often steal portal flow, and decreases in portal flow beyond a certain point negatively affect graft function. Thus, it makes sense that the presence of shunts negatively affects the outcome. The need to close portosystemic shunts may be created by removal of the spleen. A loss of splenic vein flow may increase the fraction of portal blood flow that leaves the portal system via the portosystemic shunt.

Another new finding in this study is that our modified predictive score is applicable to FHF. We excluded patients with FHF from the previous study[4] because their predictive scores did not correlate with their prognosis. When we started the LDLT program, FHF was the leading indication for adult LDLT. In the early phase of our program, 3 cases of hepatic artery thrombosis that led to graft loss occurred in patients with FHF. Our predictive formula works only with constant use of the same technique because a major vascular or biliary complication leads to a poor prognosis. We excluded 2 cases of apparent technical failure (excessive intraoperative bleeding) from this study. We also excluded 2 cases of irreversible brain damage, which definitely adversely influences the prognosis and can occur after untimely transplantation for FHF.

The recipient BMI was one of the independent risk factors for 6-month graft survival. Therefore, a recipient BMI ≥ 30 kg/m^2 is a contraindication to LDLT regardless of the predictive score. Whether obesity affects short-term survival after liver transplantation remains controversial.[28,29] It is possible that obese patients have more postoperative complications than nonobese patients and that this contributes to their poorer outcomes. Furthermore, the expression of adipokines reportedly increases in obese patients because adipose tissue induces their expression, and this leads to an accumulation of inflammatory cytokines.[30] A recent report has suggested that obesity has a proinflammatory effect on adipose tissue macrophages and enhances the secretion of tumor necrosis factor α and interleukin-6.[31] Further study is needed to clarify the role of adipose tissue in inflammation in obese patients.

In conclusion, predictive scores calculated with our formula, which incorporates the graft size, donor age, MELD score, and portosystemic shunt status, reliably predict 6-month graft survival. Furthermore, our treatment strategy has widened the safety range for donor ages and graft sizes.

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VIDEOS

Laparoscopic liver resection in the semiprone position for tumors in the anterosuperior and posterior segments, using a novel dual-handling technique and bipolar irrigation system

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Abstract
Background Hepatic tumors in the lower edge and lateral segments are commonly treated by laparoscopic liver resection. Tumors in the anterosuperior and posterior segments are often large and locally invasive, and resection is associated with a higher risk of insufficient surgical margins, massive intraoperative bleeding, and breaching of the tumor. Laparoscopic surgery for such tumors often involves major hepatectomy, including resection of a large volume of normal liver tissue. We developed a novel method of laparoscopic resection of tumors in these segments with the patient in the semiprone position, using a dual-handling technique with an intercostal transthoracic port. The aim of this study was to evaluate the safety and usefulness of our technique.
Methods Of 160 patients who underwent laparoscopic liver resection at our center from June 2008 to May 2013, we retrospectively reviewed those with tumors in the anterosuperior and posterior segments. Patients were placed supine or semilateral during surgery until January 2010 and semiprone from February 2010.
Results Before the introduction of the semiprone position in February 2010, a total of 7 of 40 patients (17.5 %) with tumors in the anterosuperior and posterior segments underwent laparoscopic liver resection, and after introduction of the semiprone position, 69 of 120 patients (57.5 %) with tumors in the anterosuperior and posterior segments underwent laparoscopic liver resection ($P < 0.001$). There were no conversions to open surgery, reoperations, or deaths. The semiprone group had a significantly higher proportion of patients who underwent partial resection or segmentectomy of S7 or S8, lower intraoperative blood loss, and shorter hospital stay than the supine group (all $P < 0.05$). Postoperative complication rates were similar between groups.
Conclusions Laparoscopic liver resection in the semiprone position is safe and increases the number of patients who can be treated by laparoscopic surgery without increasing the frequency of major hepatectomy.

