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HEPATOBILIARY-PANCREAS

Clinical usefulness of gadoxetic acid–enhanced MRI for evaluating biliary anatomy in living donor liver transplantation

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Abstract

Objectives To determine the incremental value of hepatobiliary-phase-MRC (HBP-MRC) added to T2-magnetic resonance cholangiography (T2-MRC) for evaluating biliary anatomy in living donor liver transplantation (LDLT) and to correlate T2+HBP-MRC findings with surgical results.

Methods A total of 276 donors who underwent T2 and gadoxetic acid–enhanced MRI before right hemihepatectomy for LDLT between January and December 2016 were retrospectively enrolled. Two reviewers evaluated biliary anatomy classification using T2-MRC in the first session and T2+HBP-MRC in the second session. The sensitivity, specificity, and confidence level (5-point scale) of T2-MRC and T2+HBP-MRC for variant biliary anatomy were evaluated. The agreement rates between MRC and operative cholangiography for each biliary anatomy classification and the underestimation rates for multiple bile duct openings (BDOs) for both MRC techniques were evaluated.

Results Of the 276 donors, variant biliary anatomy was observed in 36.2% (100/276). T2+HBP-MRC showed a significantly higher sensitivity for diagnosing variant biliary anatomy than T2-MRC alone (99.0% [99/100] vs. 89.0% [89/100], $p = 0.006$), with better observer confidence level (4.9 ± 0.3 vs. 4.6 ± 0.7, $p < 0.001$) and inter-observer agreement (kappa, 0.902 vs. 0.730). Compared with T2-MRC alone, T2+HBP-MRC provided significantly higher agreement with operative cholangiography in biliary anatomy classification (98.6% [272/276] vs. 89.9% [248/276], $p < 0.001$), and significantly lower underestimation rate for multiple BDOs (5.8% [16/276] vs. 9.4% [26/276], $p = 0.002$).

Conclusion T2+HBP-MRC might be considered than T2-MRC alone, as a better depiction of biliary anatomic variations, correlated with surgical findings.

Key Points

•T2+HBP-MRC predicted variant biliary anatomy more accurately than T2-MRC alone.

•T2+HBP-MRC might have clinical usefulness by reducing the underestimation rate of multiple bile duct openings, which requires more complicated biliary anastomoses.

Keywords Bile ducts · Anatomy · Magnetic resonance imaging · Cholangiography · Gadoxetate disodium

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Abbreviations

BDO	Bile duct opening
CBD	Common bile duct
CHD	Common hepatic duct
HBP-MRC	T1-weighted hepatobiliary-phase magnetic resonance cholangiography
LDLT	Living donor liver transplantation
LHD	Left hepatic duct
OPC	Operative cholangiography
PV	Portal vein
RAHD	Right anterior hepatic duct
RHD	Right hepatic duct
RPHD	Right posterior hepatic duct
T2-MRC	T2-weighted magnetic resonance cholangiography
T2+HBP-MRC	Combination of T2-MRC and HBP-MRC

Introduction

Living donor liver transplantation (LDLT) is a widely accepted important therapeutic option for managing end-stage liver disease. Because LDLT has the anatomical limitations associated with partial liver grafts, preventing injury to the portal vein, hepatic artery, and biliary systems both in the liver graft and in the remaining donor liver is very important. Regarding biliary system, biliary complications such as biliary stricture or bile leak remain the most intractable problems in LDLT, with reported incidence rates ranging from 15 to 30% [1–3]. Biliary complications might be closely related to the biliary anatomy variation in the donor, occurring in up to 45% of the general population [4, 5]. Biliary anatomy variation can result in multiple bile duct openings (BDOs) and requires more complicated biliary anastomosis in the recipient [6]. Therefore, to reduce biliary complications, accurate preoperative knowledge of the biliary anatomy of the LDLT donor, notably the presence of variant biliary anatomy, the type of variant biliary anatomy, and estimated BDO, is critical.

T2-weighted magnetic resonance cholangiography (T2-MRC) has been widely used to evaluate biliary anatomy. Although recent T2-MRC imaging techniques such as 3-dimensional T2-MRC have further improved the ability to visualize biliary anatomy, the technique still suffers from several limitations in respect of the determination of variant biliary anatomy in a non-dilated biliary system, including its poor spatial resolution and the presence of severe motion artifacts related to breathing [7–9]. Recently, T1-weighted MRC following administration of hepatobiliary contrast agents (HBP-MRC) has been introduced as an alternative imaging technique for the evaluation of biliary anatomy. As the contrast agent is taken up by hepatocytes and then excreted into bile, with a peak biliary enhancement at approximately 20 min [10], HBP-MRC may be useful for evaluating biliary anatomy, as well as vascular anatomy.

Previous studies have reported the diagnostic accuracy of MRC [11–19] and generally agree on the potential of HBP-MRC as an alternative imaging technique for evaluating biliary anatomy [11–14]. However, there are conflicting results over whether the combination of T2-MRC and HBP-MRC (T2+HBP-MRC) provides an incremental diagnostic benefit over T2-MRC alone, with some studies reporting that T2-MRC was superior to HBP-MRC [15, 17], but other studies reporting that HBP-MRC provided added value for the evaluation of biliary anatomy [12–14]. These previous studies had several limitations, including the small number of study subjects [11–14], insufficient reference standard [16, 18], and the absence of a systematic classification of biliary anatomy [12, 19]. In addition, as most previous studies only focused on the diagnostic performance for evaluation of variant biliary anatomy, without considering clinical usefulness, their results had only limited applicability to clinical practice.

