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ABDOMINAL IMAGING

ORIGINAL ARTICLE

Donor bile duct evaluation with magnetic resonance cholangiography in living-donor liver transplantation: a novel anatomical classification for predicting surgical techniques

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PURPOSE

To propose a novel, inclusive classification that facilitates the selection of the appropriate donor and surgical technique in living-donor liver transplantation (LDLT).

METHODS

The magnetic resonance cholangiography examinations of 201 healthy liver donors were retrospectively evaluated. The study group was classified according to the proposed classification. The findings were compared with the surgical technique used in 93 patients who underwent transplantation. The Couinaud, Huang, Karakas, Choi, and Ohkubo classifications were also applied to all cases.

RESULTS

There were 118 right-lobe donors (58.7%) and 83 left-lateral-segment donors (41.3%). Fifty-six (28.8%) of the cases were classified as type 1, 136 (67.7%) as type 2, and 7 (3.5%) as type 3 in the proposed classification; all cases could be classified. The number of individuals able to become liver donors was 93. A total of 36 cases were type 1, 56 were type 2, and 1 was type 3. Of the type 1 donors, 83% required single anastomosis during transplantation, whereas six patients classified as type 1 required two anastomoses, all of which were caused by technical challenges during resection. Moreover, 51.8% of the cases classified as type 2 required additional anastomosis during transplantation. The type 3 patient required three anastomoses. The type 1 and type 2 donors required a different number of anastomoses ($P < 0.001$).

CONCLUSION

The proposed classification in this study includes all anatomical variations. This inclusive classification accurately predicts the surgical technique for LDLT.

KEYWORDS

Bile duct variations, intrahepatic bile ducts, liver transplantation, magnetic resonance imaging, magnetic resonance cholangiography

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Liver transplantation is being increasingly performed worldwide. This is mainly because of the increasing incidence of fatty liver disease and alcohol abuse. Liver transplantation is a treatment option for acute or chronic liver diseases. It offers a second chance to live and enhances the quality of life, especially for patients who do not respond to medical or surgical treatments.[1] Liver transplantation can involve cadavers or living donors. Whereas cadaveric transplantation involves the transplantation of an organ from a deceased patient, living-donor liver transplantation (LDLT) is a surgical operation in which a portion of the liver from a healthy living person is removed and transplanted into the patient in need. In LDLT, the donor should have normal physical and mental health to ensure their protection. Specifically, liver function, vascular structure, and bile ducts should have a suitable structure and be

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of sufficient volume in terms of anatomy and function in both the donor and recipient.[2,3] Despite advances in liver surgery techniques, complications in vascular and biliary structures are major causes of morbidity and mortality in the postoperative period. Therefore, the accurate evaluation of biliary tract anatomy and vascular structures is essential in the preoperative period. Determining the anatomy and variations of vessels and bile ducts reduces the complications that may occur in the donor or recipient. Identifying situations hindering the operation is vital, especially for donor candidates.[4] Bile duct variations present one of these situations, with bile leakage, biliary tract stricture, cholangitis, and biliary tract stones constituting the main complications.[5] Knowledge of intrahepatic biliary tract variations is essential in determining the surgical technique.

Various classifications for the evaluation of the biliary tract exist. These include the Huang, Couinaud, Choi, Ohkubo, and Karakas classifications, all of which describe the anatomy of the intrahepatic biliary tract. However, the current classifications cannot predict the surgical technique and number of anastomoses required. In addition, none of these classifications can be applied to all possible anatomical variations.

This study aims to propose a novel, inclusive classification that facilitates the selection of the appropriate donor and surgical technique.

Methods

This research was approved by the Ethics Committee of Koc University (protocol number: 2019.140.IRB1.014). Informed consent was obtained from all patients. A total of 201 magnetic resonance cholangiography (MRCP) examinations of healthy liver donor candidates obtained at our university hospital between June 2019 and October 2021 were retrospectively reviewed. Of the 201 healthy donors [mean age ± standard deviation (SD): 34 ± 9 years], 118 (58.7%) were men and 83 (41.3%) were women. The Couinaud,[6] Huang,[7] Karakas,[8] Choi,[9] and Ohkubo[10] classifications were applied to all cases. Following this, the study group was classified according to the proposed classification. The number of anastomoses in the operated cases was recorded. Three patients with non-optimal imaging were excluded from the study.

