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ORIGINAL SCIENTIFIC REPORT WITH VIDEO

Preserving a Replaced Left Hepatic Artery Arising from the Left Gastric Artery During Laparoscopic Distal Gastrectomy for Gastric Cancer

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Abstract

Background A replaced left hepatic artery (RLHA) arising from the left gastric artery (LGA) is occasionally encountered during laparoscopic gastrectomy. Although the RLHA is usually divided at the root level as RLHA preservation might result in inadequate lymph node dissection, blood flow disruption by RLHA division may lead to hepatic ischemia. To date, there is no consensus on RLHA preservation. Thus, we aimed to evaluate the efficacy of RLHA preservation by investigating the short-term outcomes of patients with RLHA who underwent laparoscopic distal gastrectomy (LDG).
Methods A total of 106 patients with an aberrant LHA from the LGA were identified as having gastric cancer and underwent LDG from 2012 to 2018. Finally, 55 patients were retrospectively diagnosed with RLHA by preoperative computed tomography and included in this study. Patients were classified into the divided (n = 18) or preserved (n = 37) group. Clinicopathological factors and surgical outcomes were compared between the two groups.
Results The RLHA preservation rate in patients who had been preoperatively diagnosed with RLHA was 88%. No significant difference was found in the number of harvested lymph nodes between the groups. The incidence of hepatic infarction was significantly higher in the divided group (16.7% vs. 0%, p = 0.031). Moreover, RLHA division caused postoperative transaminase elevation and was an independent risk factor for postoperative transaminase elevation (odds ratio: 55.8, $p < 0.001$).
Conclusions Surgical procedures of RLHA preservation reduced postoperative transaminase elevation and hepatic infarction in patients who underwent LDG. Surgeons should confirm the RLHA preoperatively and preserve it to prevent hepatic damage.

Introduction

An aberrant left hepatic artery (ALHA) arising from the left gastric artery (LGA) is a common anomaly of the LGA and hepatic artery that is occasionally encountered during gastric surgery [1–3]. ALHA is classified as either a replaced left hepatic artery (RLHA), a substitute for the normal LHA, or as an accessory LHA in addition to the normal LHA [3]. In gastric surgery, LGA is usually divided at the root level to ensure lymph node dissection of station number 7 of the Japanese Classification of Gastric Carcinoma (JCGC) [4]. However, this procedure may cause

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hepatic ischemia in RLHA patients, as it might be the only artery supplying blood to the left hepatic lobe. In several case reports, serious postoperative complications, including abscess formation, cholangitis, and left hepatic lobe necrosis, occurred during RLHA division [5–8]. Contrarily, several studies showed that ALHA division, including RLHA division, did not result in severe hepatic ischemia but only elevated the liver enzymes [9, 10]. However, none of these studies divided the RLHA or accessory LHA using preoperative computed tomography (CT) images. Furthermore, whether radical lymph node dissection can be performed with RLHA preservation in gastric surgery is unclear. Therefore, there is no consensus of the treatment strategy for RLHA during gastric surgery.

To identify the ALHA preoperatively, multidetector-row CT (MDCT) with three-dimensional CT angiography (3DCTA) is useful. Recently, several studies have reported that the number of hepatic vascular arterial anomaly detected by 3DCTA was comparable to that of classical studies using cadaver or conventional angiography [11–14]. Thus, MDCT with 3DCTA is thought to be useful for detecting ALHA and its subtypes preoperatively.

Laparoscopic distal gastrectomy (LDG) for clinical stage I gastric cancer is reportedly safe as open distal gastrectomy, and the non-inferiority of LDG to open distal gastrectomy in terms of relapse-free survival has been demonstrated [15, 16]. Generally, compared to open surgery, laparoscopic surgery has the disadvantage of limited exposure and visualization of the entire surgical field and limited tactile sensation of the surgeon while holding laparoscopic forceps. Thus, in laparoscopic surgery, the narrow view and limited palpation of arterial pulsation make intraoperative ALHA confirmation more difficult compared to open surgery. Moreover, it is impossible to identify whether an ALHA is either a replaced or an accessory type only through visual information during laparoscopic surgery, similar to open surgery. Therefore, in laparoscopic surgery, recognizing the existence of RLHA on preoperative MDCT images is necessary.

We investigated the short-term outcomes of gastric cancer patients with RLHA who underwent LDG to evaluate the efficacy of RLHA preservation.

Material and methods

Patients

Altogether, 513 primary gastric cancer patients who underwent LDG at our institute from January 2012 to December 2018 were included. Among them, the surgical records of 106 patients (20.7%) with ALHA were retrieved; of these, after a retrospective review of preoperative MDCT according to this study's definition and determination of the presence of RLHA or accessory-type ALHA, those who underwent combined resection of organs besides the gallbladder and spleen and were converted to open laparotomy and those with accessory-type ALHA were excluded. Finally, 55 RLHA patients were evaluated (Fig. 1). This study was approved by the Institutional Review Board of our hospital (J2019-42–2019-1–3). Informed consent was waived by the ethical committee owing to the retrospective nature of the study.

Retrospective detection method of ALHA types and RLHA diameter measurement.