Therefore, this study aimed to determine the added value of T2+HBP-MRC for evaluating biliary anatomy in living liver donors in comparison with T2-MRC alone and to correlate T2+HBP-MRC findings with surgical results.

Materials and methods

This study was approved by our Institutional Review Board and the requirement for informed consent was waived due to the retrospective nature of this study.

Study subjects

We identified a total of 364 consecutive healthy donors who underwent hepatic resection for LDLT between January 2016 and December 2016. All 364 donors underwent an MRI examination to determine their appropriateness as a live liver donor. Of these 364 donors, 55 who underwent left hemihepatectomy for LDLT and 33 who did not undergo gadoxetic acid–enhanced MRI because they were under 18 years of age were excluded. Finally, 276 donors who underwent gadoxetic acid–enhanced MRI before a right hemihepatectomy for LDLT were included in this study. The donors consisted of 171 men (mean age, 28.4 years; range, 18–58) and 105 women (mean age, 30.7 years; range, 18–56), with an overall mean age of 29.3 years (range, 18–58).

MR techniques

Donors underwent MR examinations on a 3.0-T scanner (Skyra; Siemens Medical Solutions) with a phased-array torso coil. For routine T2-MRC, breath-hold half-Fourier acquisition single-shot two-dimensional turbo spin echo T2-weighted

images were acquired in the axial and coronal directions, and two-dimensional projectional MRC was acquired using a breath-hold two-dimensional single-shot rapid acquisition with relaxation enhancement sequence. Images were acquired in two orientations, providing a rotatory coronal set (sequential coronal and oblique coronal slabs at 15° rotational increments) and a rotatory axial set (sequential axial and oblique axial slabs at 15° rotational increments), with nine slices in each orientation. The axes of rotation were centered at the primary confluence of the main intrahepatic ducts. In addition, respiratory-triggered multi-section three-dimensional turbo spin echo T2-weighted images were obtained in the coronal direction. For routine contrast-enhanced MRC, a fat-suppressed three-dimensional volumetric interpolated breath-hold examination (VIBE, Siemens) was performed following a bolus injection of 0.1 mL/kg gadoxetic acid (Primovist; Bayer Schering Pharma AG) delivered at a rate of 1.0 mL/s using a power injector (Spectris Solaris; Medrad) and followed by a 20-mL saline flush. HBP images were obtained in axial and coronal directions 20 min after the contrast injection. The MR sequence parameters are listed in Supplementary Table 1.

Image analysis

Two board-certified abdominal radiologists who were blinded to the surgical records, i.e., operative cholangiography (OPC) findings, independently analyzed the MR images. The MR images of each subject were analyzed at two separate sessions 4 weeks apart. The patient order was shuffled for each reading session. After completing the independent review sessions, the two reviewers performed a consensus review session to resolve any discrepancies between them.

Each reader evaluated the presence of variant biliary anatomy using T2-MRC in the first session and T2+HBP-MRC in the second session. The biliary anatomy type was classified according to the confluence pattern of the bile duct at the hepatic hilum (Fig. 1). Type I-1 is defined as classic biliary anatomy and other types as variant biliary anatomy. The