Magnetic resonance cholangiography protocol

Patients were required to fast for 4 h to reduce gastric and duodenal fluid secretions, intestinal peristalsis, and increased gallbladder distension. An antiperistaltic agent (butylscopolamine, Buscopan®) was routinely used. The antiperistaltic agent was administered intravenously immediately before the examination. The MRCP images were obtained using a 1.5 and 3 T magnetic resonance imaging system (*Siemens*, Erlangen, Germany). First, a two-dimensional, breath-hold half Fourier single-shot turbo spin-echo sequence was obtained in the axial plane. The entire biliary tract could be visualized up to the duodenal ampulla with two breath holds. Subsequently, two three-dimensional respiration-triggered heavily T2-weighted fast spin echo sequences were obtained in the coronal oblique plane. The imaging plane was selected from the first axial T2-weighted images. The first acquisition was aligned to the common hepatic duct (CHD) at the level of the pancreatic head, and the second acquisition was aligned to the pancreatic duct approximately 90° to the first imaging plane. Breath triggering was performed by monitoring the respiratory movement with navigation. The navigator was placed at the edge of the diaphragm in the coronal and sagittal localizers. The images were acquired when the position of this diaphragm interface with the lung entered the predetermined window, which ensured a consistent position in the imaging slice. An imaging series with 40 consecutive sections (all 1.5-mm thick) was obtained. The pancreaticobiliary tree has high signal intensity, whereas neighboring structures have low signal intensity because the images are predominantly T2-weighted. A maximum intensity projection (MIP) format was generated from this data volume; MIP reformats can be generated in various planes, such as coronal and sagittal obliques.

Standards of the novel classification

From the MRCP images, the separation and length of the right hepatic duct (RHD) and left hepatic duct (LHD), the total number of bile ducts joining to the CHD, and the way the cystic duct joined the CHD (directly or in the form of a cystohepatic duct) were evaluated. Based on these data, three types emerged (Figure 1). In type 1, there must be

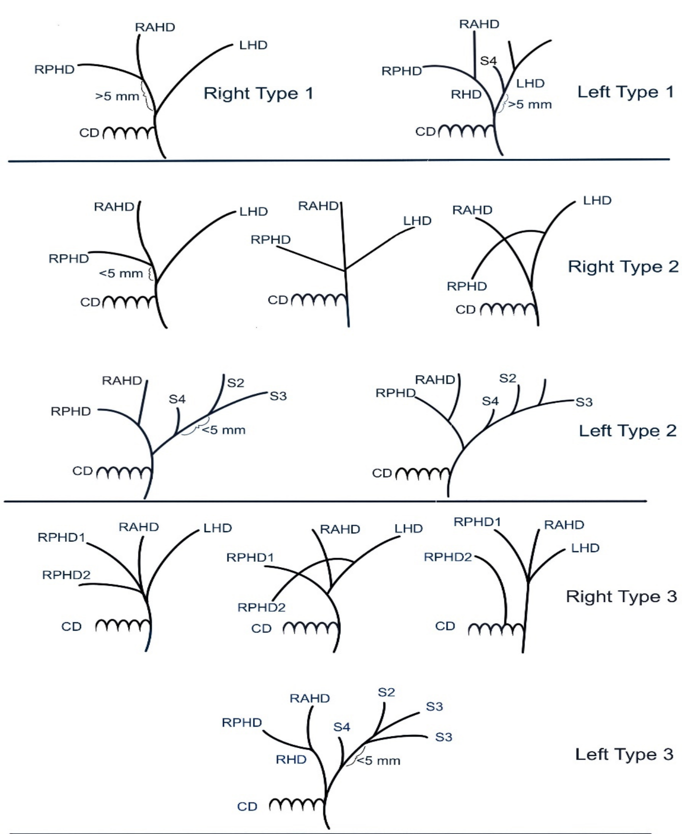

Figure 1. New classification and subtypes for both right-lobe and left-lateral-segment donors. RAHD, right anterior hepatic duct; RPHD, right posterior hepatic duct; RHD, right hepatic duct; LHD, left hepatic duct.