ALHA types were accessory (with arterial communication to the LHA in the extra-hepatic area) and replaced (RLHA) (without LHA from the proper hepatic artery and without apparent arterial communications between the

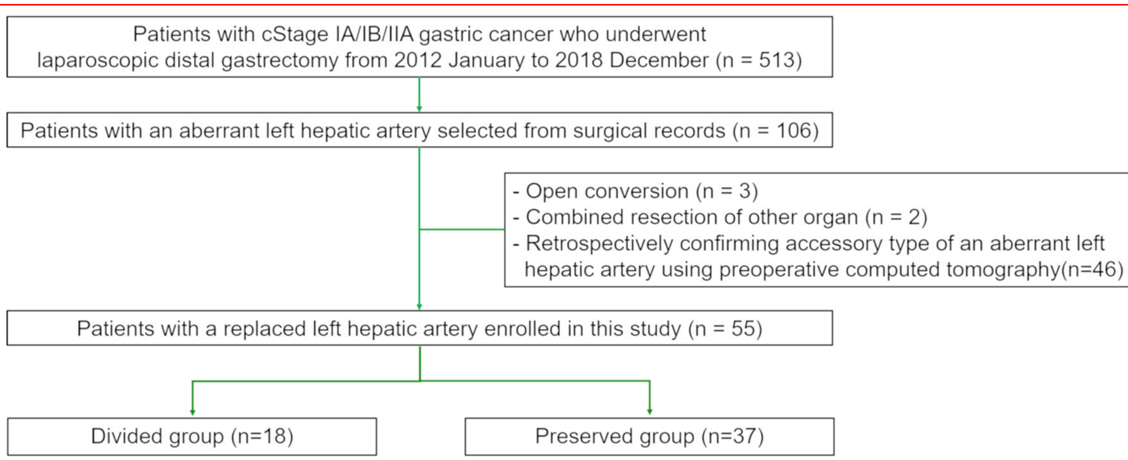

Fig. 1 Flowchart of the study population

right and left hepatic lobes in the extra-hepatic area) types (Fig. 2).

Imaging techniques are shown in supplementary material 1. RLHA was identified using MDCT with 3DCTA (Fig. 3a). RLHA's intraluminal diameter was measured using axial slices at the lesser omentum before running into the liver (Fig. 3b).

Surgical procedures

LDG was performed using 5 trocar methods. The Nathanson liver retractor was used for liver retraction, and mini laparotomy of < 4 cm at the umbilical lesion was performed for specimen retrieval and anastomosis. Extent of lymph node dissection was based on the Japanese gastric cancer treatment guidelines [17]. Reconstruction methods, either Billroth I or Roux-en Y were determined by the surgeon's preference, patient's conditions such as the presence or absence of hiatal hernia and remnant stomach size. The surgical technique of RLHA preservation was performed as follows (Supplementary Video). After lymph node dissection of the greater curvature side, the duodenum was transected distally to the pylorus ring, and the suprapyloric lymph node was dissected. Subsequently, the lesser omentum was divided from the cranial aspect of the right gastric artery to the esophagogastric junction with confirmation of the presence of RLHA (Fig. 4a). If necessary, the RLHA was taped. Next, the supra-pancreatic lymph nodes at station numbers 8a and 11p of the JCGC were dissected. During this procedure, the left and right sides of the celiac artery were sufficiently exfoliated (Fig. 4b). Additionally, after exposing LGA root, the surrounding tissues were cut open on the right side of the artery from the root toward the RLHA running into the liver to completely expose the artery (Fig. 4c). Arterial branches arising from the LGA to the stomach were identified and divided using clips (Fig. 4d). Routinely, 2 or 3 arterial branches to the stomach were identified. Finally, the lymph nodes of lesser curvature side of the stomach were retrieved, and lymph node dissection with RLHA preservation was completed (Fig. 4e).

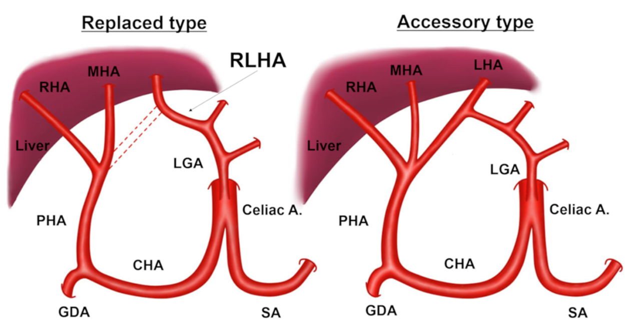

Fig. 2 Schematic diagram of the subtypes of an aberrant left hepatic artery. RLHA, replaced left hepatic artery; LGA, left gastric artery; GDA, gastroduodenal artery; SA, splenic artery; CHA, common hepatic artery; PHA, proper hepatic artery; MHA, middle hepatic artery; RHA, right hepatic artery

In patients diagnosed with RLHA preoperatively, the RLHA was basically preserved. However, RLHA division was performed in patients with hepatic artery communications from the proper hepatic artery to the left medial and/or lateral segment according to the Healey and Schroy classification on preoperative MDCT images [18], or without hepatic ischemia by performing temporary clamping of the RLHA.