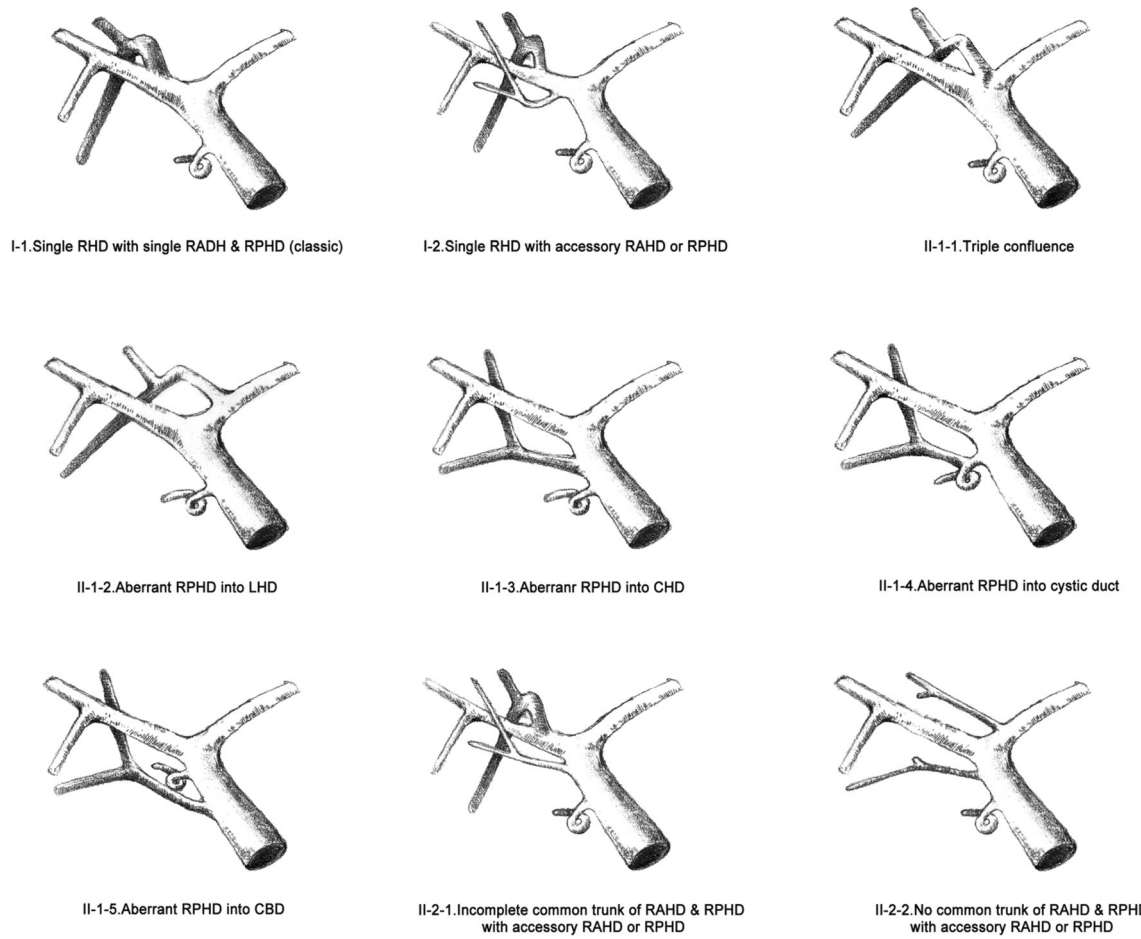

Fig. 1 Schematic drawing of the biliary anatomy classification. Cases were divided into type I or II according to the presence or absence of a single right hepatic duct (RHD). Type I was then subdivided according to the presence of a single right anterior hepatic duct (RAHD) and a single right posterior hepatic duct (RPHD). Type II, with the absence of a single RHD, was subdivided into types II-1 and II-2 according to the presence or absence of a single RAHD and single RPHD

simple variations include II-1-1, II-1-2, II-1-3, II-1-4, and II-1-5, and the complex variations include I-2, II-2-1, and II-2-2. The readers also scored their confidence in determining biliary anatomy in both sessions using a 5-point scale: 1, biliary anatomy cannot be assessed; 2, moderately low confidence of biliary anatomy determination; 3, equivocal; 4, moderately high confidence of biliary anatomy determination; and 5, biliary anatomy can be clearly assessed.

To evaluate the relationship between anatomical variation in the major portal vein (PV) and biliary anatomy, we classified the subjects into two groups (classic PV anatomy and variant PV anatomy) according to the major branching patterns of the PV. Classic PV anatomy was defined as the main PV bifurcating into right and left PVs, and the right PV then dividing into the right anterior and right posterior PVs. Other patterns were considered as variant PV anatomy. In addition, we evaluated the course of the RPHD or RPHDs in relation to the right anterior PV, classifying it into one of the three following categories: the supraportal type with the RPHD, the infraportal type with the RPHD, and the combined type (Fig. 2).

Review of surgical records

OPC was performed after cholecystectomy, by injecting contrast media through the cystic duct stump. To identify the optimal site of bile duct division, we again performed OPC using the radio-opaque marker tagging. All OPCs were available and a third reviewer classified the type of biliary anatomy on the OPC using the same classification used for the MRC. These results were then used as a reference standard against which the diagnostic performance of the MRC was evaluated. Surgical reports were predefined and standardized including the presence of variant biliary anatomy, the type of variant biliary anatomy, the number of BDOs, bile duct size, the method of bile duct anastomosis, and the performance of ductoplasty. The surgical records of each study subject were reviewed to investigate operational information on the bile duct anastomosis.

Statistical analysis

To evaluate the diagnostic performance of T2-MRC and T2+HBP-MRC for diagnosing variant biliary anatomy, the sensitivity, specificity, and confidence level of T2-MRC and T2+HBP-MRC were calculated using OPC as the reference standard, with comparisons between them using McNemar's test or a paired *t* test. Subgroup analyses were also performed for the simple (II-1-1, II-1-2, II-1-3, II-1-4, II-1-5) and complex (I-2, II-2-1, II-2-2) variations. Inter-observer agreement in the determination of the biliary anatomy classification on T2-MRC and T2+HBP-MRC was evaluated using the overall percentage of agreement and kappa statistics. We also evaluated the discordance rate between the original reports of MRC at the time of clinical practice and the results of retrospective analyses of T2+HBP-MRC.

To evaluate the relationship between PV anatomy and biliary anatomy, the incidence of variant biliary anatomy was compared between the classic PV anatomy and variant PV anatomy groups using a chi-squared test. In addition, the RPHD running course type was evaluated according to both PV anatomy and biliary anatomy.

To correlate T2+HBP-MRC findings with surgical results, the agreement rate of each biliary anatomy classification between T2-MRC and OPC, and between T2+HBP-MRC and OPC, were assessed. We predicted the number of BDOs for each biliary anatomy classification by MRC and compared this number with the surgical findings. The underestimation rates for multiple BDOs were calculated for T2-MRC and T2+HBP-MRC and were compared using McNemar's test. As a single BDO after ductoplasty initially consisted of two or more BDOs before the ductoplasty, we considered such cases

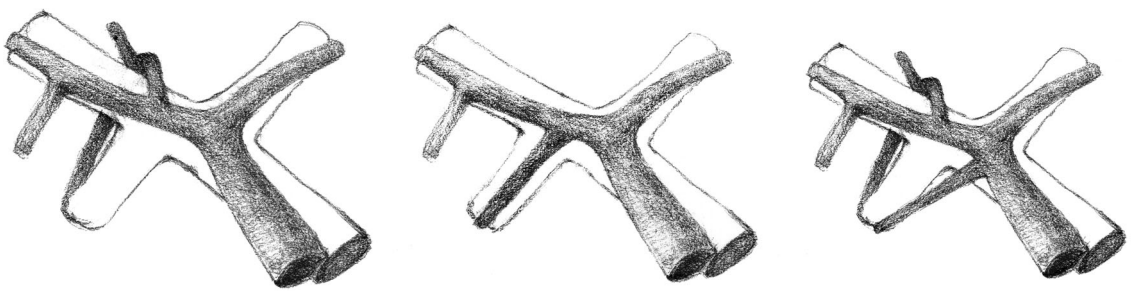

Fig. 2 Schematic drawing of the course of right posterior hepatic duct in relation to the right anterior portal vein. **a** Supraportal type: the right posterior hepatic duct (RPHD) running cranially around the right portal vein (PV) to form a confluence with the right anterior hepatic duct (RAHD) at the cranial side of the right PV. **b** Infraportal type: the RPHD running caudal to the right PV and joining the RAHD at the caudal side of the right PV. **c** Combined type: the ducts from segments 6 and 7 having separate confluences with the remaining biliary tree, consisting of one segmental duct running in a supraportal position and the other running in an infraportal position

as multiple BDOs. In other words, multiple BDOs were determined as ≥ 2 BDOs or a single BDO with ductoplasty.

