC emerging as a safe and useful method for preoperative donor evaluation. Mn-DPDP-enhanced MRC has been reported to be as accurate as IOC, suggesting its use for preoperative planning of biliary anastomosis [9–11]. However, MR protocol using Mn-DPDP has some limitations, including additional table time due to the requirement of a 10 to 15-min delay after slow injection of the contrast agent for its biliary excretion. Furthermore this agent is expensive and not widely used; It is presently unavailable in some countries.

Although conventional nonenhanced MRC is now widely used in the diagnosis of biliary diseases accompanying bile duct dilatation, its clinical usage has been limited for the evaluation of bile duct anatomy in a non-obstructed system, where very small ductal structures need to be visualized and better quality with high-resolution may be required [12]. However, several recent reports have provided encouraging results that conventional MRC was highly accurate in the preoperative biliary mapping of LDLT donors [13–15], although these studies enrolled small number of subjects. Our study, which enrolled a large number of LDLT donors and used the same MR technique (half-Fourier RARE) and the same standard for comparison (IOC), showed that MRC was 88.3% (98/111) accurate in preoperative biliary mapping. This finding indicates that conventional nonenhanced MRC has potential for the preoperative assessment of nondilated biliary system in LDLT donors, although it may not provide adequate information for accurate assessment in a minority of cases with delicate bile ducts.

Various techniques are available for better visualization of small caliber bile ducts, including breath-hold RARE techniques [16]. ERC simulating images can be obtained by either MIP three-dimensional (3D) rendering from contiguous axial and coronal thin section raw data or from rotating thick slab images. Furthermore, newer scanners with parallel imaging acquisition capabilities can obtain 3D volumetric T2-weighted MRC images with section thickness <1 mm, which can be used to evaluate the relationship of the right, left, and common hepatic ducts. Further improvements in quality and accuracy are needed, however, in patients with small sized and/or delicate bile ducts.

In conclusion, we found that the diagnostic accuracy of conventional nonenhanced MRC was acceptable in the evaluation of biliary anatomy in LDLT donors. However, further technical advances are needed to accurately detect minute aberrant bile ducts.

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