Analyzed factors

Clinicopathological data, including age, sex, the Eastern Cooperative Oncology Group performance status, body

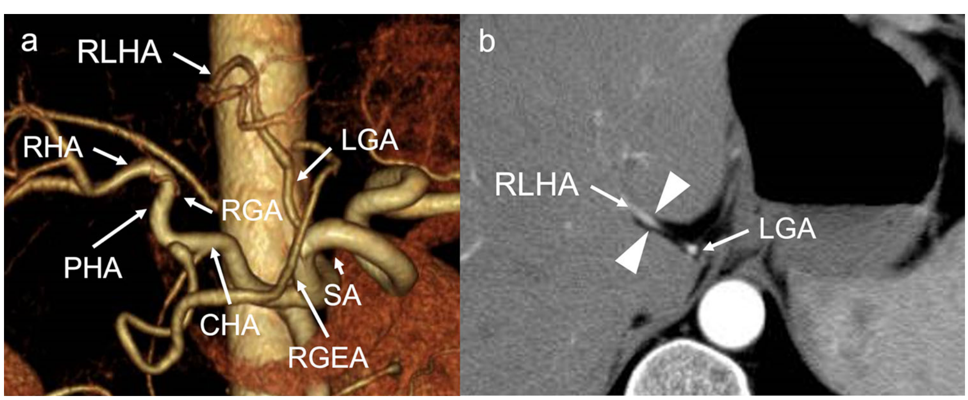

Fig. 3 Preoperative classification and measurement of the RLHA diameter on CT images **a** RLHA did not originate from the PHA in the extra-hepatic area on 3DCTA. **b** The intraluminal diameter of the RLHA was measured between the white arrow heads using axial slices at the lesser omentum before running into the liver. RLHA, replaced left hepatic artery; CT, computed tomography; PHA, proper hepatic artery; 3DCTA, three-dimensional computed tomography angiography; LGA, left gastric artery; RGA, right gastric artery; SA, splenic artery; CHA, common hepatic artery; RHA, right hepatic artery; RGEA, right gastro epiploic artery.

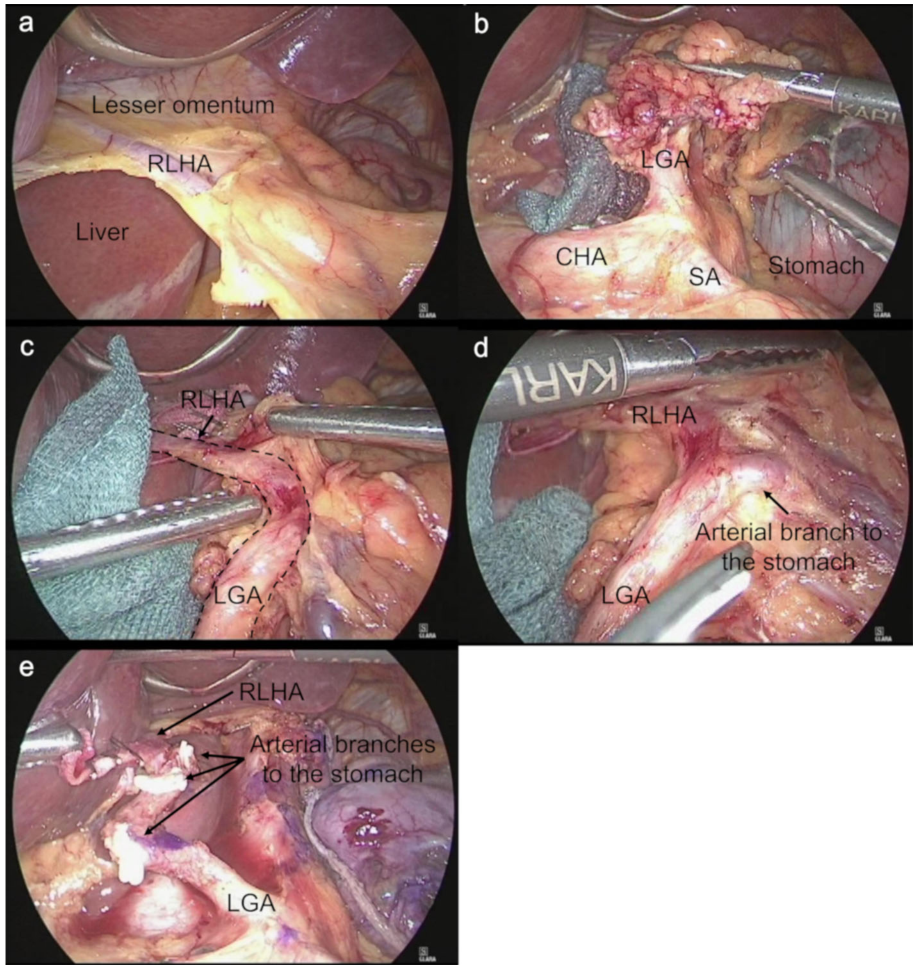

Fig. 4 Practical techniques of RLHA preservation during laparoscopic gastrectomy. **a** Identifying an RLHA in the lesser omentum, **b** exfoliating the left and right sides of the celiac artery and LGA, **c** cutting open the right side of the artery from the root of the LGA toward the RLHA running into the liver (black dotted line), **d** confirming the arterial branch to the stomach, **e** complete view after the preservation procedure of the RLHA. RLHA, replaced left hepatic artery; LGA, left gastric artery; SA, splenic artery; CHA, common hepatic artery

mass index, comorbidities, internal RLHA diameter, tumor location, and clinical and pathological TNM classifications according to the JCGC were collected for all patients. Preoperative confirmation rates of ALHA and RLHA were also collected from the medical records. Surgical outcomes included operative time, blood loss, extent of lymph node dissection, number of harvested lymph nodes as a whole and at each station around the LGA according to the JCGC, length of postoperative hospitalization, and postoperative complications according to the Clavien-Dindo classification (CD) [19]. Liver function test results, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), and bilirubin levels, preoperatively and on postoperative days 1 and 3 were collected and graded according to the National Cancer Institute Common Terminology Criteria for Adverse Events (CTCAE) version 4.0. The incidence of CD grade II or higher postoperative complications during the postoperative hospitalization was investigated. Hepatic infarction was diagnosed by radiologists when enhanced MDCT images showed an area of non-contrasted hepatic parenchyma. Long-term outcomes were also evaluated.