All statistical analyses were performed using SPSS statistical software (version 21.0; SPSS), with a p value < 0.05 being considered as statistically significant.

Results

Biliary anatomy classifications

On OPC, classic biliary anatomy was observed in 63.8% (176/276) of donors and variant biliary anatomy in 36.2% (100/276; Table 1). Of the 100 variant biliary anatomies, II-1-2 (aberrant RPHD into the LHD) was the most common variant biliary anatomy classification. The incidences of hepaticojejunostomy and ductoplasty in the classic biliary anatomy group were significantly lower than those in the variant biliary anatomy group (2.8% [5/176] vs. 9.0% [9/100], $p = 0.042$; 6.8% [12/176] vs. 20.0% [20/100], $p = 0.002$, respectively).

Diagnostic performance of MRC for diagnosing variant biliary anatomy

The diagnostic performances of T2-MRC and T2+HBP-MRC are summarized in Table 2. Compared with T2-MRC alone, T2+HBP-MRC significantly increased the observer confidence in biliary anatomy classification, from 4.4 ± 0.9 to 4.8 ± 0.4 ($p < 0.001$) for reviewer 1, 3.7 ± 0.9 to 4.5 ± 0.7 ($p < 0.001$) for reviewer 2, and 4.6 ± 0.7 to 4.9 ± 0.3 ($p < 0.001$) for review in consensus. In comparison with T2-MRC alone, T2+HBP-MRC significantly increased the sensitivity for differentiating variant biliary anatomy from classic biliary anatomy from 89.0 (89/100) to 99.0% (99/100; $p = 0.006$), although there was no

Table 1 Incidence of biliary anatomy variations determined by operative findings

Biliary anatomy type	Incidence (%)	No. of expected BDOs	Bile duct anastomosis (no. of ductoplasties)	No. of operative BDOs (single*; ≥ 2 BDO)
I. Single RHD				
I-1 Single RAHD and RPHD (= classic)	176 (63.8)	1	DD, 171 (12) HJ, 5 (0)	Single, 163; ≥ 2 BDO, 8 Single, 4; ≥ 2 BDO, 1
I-2 No single RAHD or RPHD				
I-2a Accessory RAHD	2 (0.7)	1	DD, 2 (0) HJ, 0 (0)	Single, 2; ≥ 2 BDO, 0 –
I-2b Accessory RPHD	7 (2.5)	1	DD, 6 (0) HJ, 1 (1)	Single, 3; ≥ 2 BDO, 3 Single, 1; ≥ 2 BDO, 0
II. No single RHD				
II-1 Single RAHD and RPHD				
II-1-1 Triple confluence	14 (5.1)	2	DD, 11 (3) HJ, 3 (1)	Single, 3; ≥ 2 BDO, 8 Single, 1; ≥ 2 BDO, 2
II-1-2 Aberrant RPHD into LHD	43 (15.6)	2	DD, 38 (9) HJ, 5 (0)	Single, 2; ≥ 2 BDO, 36 Single, 0; ≥ 2 BDO, 5
II-1-3 Aberrant RPHD into CHD	15 (5.4)	2	DD, 15 (1) HJ, 0 (0)	Single, 0; ≥ 2 BDO, 15 –
II-1-4 Aberrant RPHD into cystic duct	3 (1.1)	2	DD, 3 (0) HJ, 0 (0)	Single, 0; ≥ 2 BDO, 3 –
II-1-5 Aberrant RPHD into CBD	0 (0.0)	2	–	–
II-2 No single RAHD or RPHD				
II-2-1 Incomplete common trunk of RAHD and RPHD				
II-2-1a Accessory RAHD	3† (1.1)	2	DD, 3 (1) HJ, 0 (0)	Single, 0; ≥ 2 BDO, 3 –
II-2-1b Accessory RPHD	4† (1.4)	2	DD, 4 (1) HJ, 0 (0)	Single, 1; ≥ 2 BDO, 3 –
II-2-2 No common trunk of RAHD and RPHD				
II-2-2a Aberrant RPHD and accessory RAHD	7# (2.5)	3	DD, 7 (3) HJ, 0 (0)	Single, 1; ≥ 2 BDO, 6 -
II-2-2b Aberrant RPHD and accessory RPHD	2# (0.7)	3	DD, 2 (0) HJ, 0 (0)	Single, 0; ≥ 2 BDO, 2 –

BDO, bile duct opening; *RHD*, right hepatic duct; *RAHD*, right anterior hepatic duct; *RPHD*, right posterior hepatic duct; *CBD*, common bile duct; *DD*, duct-to-duct anastomosis; *HJ*, hepaticojejunostomy; *CHD*, common hepatic duct; *LHD*, left hepatic duct

*Single BDO includes single BDO without ductoplasty and single BDO after ductoplasty