Main points

- The classification used in this study covers all variations.
- It estimates the surgical technique as well as the biliary tract classifications devised thus far.
- The proposed classification can accurately predict the surgical technique.

only one duct from the lobe to be donated that joins to the CHD, and the length of this duct must be at least 5 mm (Figure 2). In type 2, there must be a maximum of two ducts from the lobe to be donated that join to the CHD or one duct with a length of <5 mm (Figure 3). Type 3 involves complex biliary variants, with more than two ducts from the lobe to be donated that join to the CHD (Figure 4). All the participants could be grouped according to this new classification. The predictions of our classification in relation to surgical technique were as follows: type 1 can be considered a safe donor, type 2 can be a donor but may require additional anastomosis, and type 3 is not suited to being a donor because this type requires more than two anastomoses (Figure 5).

Figure 2. Type 1 configuration in right-lobe donors according to the new classification.

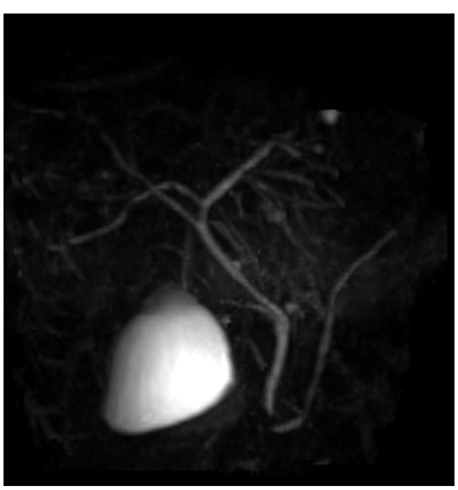

Figure 3. Type 2 configuration in right-lobe donors according to the new classification. The right posterior hepatic duct drains into the left hepatic duct.

Statistical analysis

The mean and SD were used to express all continuous data, and frequencies were used to express all categorical data. The relationship between the donor type of the proposed classification and the surgical technique was evaluated using the chi-square test. Statistical significance was defined as $P < 0.05$. The analysis was performed using IBM SPSS v.21.0 software.

Results

In this study, in which a total of 201 donors were evaluated, 118 participants were right-lobe (58.7%) and 83 were left-lateral-lobe (41.3%) donors (Table 1). In 196 of the donors, the cystic duct joined the CHD independently. Cystohepatic duct variation was present in five donors. In four of these cases, the right posterior duct joined the cystic duct, and in one case, the RHD joined the cystic duct. Regarding the total number of ducts joining the CHD, two were identified in 152 donors, three in 41 donors, four in seven donors, and five in one donor.

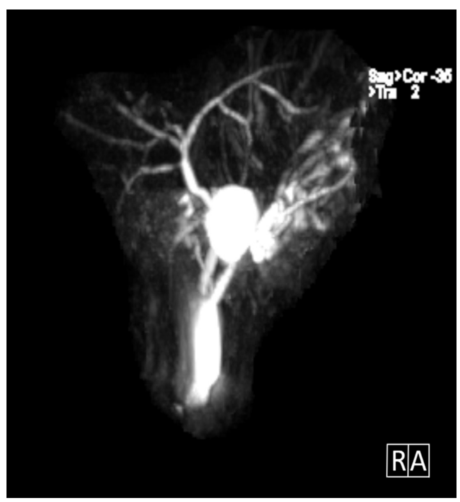

Figure 4. Type 3 configuration in right-lobe donors according to the new classification. From the right lobe, three channels drain into the common hepatic duct.

The distribution of donors according to the Huang, Couinaud, and Karakas classifications are summarized in Table 2, and those of the Ohkubo, and Choi classifications in Table 3.

A total of 56 (28.8%) of the cases were classified as type 1, 136 (67.7%) as type 2, and 7 (3.5%) as type 3. All cases could be classified (Table 3).

The number of participants that could become liver donors was 93. A number of donors were rejected because of hepatosteatosis, vascular variation, or insufficient remnants; however, crucially, six donors were rejected because of biliary tract variations.