Statistical analysis

All statistical analyses were performed using R version 3.4 software package (R Foundation for Statistical Computing, Vienna, Austria). Continuous data are presented as median (range), and continuous variables were nonparametrically analyzed using the Mann–Whitney test. Categorical variables were compared using Fisher's exact test. All variables with p-values < 0.15 in the univariate analyses were included and analyzed in the multivariate logistic regression analysis. P-values < 0.05 were considered statistically significant.

Results

Study subject

In 55 patients diagnosed with RLHA, 37 had RLHA preservation and 18 had RLHA division. The reasons for RLHA division were preoperative misdiagnosis of RLHA as accessory-type ALHA ($n = 10$, 55.6%), intrahepatic communication (n = 3, 16.7%), blood supply confirmation after temporary clamping (n = 3, 16.7%), suspected direct invasion of the lymph node to the artery (n = 1, 5.6%), and injury during operation (n = 1, 5.6%). Short-term and long-term outcomes were compared between the two groups.

Patients' characteristics

Preoperative confirmation rate of RLHA was significantly lower in the divided group. The RLHA diameter was significantly larger in the preserved group. The other clinical findings were not significantly different between the two groups (Table 1).

Short-term outcomes and pathological findings

Operative time, blood loss, postoperative hospitalization, and number of harvested lymph nodes were not significantly different between the two groups (Table 2).

Perioperative blood examinations

ALT and AST levels on postoperative days 1 and 3 as well as postoperative ALT and AST elevation grades according to CTCAE were significantly higher in the divided group (Fig. 5 and Table 3).

Table 1 Patients' characteristics

Variables	Divided (n = 18)	Preserved (n = 37)	p-value
Age [years; median (range)]	71.5 (58–86)	68 (32–88)	0.302
Sex, n (%)			0.246
Male	9 (50.0)	12 (32.4)	
Female	9 (50.0)	25 (67.6)	
ECOG-PS, n (%)			1.000
0	17 (94.4)	36 (97.3)	
1	1 (5.6)	79 1 (0.6)	
BMI [kg/m^2; median (range)]	21.6 (16.5–37.7)	22.9 (18.0–31.6)	0.588
Comorbidity, yes, n (%)	8 (44.4)	17 (46.0)	1.000
Preoperative confirmation of ALHA, yes, n (%)	18 (100)	37 (100)	1.000
Preoperative confirmation of RLHA, yes, n (%)	8 (44.4)	36 (97.3)	< 0.001*
Diameter of RLHA [mm; median (range)]	1.5 (1.1–2.0)	1.7 (1.0–3.4)	0.021*
Location, n (%)			0.625
U	0 (0.0)	3 (8.1)	
M	8 (44.4)	12 (32.4)	
L	10 (55.6)	22 (59.5)	
Clinical T stage [a], n (%)			0.851
cT1	16 (88.9)	30 (81.1)	
cT2	2 (11.1)	5 (13.5)	
cT3	0 (0.0)	2 (5.4)	
Clinical N stage [a], n (%)			0.327
cN0	17 (94.4)	37 (100)	
cN1	1 (5.6)	0 (0.0)	
Clinical stage [a], n (%)			1.000
IA	15 (83.3)	30 (81.1)	
IB	3 (16.7)	5 (13.5)	
IIA	0 (0.0)	2 (5.4)	

ECOG-PS, the Eastern Cooperative Oncology Group performance status; BMI, body mass index; ALHA, aberrant left hepatic artery; RLHA, replaced left hepatic artery

*Statistically significant

[a]14th edition of the Japanese Classification of Gastric Carcinoma

Table 2 Surgical outcomes and pathological findings

Variables	Divided (n = 18)	Preserved (n = 37)	p-value
Lymph node dissection, n (%) [a]			1.000
D1 +	15 (83.3)	29 (78.4)	
D2	3 (16.7)	8 (21.6)	
Operative time [min; median (range)]	285 (171–490)	301 (173–476)	0.360
Blood loss [mL; median (range)]	10 (0–155)	18 (0–308)	0.427
Postoperative hospitalization duration [day; median (range)]	10 (7–38)	9 (7–21)	0.113
Retrieved lymph nodes [n; median (range)]			
D1 + lymph node dissection [a]	37 (19–74)	40 (13–91)	0.701
D2 lymph node dissection [a]	59 (34–64)	36.5 (21–53)	0.152
Station No. 1 [b]	3 (1–7)	3 (0–23)	0.397
Station No. 3a [b]	5.5 (0–25)	6 (0–23)	0.571
Station No. 7 [b]	3 (0–8)	3 (0–15)	0.723
Station No. 8a [b]	2 (1–5)	3 (0–10)	0.234
Station No. 9 [b]	4 (0–8)	3 (0–13)	0.395
Pathological stage [b]			1.000
IA/IB	16 (88.9)	32 (86.5)	
IIA/IIB	2 (11.1)	3 (8.1)	
IIIB	0 (0)	2 (5.4)	

[a] Japanese Gastric Cancer Treatment Guideline 2014

[b] 14th edition of the Japanese Classification of Gastric Carcinoma

Postoperative complications

Although the incidence of postoperative bleeding was not significantly different between the two groups, the incidence of hepatic infarction in the medial and/or lateral segment (Fig. 6) was significantly higher in the divided group (n = 3; 16.7% vs. n = 0; 0%, p = 0.031) (Table 4). Postoperative hepatic transaminase values of patients with hepatic infarction in the divided group are shown in Supplementary material 2.