† Accessory RAHDs drained to the CBD ($n = 2$) and CHD ($n = 1$); accessory RPHDs drained to the primary confluence ($n = 1$), CHD ($n = 2$), and LHD ($n = 1$), respectively

Accessory RAHDs drained to the primary confluence ($n = 3$) and CHD ($n = 4$); accessory RPHDs drained to the CHD ($n = 2$)

Table 2 Results of biliary anatomy analysis on T2-MRC and T2+HBP-MRC

	Consensus review		Reviewer 1		Reviewer 2	
	T2WI	T2WI+HBP	T2WI	T2WI+HBP	T2WI	T2WI+HBP
Confidence level	4.6 ± 0.7	4.9 ± 0.3	4.4 ± 0.9	4.8 ± 0.4	3.7 ± 0.9	4.5 ± 0.7
p value	< 0.001		< 0.001		< 0.001	
Sensitivity for overall variation	89.0% (89/100)	99.0% (99/100)	89.0% (89/100)	97.0% (97/100)	89.0% (89/100)	99.0% (99/100)
p value	0.006		0.008		0.002	
Specificity for overall variation	96.6% (170/176)	98.9% (174/176)	98.3% (173/176)	99.4% (175/176)	94.9% (167/176)	98.9% (174/176)
p value	0.219		0.625		0.039	
Sensitivity for simple variation*	92.0% (69/75)	98.7% (74/75)	92.0% (69/75)	98.7% (74/75)	89.3% (67/75)	98.7% (74/75)
p value	0.125		0.063		0.039	
Sensitivity for complex variation†	56.0% (14/25)	96.0% (24/25)	48.0% (12/25)	92.0% (23/25)	60.0% (15/25)	96.0% (24/25)
p value	0.006		0.001		0.004	

T2, T2-weighted; *MRC*, MR cholangiography; *HBP*, hepatobiliary phase

*Simple variation includes triple confluence (II-1-1), aberrant RPHD into LHD (II-1-2), aberrant RPHD into CHD (II-1-3), aberrant RPHD into cystic duct (II-1-4), and aberrant RPHD into CBD (II-1-5)

† Complex variation includes single RHD with accessory RAHD or RPHD (I-2), incomplete common trunk of RAHD and RPHD with accessory RAHD or RPHD (II-2-1), and no common trunk of RAHD and RPHD with accessory RAHD or RPHD (II-2-2)

significant difference in specificity between T2-MRC and T2+HBP-MRC (96.6% [170/176] vs. 98.9% [174/176], $p = 0.219$) (Fig. 3). For both reviewers, T2+HBP-MRC had a significantly higher sensitivity than T2-MRC alone (97.0% [97/100] vs. 89.0% [89/100], $p = 0.008$ for reviewer 1; 99.0% [99/100] vs. 89.0% [89/100], $p = 0.002$ for reviewer 2), but only reviewer 2 showed that T2+HBP-MRC had a significantly higher specificity than T2-MRC alone ($p = 0.039$). Compared with T2-MRC alone, the sensitivity for diagnosing complex variant biliary anatomy significantly increased with T2+HBP-MRC, from 56.0 (14/25) to 96.0% (24/25; $p = 0.006$) (Fig. 4), although there was no significant difference in the diagnosis of simple variant biliary anatomy between the two examinations ($p = 0.125$). For both reviewers, T2+HBP-MRC had a significantly higher sensitivity for diagnosing complex biliary variation than T2-MRC alone (48.0% [12/25] vs. 92.0% [23/25], $p = 0.001$ for reviewer 1; 60.0% [15/25] vs. 96.0% [24/25], $p = 0.004$ for reviewer 2), but only reviewer 2 showed a significantly increased sensitivity for diagnosis of simple biliary variation ($p = 0.039$).

The inter-observer agreement in the determination of biliary anatomy classification on T2+HBP-MRC was better than that on T2-MRC alone (overall percentage of agreement, 94.6% [261/276] vs. 84.8% [234/276]; kappa statistics, 0.902 vs. 0.730).

The discordance rate between the original reports of MRC at the time of clinical practice and OPC was 9.1% (25/276) in 276 total cases, and 1.1% (2/176) in the classical biliary anatomy group and 23.0% (23/100) in the variant biliary anatomy group, respectively. In addition, the discordance rate between the original reports of MRC at the time of clinical practice and the results of retrospective analyses of T2+HBP-MRC was 9.4% (26/276) in 276 total cases, and 2.3% (4/176) in the classical biliary anatomy group and 24.0% (24/100) in the variant biliary anatomy group, respectively.

Relationships between PV anatomy variation and biliary anatomy variation

Of the total 276 donors, 48 (17.4%) had variant PV anatomy. The variant PV anatomy group showed a significantly higher incidence of variant biliary anatomy than the classic PV anatomy group (54.2% [26/48] vs. 32.0% [73/228], $p = 0.005$; Table 3).