Among these 93 donors, 36 were type 1, 56 were type 2, and 1 was type 3 according to the proposed classification. A single anastomosis was required in 57 donors, two anastomoses were required in 35, and three in 1. A single anastomosis (single Roux-en-Y or single end-to-end) was performed during transplantation in 83.3% of the type 1 cases predicted to require a single procedure, whereas 51.8% of the type 2 cases required additional anastomosis during surgery (double Roux-en-Y or double-end) (Table 1). The participant classified as type 3 was excluded from the analysis because the case did not meet the chi-square test assumptions; however,

Table 1. Distribution of donated liver parts and surgical technique in patients undergoing transplantation

Donated liver	n = 201 (%)
Right lobe	118 (58.7)
Left lobe lateral segment	83 (41.3)
Surgical technique	n = 93 (%)
End-to-end	20 (18.7)
Roux-en-Y	37 (34.5)
Double end-to-end	12 (11.2)
Double Roux-en-Y	23 (21.5)
Triple Roux-en-Y	1 (0.9)

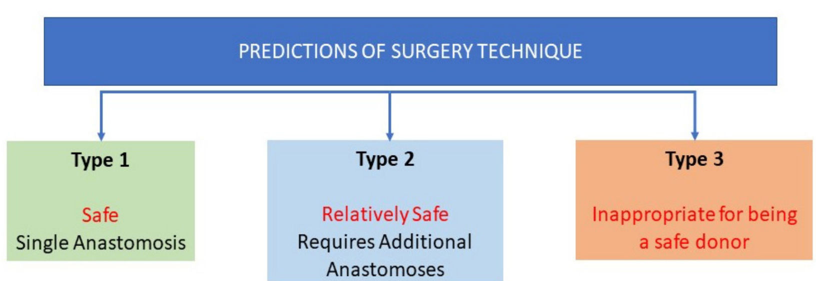

Figure 5. The choice of surgical technique according to the new classification.

this participant required three anastomoses. The donors with radiologically different bile duct types (type 1 and type 2) required a different number of anastomoses (83.3%, and 48.2%, respectively, $P < 0.001$) (Table 4).

Discussion

Right–left hepatic duct bifurcation and length, the total number of bile ducts joining the CHD, and the way the cystic duct joins to the CHD (directly or in the form of the cystohepatic duct) were evaluated in this study, and all cases could be classified as a specific type. A total of 83% of the donors who were predicted to require a single anastomosis (type 1) were found to require this single procedure during transplantation surgery. In addition, a different surgical technique involving more than one anastomosis was required in >50% of the type 2 cases expected to require additional anastomosis. Only one of the nine participants classified as not being suitable as a donor (type 3) could, in fact, be a donor, because of an urgent transplantation need.

Table 2. Distribution of the donors according to the Couinaud, Huang, and Karakas classifications

Couinaud	n (%)
A	106 (52.7)
B	19 (9.5)
C1	22 (10.9)
C2	22 (10.9)
D1	10 (4)
D2	4 (2)
E1	3 (1)
E2	3 (1)
F	4 (1.5)
Unclassified	8 (4)
Huang	
1	106 (52.7)
2	21 (10.4)
3	33 (16.4)
4	30 (14.9)
5	4 (2)
Unclassified	7 (3.5)
Karakas	
K1	28 (13.9)
K2a	77 (38.3)
K2b	21 (10.4)
K3a	21 (10.4)
K3b	11 (5.5)
K4	30 (14.9)
Unclassified	13 (6.5)

This study aimed to draw attention to distinguishing types 1 and 2 and the relationship between radiological type and the number of anastomoses needed. During surgery, 51.8% of type 2 cases required additional anastomosis. This rate is lower than expected. The main reason for this relates to the tendency of transplantation surgeons to anastomose two separate bile ducts together to reduce the complication risk. Six participants classified as type 1 required two anastomoses. All of these participants underwent two anastomoses because the biliary duct was resected shorter than planned during resection. The main reason for this pertains to the resection technique, which follows the demarcation line that occurs after clamping the hepatic artery and portal vein, with the ultimate goal of protecting the donor.