Keywords Pure laparoscopic hepatectomy · Semiprone position · Anterosuperior and posterior segments · Dual-handling technique · Intercostal transthoracic port

The first laparoscopic nonanatomical liver resection for focal nodular hyperplasia was reported by Gagner et al. [1]. Since then, improvements in laparoscopic instruments have significantly improved the safety of laparoscopic liver resection [2–9]. However, laparoscopic nonanatomical resection generally is performed only for tumors located in the lower edge and lateral segments (Couinaudrs segments S2, S3, S4b, S5, and S6), because the posterosuperior segments (S1, S4a, S7, and S8) are difficult to visualize and beyond the reach of the surgical instruments. Nonanatomical partial resection and anatomical minor resection

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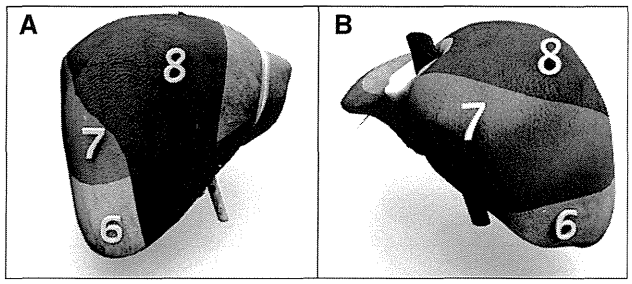

Fig. 1 Illustration of liver segments. Patients who underwent laparoscopic resection of malignant tumors of the anterosuperior segment (S8), posterosuperior segment (S7), posteroinferior segment (S6), and right superior portion of the caudate lobe (S1) were included in this study. **a** Right anterior view. **b** Right posterior view

(S6, S7, or S8 segmentectomy) preserve liver parenchyma and are less invasive than right hemihepatectomy. Tumors in the posterosuperior segments are usually are resected by open surgery, which is much more invasive than laparoscopic surgery and leaves a large wound.

We developed a novel method for laparoscopic nonanatomical resection of tumors located in the right portions of S1, S6, S7, and S8. This includes the anterosuperior and posterior areas of the liver, except S4a but plus S6, and represents almost half of the liver volume.

Some high-volume centers have reported that laparoscopic resection of the posterosuperior segments can be performed as safely as resection of the anterolateral segments by an experienced surgeon [10, 11]. However, few specific techniques have been described. Reports indicate that patients with tumors of the posterosuperior segments (S1, S7, S8, and S4a) are more likely to undergo hemihepatectomy and less likely to undergo nonanatomical resection or segmentectomy than patients with tumors of the anterolateral segments (S2, S3, S4b, S5, and S6) [12, 13].

The aim of this study was to retrospectively evaluate the outcomes of laparoscopic liver resection in the semiprone position in patients with tumors in the anterosuperior segment (S8), posterior segments (S6 and S7), and parts of the caudate lobe (caudate process and paracaval portion of S1) compared with outcomes of resection in the conventional supine position [14, 15].

Methods

Patients

A total of 160 patients underwent laparoscopic resection of liver tumors at our center between June 2008 and May 2013. Of these, 76 patients had tumors located in the anterosuperior or posterior segments. The first 20 of these 76 patients underwent surgery in the supine position. Patients were carefully positioned according to tumor location and patient habitus; in some cases the right side of the patient was tilted upward by up to 45°. The first laparoscopic partial hepatectomy in the semiprone position was performed in February 2010 in a patient with a tumor in S7. Until October 2011, we performed laparoscopic liver resection on patients in the semiprone position only for tumors in S6, S7, and the posterior portion of S8. We now perform laparoscopic liver resection in the semiprone position for tumors in all parts of S6, S7, and S8 and the right portion of S1 (Fig. 1).