Investigation of the relationship between PV anatomy and the RPHD running course revealed no significant difference in the running course of the RPHD between the variant and classic PV anatomy groups. Of the three types of RPHD running course relating to the right anterior section PV, the supraportal course was most frequently noted in both groups (85.4% [41/48] in the variant PV anatomy group and 88.2% [201/228] in the classic PV anatomy group). An infraportal course was more frequently noted in the variant PV anatomy group than in the classic PV anatomy group (12.5% [6/48] vs. 8.8% [20/228], $p = 0.418$), but the difference was not statistically significant. Investigation of the relationship between biliary anatomy and RPHD running course revealed that a supraportal course was significantly less frequent in the variant biliary

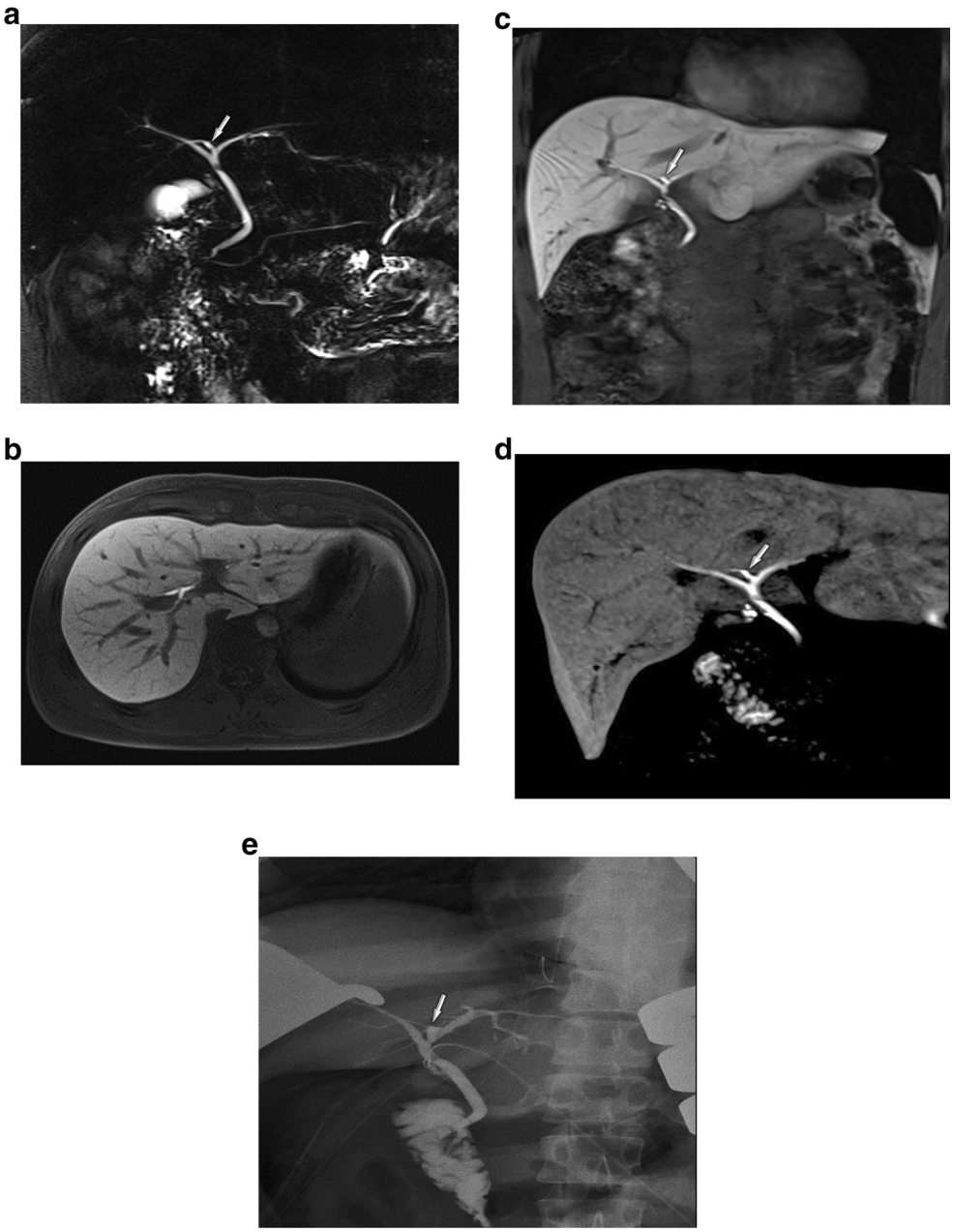

Fig. 3 A 29-year-old man with type II-1-2 variant biliary anatomy. **a**–**e** Two-dimensional projectional T2-MRC (**a**), axial HBP-MRC (**b**), coronal HBP-MRC (**c**), and maximum intensity projection reconstruction image (**d**) show that the right posterior hepatic duct (arrows) aberrantly drains into the left hepatic duct. Operative cholangiography confirms type II-1-2 variant biliary anatomy (**e**)

anatomy group (74.0% [74/100] vs. 95.5% [168/176], $p < 0.001$), whereas infraportal and combined courses were significantly more frequent in the variant biliary anatomy group than in the classic biliary anatomy group (18.0% [18/100] vs. 4.5% [8/176] and 8.0% [8/100] vs. 0.0% [0/176]; $p < 0.001$ for both).

Correlation of MRC findings with surgical results

Of the 276 cases, 14 hepaticojejunostomies were performed as a bile duct anastomosis, five in the classic biliary anatomy group and nine in the variant biliary anatomy group. The agreement rates for the classification of biliary anatomy are summarized in Supplementary Table 2. The overall agreement rates for biliary anatomy classification were 89.9% (248/276) between T2-MRC and OPC, and 98.6% (272/276) between T2+HBP-MRC and OPC, with a significant difference being found between T2-MRC and T2+HBP-MRC ($p < 0.001$). Of the 25 complex variant biliary anatomies, T2+HBP-MRC had a 96.0% (24/25) agreement rate with OPC, whereas T2-MRC alone had a 52.0% (13/25) agreement rate.