Table 3. Distribution of donors according to the Choi, Ohkubo, and proposed classifications

Choi	n (%)
1	105 (52.2)
2	19 (9.5)
3A	26 (12.9)
3B	35 (17.4)
3C	3 (1.5)
4	2 (1)
5	1 (0.5)
Unclassified	10 (5)
Ohkubo	
A	105 (52.2)
B	19 (9.5)
C	34 (16.9)
D	27 (13.4)
E	2 (1)
F	3 (1.5)
G	3 (1.5)
Unclassified	8 (4)
Proposed classification	
1	58 (28.8)
2	136 (67.7)
3	7 (3.5)
Unclassified	0

Table 4. Association of the donor's biliary anatomy type according to the proposed classification and the number of anastomoses needed during transplantation surgery

Class	Number of anastomoses		
	1	2	*P*
Type 1	30 (83.3%)	6 (16.7%)	<0.001
Type 2	27 (48.2%)	29 (51.8%)	

One of the most critical points in the transplantation process is the evaluation of the donor. This entails identifying the most suitable donor for the recipient and minimizing the risk of complications in the donor. A radiological evaluation in transplantation centers is commenced following a clinical and psychiatric evaluation regarding donor suitability. Multi-detector computed tomography (MDCT) and MRCP are used in the radiological assessment of the donor. The presence of hepatic steatosis, vascular variations (hepatic artery, portal vein, and hepatic vein), and any systemic disease are evaluated using MDCT, whereas volumetric measurements are performed using CT images. The anatomy and variations of the bile ducts are evaluated using MRCP. The donor's biliary tract evaluation for identifying bile duct variations exclude donors with anatomical variations that may cause complications in the recipient after transplantation[11] and in planning the surgical resection line and biliary anastomosis technique.[10,12-14] Therefore, the donor's bile ducts should be investigated using imaging techniques. Among these, MDCT cholangiography and MRCP are non-invasive methods, whereas endoscopic retrograde cholangiopancreatography is an invasive method[15] and is considered the gold standard in biliary imaging. However, this invasive technique can lead to severe complications, such as acute pancreatitis and perforation. For this reason, it is not the preferred option for healthy people such as donor candidates. Because MDCT and MRCP allow for precise definitions of biliary and cystic duct anatomy, they are used preoperatively to identify anatomical variations that require special attention from the surgeon.[16,17]

In our center, where liver transplantations involving a living donor are performed in high volume, MRCP is used to evaluate bile duct variations. Biliary surgery is complex and challenging. Since the ducts are thin, anastomosis is difficult. In addition, anatomical variations of the biliary tract in the donor alter the surgical technique used for the recipient. The details on anatomy pertain to the field of transplantation radiology, which is a key component of liver transplantation teams. Many classifications, including the Huang, Couinaud, Choi, Ohkubo, and Karakas classifications, describe the anatomy of the biliary tract. The first known study of bile duct variation was published in 1957 by Couinaud et al.[6], an anatomist and surgeon. According to this classification, the liver consists of eight distinct segments, each with its own portal venous supply and hepatic venous drainage system. In each segment, the biliary drainage system is parallel to the portal venous supply.[18] The RHD drains segments of the right liver lobe (V–VIII) and has two main branches: the right posterior hepatic duct (RPHD), which drains the posterior segments, and the right anterior hepatic duct (RAHD), which drains the anterior segments. The RPHD tends to have an almost horizontal course, whereas the RAHD tends to have a more vertical course. The RPHD usually passes behind the RAHD and combines it with a left (medial) approach to form the RHD. The LHD is formed by segmental branches that drain segments II–IV. The RHD and LHD unite to form the CHD. The bile duct draining the caudate lobe usually joins the origin of the LHD or RHD. This normal biliary anatomy is thought to be present in 58% of the population.[19] The Couinaud classification does not consider the accessory ducts; however, 2%–6% of the population have an accessory canal.[9] Identification of accessory ducts is essential for liver resections and biliary drainage.[20-23] Unmentioned accessory ducts may be a source of biliary leakage or cholangitis. The basis for our proposed classification is the number of ducts joining the CHD. This is crucial in predicting the surgical techniques and reducing complications. Some variations are not included in Couinaud's classification.