Univariate and multivariate analyses for postoperative AST/ALT elevation

Univariate analysis showed that RLHA division was associated with postoperative ALT and/or AST increase of grade 3 or higher according to CTCAE. Multivariate analysis showed that RLHA division was identified as an independent risk factor for postoperative ALT and/or AST elevation (Table 5).

Survival and recurrence outcomes

The median follow-up period for all enrolled patients was 29.9 months (range, 5–72; interquartile range, 15–51). During this period, in the preserved group, one patient died of other diseases and another had bone metastasis relapse. There was no local recurrence around the LGA in both groups.

Discussion

The present study demonstrated that RLHA division during LDG is significantly associated with the elevation of ALT and AST levels on postoperative days 1 and 3. Moreover, in the divided group, three patients (16.5%) developed hepatic infarction of the lateral segment during postoperative hospitalization. RLHA division was demonstrated as an independent risk factor for postoperative transaminase increase of grade 3 or worse according to CTCAE.

Previously, the intraoperative identification rate of ALHA arising from the LGA has been reported to be 6%–22% during gastric surgery, and RLHA accounts for 45% of all ALHA cases from studies using cadaver [1–3]. For RLHA patients, the usual procedure of lymph node removal along the LGA during gastric cancer surgery includes RLHA division and blood flow disruption to the left lobe. Moreover, RLHA division results in hepatic infarction, which causes serious complications, including cholangitis and liver abscess [5–8]. However, ALHA division, including RLHA division, does not cause severe

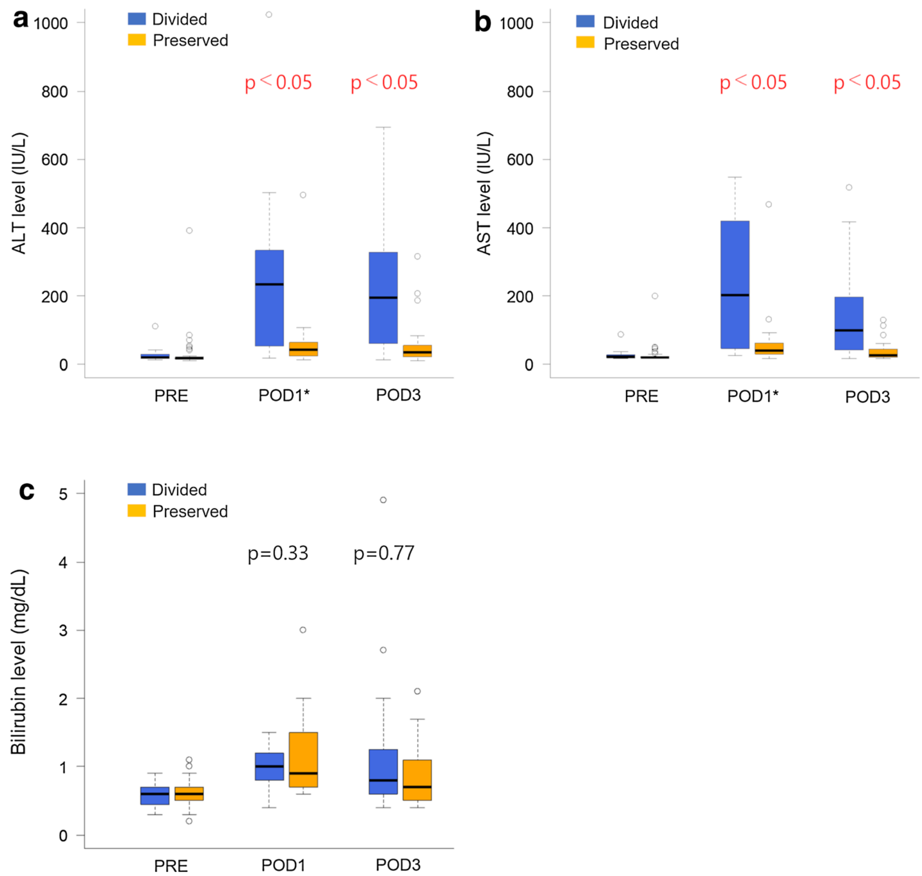

Fig. 5 Sequential changes in perioperative blood examinations. **a** ALT, **b** AST, and **c** bilirubin. ALT, alanine aminotransferase; AST, aspartate aminotransferase; PRE, preoperative; POD, postoperative day. *Including two patients with very high ALT and AST liver enzyme levels (> 1000 IU/L)

hepatic ischemia but only an elevation of liver enzymes [9, 10]. Despite this issue, no studies have evaluated the clinical impact of RLHA division among RLHA patients. Another concern of RLHA division is an oncological issue. For the RLHA preservation, the tissues surrounding the LGA and RLHA should be divided, and these vessels must be exposed. This additional procedure may increase the blood loss amount, operative time, and risk of inadequate lymph node dissection. The oncological safety of the procedure involving RLHA preservation, in terms of the accuracy of lymph node dissection around the LGA, has been scarcely reported. Therefore, there is still no consensus on whether to preserve or divide the RLHA during gastric cancer surgery.