For the total of 276 donors, the underestimation rate for multiple BDOs for T2+HBP-MRC was significantly lower than that for T2-MRC alone (5.8% [16/276] vs. 9.4% [26/276], $p = 0.002$). Of the 87 donors with multiple BDOs in the group of 100 variant biliary anatomy donors, no

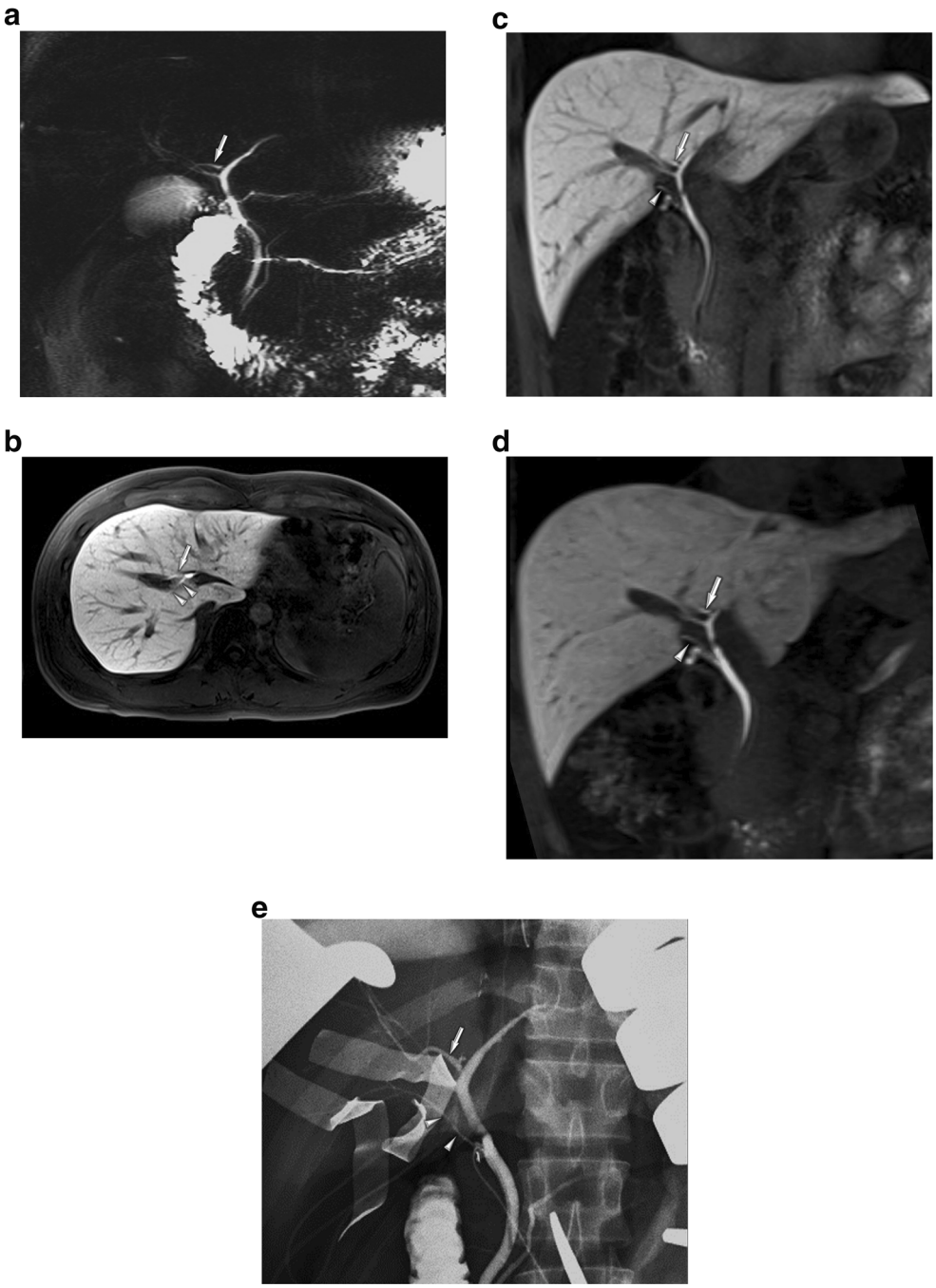

Fig. 4 A 31-year-old man with type II-2-2 variant biliary anatomy. **a**–**d** Two-dimensional projectional T2-MRC shows the right posterior hepatic duct (arrows) aberrantly drains into the left hepatic duct (**a**), but axial, coronal HBP-MRC, and maximum intensity projection reconstruction image show the right posterior hepatic duct (arrows) draining into the left hepatic duct, and the accessory right posterior hepatic duct (arrowheads) draining into the common hepatic duct (**b**–**d**). Operative cholangiography confirms type II-2-2 variant biliary anatomy (**e**)

underestimated case was noted on T2+HBP-MRC, but the rate of multiple BDOs was underestimated in 11.5% of donors (10/87) on T2-MRC alone.

Discussion

Our study demonstrated that T2+HBP-MRC had a significantly higher sensitivity for differentiating variant biliary anatomy from classic biliary anatomy than T2-MRC alone (99.0% [99/100] vs. 89.0% [89/100], $p = 0.006$), with better observer confidence level and inter-observer agreement. In addition, compared with T2-MRC alone, T2+HBP-MRC showed a higher agreement with OPC in biliary anatomy classification (98.6% [272/276] vs. 89.9% [248/276], $p < 0.001$) and resulted in a significantly decreased underestimation rate for multiple BDOs (5.8% [16/276] vs. 9.4% [26/276], $p = 0.002$).