One of the most widely used classifications is the Huang classification, the basis of which is the drainage site of the RPHD.[7] Although this classification is widely used, its major limitation is that it only evaluates variations of the right biliary tract. In the study by Choi et al.[9], 300 consecutive donors who underwent intraoperative cholangiography during liver transplantation were examined, and anatomical variations of the intrahepatic bile ducts, their frequency, and their branching patterns were defined. The classification was performed according to the RAHD and RPHD branching pattern, presence of a first-degree branch of the RHD, and presence of an accessory hepatic duct. In the study results, type 1, representing the classical anatomy, was detected in 63% of donors, whereas a variation was observed in the remaining 37%, and 1% could not be classified. The key limitation of this study is that the imaging was intraoperative and invasive. For this reason, the method is unsuitable for routine donor evaluation and has the potential to induce severe complications in donors who undergo this procedure.

The classification proposed in the present study was performed using MRCP, a non-invasive imaging technique that does not require contrast material or cause ionizing radiation exposure. All donors could be classified into a specific type. In short, when the two classifications are compared, our classification is more straightforward and inclusive and uses a non-invasive imaging test.

The purpose of the Ohkubo classification is to evaluate the anatomical variations of the biliary tree in patients undergoing liver transplantation involving a living donor. In this study, the junctional patterns of the intrahepatic bile ducts in the hepatic hilum were evaluated following an examination of extrahepatic bile duct resection and major hepatectomy surgical materials in 165 patients (right-sided hepatectomy in 110 patients and left-sided hepatectomy in 55 patients). A key message of this study is that anatomical variability is a rule rather than an exception in liver surgery. In addition, the importance of correctly identifying biliary tract variations for successful LDLT was emphasized. The segment 4 duct is always considered to be single in the Ohkubo classification.[10] However, more than one accessory duct may join from segment 4. Thus, a significant disadvantage of the Ohkubo classification is that it is impossible to classify a donor in cases where two or more segment 4 ducts joining to the LHD separately are present. In this study, since the number of all channels participating in the CHD was considered, all variations of segment 4 ducts could be included in the classification, meaning there is no unclassified variation.

The classification devised by Karakas et al.[8] is for liver transplantation involving a living donor, with the donor's compliance with standard surgical techniques evaluated using MRCP, as in the present study. The classification proposed in the present study is, as with the Huang classification, based on the relationship between the RPHD and CHD. However, RHD and LHD lengths have been added to the Huang classification, with those below 1 cm labeled as another subtype, although they are morphologically similar. Length is a further parameter used in the present study. However, in our classification, if the duct length is <5 mm, it is considered type 2 because this length is generally sufficient for anastomosis, especially in right-lobe donors. However, since this length is affected by the transverse diameter of segment 4 in left-lobe donors, it may not be sufficient for anastomosis in these donors, which is one of the limitations of our proposed classification.

This study has a number of limitations. Crucially, it was impossible to demonstrate that a type 3 donor, classified as unsuitable for surgery, was genuinely unsuitable. One donor of this type, whose donation was accepted under emergency conditions, was operated on, and the recipient required three anastomoses. However, this also supports our results because the increased number of anastomoses is a factor that increases the risk of surgical complications. Another limitation is the retrospective design of the study. The inherent disadvantage of MRCP is that it does not reveal very thin bile ducts because of the low spatial resolution and lack of contrast material. Furthermore, artifacts secondary to intestinal peristalsis and respiration can reduce image quality. In addition, although the study population comprised healthy adults, it may not reflect the general population. Another disadvantage of our study is that only healthy donors were evaluated, and the classification could only be used for liver transplantation involving living donors. There is a need to improve the study and classification in terms of evaluating oncological patient groups. Although a power analysis was performed, the study involves a limited number of cases because the biliary system has an excessive variation. However, all donors in this study could be classified according to our classification, and there is no variation that does not fit into the three types. Ultimately, the proposed classification was inclusive, and there was a high correlation between the number of ducts counted using this classification system and the surgical technique.

In conclusion, the classification proposed in this study includes all anatomical variations. This inclusive classification accurately predicts the surgical technique for LDLT.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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