Few reports have clearly demonstrated ALHA subtypes based on preoperative MDCT images. Recently, the number of hepatic vascular arterial anomalies detected using 3DCTA was comparable to that of the classical autopsy series or conventional angiography, suggesting that preoperative evaluation using 3DCTA before gastrectomy can help in recognizing ALHA [11–14]. In this study, RLHA detection rate in the divided group was lower, which might be due to the preoperative misdiagnosis of RLHA as an accessory-type ALHA by preoperative MDCT image review. Conversely, 36 out of 44 patients diagnosed with RLHA by preoperative MDCT had RLHA preservation in our series. Therefore, surgeons should carefully find RLHA when using preoperative MDCT with 3DCTA images.

LDG has become the widely used standard treatment for early gastric cancer [15, 16]. Although RLHA preservation requires additional surgical procedures, several studies have demonstrated that surgical techniques for ALHA preservation do not affect blood loss, operative time, or number of harvested lymph nodes compared with the division techniques [20, 21]. Similarly, our study demonstrated no significant difference in blood loss, operative time, and number of retrieved lymph nodes around the LGA between the two groups. This result could be attributed to the arterial anatomy around the LGA that could be routinely confirmed using preoperative MDCT images, and the sharing of information of the anomaly among operators and assistant surgeons facilitated the surgery. Therefore, this surgical technique of RLHA preservation could be feasible in LDG and enable exfoliation of surrounding tissue and dissection of gastric arterial branches around the RLHA without taping several arteries owing to the magnifying effect of laparoscopic surgery.

Table 3 Perioperative hematological examinations and postoperative CTCAE grading

	Divided (n=18)				Preserved (n=37)				p-value
ALT (IU/L)[a]									
PRE	20 (12–111)				17 (10–391)				0.359
POD1	234 (17–1246)				42 (12–495)				<0.001*
POD3	195 (13–1063)				35 (10–315)				<0.001*
AST (IU/L)[a]									
PRE	21 (16–86)				20 (15–198)				0.331
POD1	202 (25–2122)				40 (16–466)				<0.001*
POD3	99 (16–517)				26 (15–128)				<0.001*
BIL (mg/dL)[a]									
PRE	0.6 (0.2–1.1)				0.6 (0.3–1.0)				0.848
POD1	0.9 (0.6–1.5)				1.0 (0.4–3.0)				0.330
POD3	0.8 (0.4–4.9)				0.9 (0.4–2.7)				0.766
Grade[b]	1	2	3	4	1	2	3	4	
ALT, n (%)	2 (11.1)	0 (0)	10 (55.6)	2 (11.1)	8 (21.6)	2 (5.4)	1 (2.7)	0 (0)	<0.001*
AST, n (%)	1 (5.6)	3 (16.7)	7 (38.9)	2 (11.1)	11 (29.7)	2 (5.4)	1 (2.7)	0 (0)	<0.001*
BIL, n (%)	1 (5.6)	1 (5.6)	1 (5.6)	0 (0)	8 (21.6)	5 (13.5)	0 (0)	0 (0)	0.173

CTCAE, National Cancer Institute Common Terminology Criteria for Adverse Events; ALT, alanine aminotransferase; AST, aspartate aminotransferase; BIL, bilirubin; PRE, preoperative; POD, postoperative day

*Statistically significant

[a]Data are shown as median (range)

[b]According to the grades of CTCAE

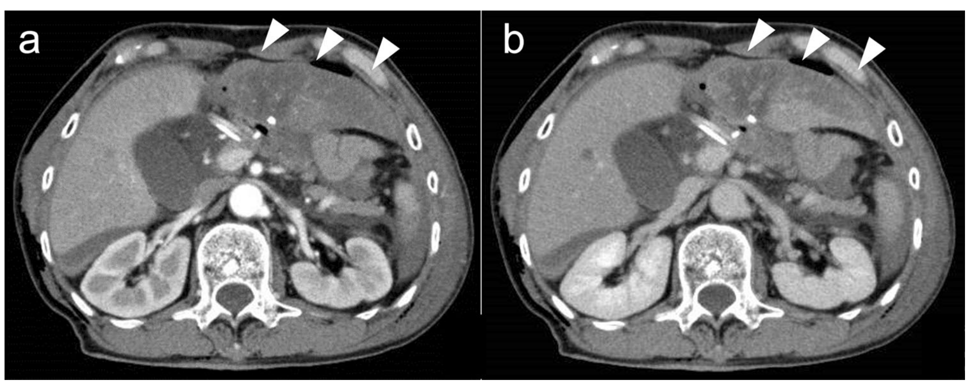

Fig. 6 Enhanced-computed tomography images of hepatic infarction in the lateral segment after RLHA division. A large low-contrast area in the lateral segment is detected on both the (**a**) arterial and (**b**) venous phases. RLHA, replaced left hepatic artery

Several studies have reported that ALHA division resulted in transient transaminase elevation without hepatic infarction [10, 20]. Generally, hepatic infarction can be caused by hepatic arterial interruption after hepatic artery division until the arterial flow is reconstituted. After hepatic artery ligation between the intrahepatic and adjacent arteries, collateralization through the inferior phrenic, pancreaticoduodenal, and intrahepatic arteries has been reported in angiographic examinations [22, 23]. In previous studies, ALHA subtypes could not be considered and classified. Contrarily, our study assessed only RLHA patients and demonstrated that RLHA division led to higher incidence of partial left hepatic lobe infarction. Therefore, when dividing the RLHA, the collateral arterial communications are occasionally insufficient to supply the arterial flow to the RLHA's dominant area.