In comparison with T2-MRC alone, T2+HBP-MRC was more accurate in depicting biliary anatomy in living liver donors and also gave a better observer confidence level. This result is similar to those of previous studies, which reported higher bile duct visibility scores, observer confidence levels,

Table 3 Relationships between portal vein anatomy and biliary anatomy

Variables	Classic portal vein anatomy ($n = 228$)	Variant portal vein anatomy ($n = 48$)		p value
Biliary anatomy				0.005
Classic anatomy	155	22		
Variant anatomy	73	26		
	Supraportal bile duct course	Infraportal bile duct course	Combined bile duct course	
Portal vein anatomy				0.687
Classic anatomy	201	20	7	
Variant anatomy	41	6*	1†	
Biliary anatomy				< 0.001
Classic anatomy	168	8	0	
Variant anatomy	74	18#	8††	

RPHD, right posterior hepatic duct

*One classic, three aberrant RPHD into CHD, and two aberrant RPHD into CBD

† One no common trunk of RAHD and RPHD

Fifteen aberrant RPHD into CHD and three aberrant RPHD into CBD

†† Four incomplete common trunk of RAHD and RPHD, three single RHD with no single RAHD or RPHD, and one no common trunk of RAHD and RPHD

and inter-observer agreement [12, 14]. In contrast to HBP-MRC, which was acquired within a breath-hold, the three-dimensional T2-MRC was performed using a respiratory-triggered technique; therefore, the image quality might have been affected by respiratory artifacts [20]. Notably, in the complex variant biliary anatomy, the agreement rate with OPC for T2+HBP-MRC was much higher than that for T2-MRC alone (96.0% vs. 52.0%). HBP-MRC provides a higher signal-to-noise ratio in the bile duct than T2-MRC, and this could result in better delineation of non-dilated small caliber accessory bile ducts, improving the diagnosis of complex variant biliary anatomy [21–23]. Therefore, T2+HBP-MRC can detect more variant biliary anatomy, especially complex variant biliary anatomy.

Our study showed a significant association between PV anatomy and biliary anatomy, with variant biliary anatomy being identified more frequently in the variant PV anatomy group than in the classic PV anatomy group (54.2% vs. 32.0%). This result is consistent with previous studies (54.0–57.0% vs. 23.0–28.4%) [24, 25]. The confluence patterns of the hilar biliary ducts are important because multiple stumps have to be reconstructed in the case of variant biliary anatomy [25]. In the 276 donors, the incidence of an infraportal course for an RPHD was 9.4%, but a higher incidence was reported in the variant PV anatomy (12.5%) and variant biliary anatomy groups (18.0%). In addition, all the combined RPHD courses noted were in donors with variant biliary anatomy. Therefore, knowledge of the incidence of infraportal or combined courses for an RPHD in relation to the PV and biliary anatomy can be useful for surgical planning when the confidence level for hilar anatomy assessment is low because of bile ducts not being fully visualized.

In the determination of the number of BDOs, Kang et al reported consistency rates of 53.4–60.3% between MRC and OPC for T2-MRC alone, and of 69.9–78.1% for T2+HBP-MRC [14]; however, these consistency rates may vary, as the expected number of BDOs on MRC could be different from the operative number because of the differences between the ideal dissection plane on the imaging examinations and the real dissection plane in the surgical approach. In contrast to this previous study, we focused on the underestimation rate of multiple BDOs (a single BDO with ductoplasty or ≥ 2 BDOs) because the accurate prediction of multiple BDOs is important in clinical practice, considering that more complicated biliary anastomoses are required in the case of multiple BDOs, including multiple reconstructions [6, 26]. In our study, T2+HBP-MRC resulted in a decrease in the underestimation rate of multiple BDOs in comparison with T2-MRC alone, and no underestimated case was noted on T2+HBP-MRC in 100 variant biliary anatomy donors. In addition, although there were 100 donors with variant biliary anatomy, hepaticojejunostomies were performed in only nine recipients, and these may be significantly associated with a higher incidence of bile leakage compared with duct-to-duct anastomoses [27]. Preoperative T2+HBP-MRC could simplify the biliary reconstruction procedure by providing accurate information on biliary anatomy.

There are several limitations to the present study. First, this was a retrospective study, and this may have led to a selection bias. To minimize selection bias, we included all consecutive living liver donors who underwent gadoxetic acid–enhanced MRI before a right hemihepatectomy for LDLT. In addition, this study had a limitation to determine the added clinical value of HBP-MRC, i.e., how HBP-MRC changed the surgical planning or reduced the need for hepaticojejunostomy, due to a retrospective study design. Although we did evaluate the underestimation rate of multiple BDOs for T2-MRC and T2+HBP-MRC, this would be limited. Further prospective study would be needed to evaluate the clinical added value of HBP-

MRC, focusing on surgical decision making or changing surgical strategy. Second, although most of the results of the biliary anatomy analyses on T2-MRC and T2+HBP-MRC were consistent between the two reviewers, there were a few inconsistent results, such as the specificity for overall variation and the sensitivity for simple variation between T2-MRC alone and T2+HBP-MRC. However, we robustly re-evaluated the biliary anatomy classifications in the consensus review session and resolved these discrepancies.

In conclusion, T2+HBP-MRC showed an incremental value over T2-MRC alone, with a significantly increased sensitivity for differentiating variant biliary anatomy from classic biliary anatomy. Moreover, the accuracy of T2+HBP-MRC for predicting biliary anatomy classification was better than that of T2-MRC alone, and T2+HBP-MRC resulted in a significant decrease in the underestimation rate of multiple BDOs. Therefore, T2+HBP-MRC might be considered than T2-MRC alone, as a better depiction of biliary anatomic variations, correlated with surgical findings.

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Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Kyoung Won Kim.

Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors (Sang Hyun Choi) has significant statistical expertise.

Informed consent The requirement for informed consent was waived due to the retrospective nature of this study.

Ethical approval This study was approved by our Institutional Review Board.

Methodology
- Retrospective
- Observational
- Performed at one institution

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