Several studies have reported the association between increased postoperative transaminase levels and immune system. In liver surgery, peak postoperative transaminase levels were associated with morbidity and mortality [24]. The liver plays an important role in innate immunity; its functions include reserving fixed-tissue macrophages,

Table 4 Postoperative complications according to the Clavien-Dindo classification (grade II or worse)

	Divided (*n* = 18)	Preserved (*n* = 37)	*p*-value
All complications	6 (33.3)	6 (16.2)	0.177
Intra-abdominal abscess	2 (11.1)	4 (10.8)	1.000
Pancreas fistula	0 (0)	1 (2.7)	1.000
Anastomotic leakage	1 (5.6)	0(0)	0.327
Postoperative bleeding	2 (11.1)	0(0)	0.103
Anastomotic stenosis	1 (5.6)	0 (0)	0.327
Delayed gastric emptying	1 (5.6)	2 (5.4)	1.000
Acute cholecystitis	1 (5.6)	0 (0)	0.327
Hepatic infarction	3 (16.7)	0 (0)	0.031*

Data are shown as n (%)

*Statistically significant

Table 5 Univariate and multivariate analyses of risk factors for the postoperative ALT and/or AST elevation (CTCAE grade 3 or worse)

	Univariate			Multivariate		
	OR	95% CI	*p*-value	OR	95% CI	*p*-value
Age, ≥ 70 vs. < 70 years	1.28	0.30–5.59	0.695			
Sex, male vs. female	0.98	0.23–4.61	0.981			
BMI, ≥ 25 vs. < 25 kg/m^2	0.83	0.16–2.92	0.765			
Comorbidity, yes vs. no	0.64	0.15–2.71	0.488			
Lymph node dissection, ≥ D2 vs. ≤ D1 +	0.67	0.07–3.83	0.636			
Operation time, ≥ 300 vs. < 300 min	1.03	0.36–3.53	0.863			
Blood loss, ≥ 50 vs. < 50 mL	1.09	0.38–3.53	0.863			
Diameter of RLHA, < 1.5 vs. ≥ 1.5 mm	2.74	0.60–12.5	0.129	1.48	0.18–13.0	0.645
Division of RLHA, yes vs. no	72.0	9.00–2686	< 0.001*	55.8	6.64–2115	< 0.001*

ALT, alanine aminotransferase; AST, aspartate aminotransferase; CTCAE, National Cancer Institute Common Terminology Criteria for Adverse Events; OR, odds ratio; CI, confidence interval; BMI, body mass index; RLHA, replaced left hepatic artery

*Statistically significant

including Kupffer cells, and regulating the synthesis of proteins responsible for pathogen recognition and opsonization [25]. Previous studies have reported that innate immunity impairment due to liver dysfunction after liver surgery was associated with both changes in innate immune response and postoperative infection [26–28]. Meanwhile, we demonstrated that RLHA division was an independent risk factor for postoperative transaminase elevation, suggesting the possible presence of innate immune impairment in patients with RLHA division. Thus, we suggest that RLHA preservation should be performed owing to its comparable short-term outcomes and minimal postoperative hepatic transaminase elevation associated with innate immune impairment, unless the tumor directly invades the RLHA in LDG.

The present study has several limitations. First, this is a retrospective analysis of a small number of patients from a single institute. Furthermore, we did not perform a detailed imaging study on RLHA using 3DCTA, and the impact of CT-defined RLHA division on the postoperative hepatic arterial collateralization and transaminase elevation is not fully understood. Second, this study did not adequately demonstrate its oncological safety in terms of long-term survival because of the short follow-up period. However, as the number of harvested lymph nodes did not differ between the divided and preserved groups, the RLHA-preserving procedure is assumed to improve the survival outcomes by reducing postoperative complications [29].

Conclusions

The RLHA preserving procedure reduced the incidence of postoperative transaminase elevation and hepatic infarction in patients undergoing LDG. Surgeons should pay close attention to the RLHA using preoperative MDCT images and preserve the RLHA to prevent hepatic damage.

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Compliance with ethical standards

Conflict of interest Masanori Terashima has received personal fees from Taiho, Chugai, Ono, Bristol-Myers Squibb, Yakult, Takeda, Eli Lilly, Pfizer, and Daiichi Sankyo, outside the submitted work. All other authors declare no conflict of interest.

Human and animal rights This study was approved by the institutional review board of Shizuoka Cancer Center (Approval no. J2019-42–2019-1–3).

Informed consent Informed consent was waived by the ethical committee owing to the retrospective nature of the study.

References

1. Hiatt JR, Gabbay J, Busuttil RW (1994) Surgical anatomy of the hepatic arteries in 1000 cases. Ann Surg 220:50–52
2. Lopez-Andujar R, Moya A, Montalva E et al (2007) Lessons learned from anatomic variants of the hepatic artery in 1,081 transplanted livers. Liver Transpl 13:1401–1404
3. Michels NA (1966) Newer anatomy of the liver and its variant blood supply and collateral circulation. Am J Surg 112:337–347
4. Japanese Gastric Cancer A (2011) Japanese classification of gastric carcinoma: 3rd English edition. Gastric Cancer 14:101–112
5. Yamamoto M, Zaima M, Yamamoto H et al (2017) Liver necrosis shortly after pancreaticoduodenectomy with resection of the replaced left hepatic artery. World J Surg Oncol 15:77
6. Friesen SR (1957) The significance of the anomalous origin of the left hepatic artery from the left gastric artery in operations upon the stomach and esophagus. Am Surg 23:1103–1108
7. Hemming AW, Finley RJ, Evans KG et al (1992) Esophagogastrectomy and the variant left hepatic artery. Ann Thorac Surg 54:166–168
8. Lurie AS (1987) The significance of the variant left accessory hepatic artery in surgery for proximal gastric cancer. Arch Surg 122:725–728
9. Oki E, Sakaguchi Y, Hiroshige S et al (2011) Preservation of an aberrant hepatic artery arising from the left gastric artery during laparoscopic gastrectomy for gastric cancer. J Am Coll Surg 212:e25-27
10. Shinohara T, Ohyama S, Muto T et al (2007) The significance of the aberrant left hepatic artery arising from the left gastric artery at curative gastrectomy for gastric cancer. Eur J Surg Oncol 33:967–971
11. Lee SW, Shinohara H, Matsuki M et al (2003) Preoperative simulation of vascular anatomy by three-dimensional computed tomography imaging in laparoscopic gastric cancer surgery. J Am Coll Surg 197:927–936
12. Matsuki M, Kani H, Tatsugami F et al (2004) Preoperative assessment of vascular anatomy around the stomach by 3D imaging using MDCT before laparoscopy-assisted gastrectomy. AJR Am J Roentgenol 183:145–151
13. Yamashita K, Sakuramoto S, Mieno H et al (2014) Preoperative dual-phase 3D CT angiography assessment of the right hepatic artery before gastrectomy. Surg Today 44:1912–1919
14. Iino I, Sakaguchi T, Kikuchi H et al (2013) Usefulness of three-dimensional angiographic analysis of perigastric vessels before laparoscopic gastrectomy. Gastric Cancer 16:355–361
15. Katai H, Mizusawa J, Katayama H et al (2020) Survival outcomes after laparoscopy-assisted distal gastrectomy versus open distal gastrectomy with nodal dissection for clinical stage IA or IB gastric cancer (JCOG0912): a multicentre, non-inferiority, phase 3 randomised controlled trial. Lancet Gastroenterol Hepatol 2:142–151
16. Katai H, Mizusawa J, Katayama H et al (2017) Short-term surgical outcomes from a phase III study of laparoscopy-assisted versus open distal gastrectomy with nodal dissection for clinical stage IA/IB gastric cancer: Japan Clinical Oncology Group Study JCOG0912. Gastric Cancer 20:699–708
17. Japanese Gastric Cancer A (2017) Japanese gastric cancer treatment guidelines 2014 (ver. 4). Gastric Cancer 20:1–19
18. Healey JE Jr, Schroy PC (1953) Anatomy of the biliary ducts within the human liver; analysis of the prevailing pattern of branchings and the major variations of the biliary ducts. AMA Arch Surg 66:599–616
19. Dindo D, Demartines N, Clavien PA (2004) Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 240:205–213
20. Kim J, Kim SM, Seo JE et al (2016) Should an Aberrant Left Hepatic Artery Arising from the Left Gastric Artery Be Preserved during Laparoscopic Gastrectomy for Early Gastric Cancer Treatment? J Gastric Cancer 16:72–77
21. Huang CM, Chen QY, Lin JX et al (2013) Short-term clinical implications of the accessory left hepatic artery in patients undergoing radical gastrectomy for gastric cancer. PLoS ONE 8:e64300
22. Plengvanit U, Chearanai O, Sindhvananda K et al (1972) Collateral arterial blood supply of the liver after hepatic artery ligation, angiographic study of twenty patients. Ann Surg 175:105–110
23. Mays ET, Wheeler CS (1974) Demonstration of collateral arterial flow after interruption of hepatic arteries in man. N Engl J Med 290:993–996
24. Olthof PB, Huiskens J, Schulte NR et al (2016) Postoperative peak transaminases correlate with morbidity and mortality after liver resection. HPB (Oxford) 18:915–921
25. Medzhitov R, Janeway C Jr (2000) Innate immunity. N Engl J Med 343:338–344
26. Lan AK, Luk HN, Goto S et al (2003) Stress response to hepatectomy in patients with a healthy or a diseased liver. World J Surg 27:761–764

27. Han DW (2002) Intestinal endotoxemia as a pathogenetic mechanism in liver failure. World J Gastroenterol 8:961–965
28. Shiomi S, Kuroki T, Ueda T et al (1996) Diagnosis by routine scintigraphy of hepatic reticuloendothelial failure before severe liver dysfunction. Am J Gastroenterol 91:140–142
29. Tokunaga M, Tanizawa Y, Bando E et al (2013) Poor survival rate in patients with postoperative intra-abdominal infectious complications following curative gastrectomy for gastric cancer. Ann Surg Oncol 20:1575–1583