The indications for laparoscopic liver resection are similar to those for open liver resection with respect to preoperative assessment of liver function, type of liver resection, and postoperative care. However, patients with tumors >4 cm in diameter, tumors invading or adjacent to the main portal pedicle or inferior vena cava (IVC), or tumors adjacent to the main hepatic veins were excluded. The type of resection was determined based on the depth of lesions, number of lesions, locations of lesions relative to major vascular structures, and hepatic functional reserve. Major liver resection, including right hepatectomy, right posterior sectionectomy, or left hepatectomy, was considered in patients with a deep tumor when the remaining liver function was expected to be adequate. For metastatic liver tumors from colorectal cancer, liver resection was performed when there was no evidence of extrahepatic disease.

Standard preoperative investigations included routine abdominal spiral computed tomography (CT) and contrast ultrasonography, abdominal magnetic resonance imaging, and positron emission tomography if required; chest X-ray or CT; and serum biochemistry testing. To determine the operative method (laparoscopic or open) and extent of resection, all patients underwent preoperative assessment of liver functional reserve with liver function testing, Child-Pugh classification, and indocyanine green retention rate at 15 min.

Laparoscopic liver resection in the semiprone position

The patient was placed in the semiprone position, which is similar to the position while breathing during front crawl swimming. The surgeon was positioned on the left cranial side of the patient, and the camera operator was positioned next to the surgeon on the left side of the patient.

The port sites for resection of S6 and the right inferior portion of S1, including the caudate process, are shown in Fig. 2. The first port was placed in the right pararectal line, 10 cm below the costal margin, and was used to introduce a 30° laparoscope. Three trocars were placed below the costal margin in the right pararectal line, anterior axillary line, and posterior axillary line.

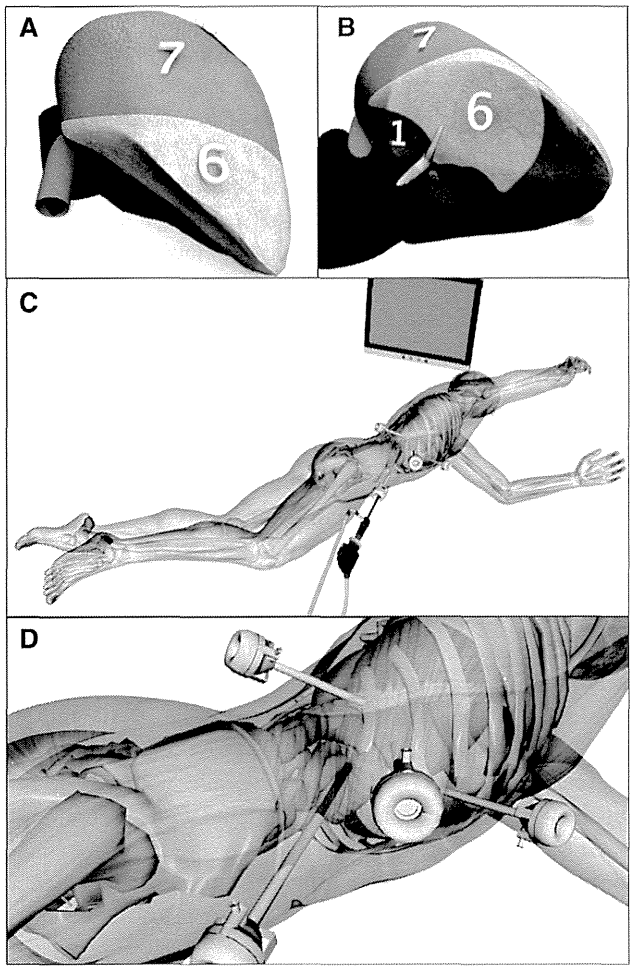

Fig. 2 Laparoscopic liver resection in the semiprone position for tumors in the posteroinferior segment (S6) and right inferior portion of the caudate lobe (S1). **a** Right posterior view immediately after inserting the laparoscope. **b** Right inferior view when the lower surface of S6 is rising to the ventral side. **c** Semiprone position during surgery. **d** Port sites: one port was placed in the right pararectal line 10 cm below the subcostal margin for the camera, and three trocars were inserted through ports below the subcostal margin in the right pararectal line, anterior axillary line, and posterior axillary line

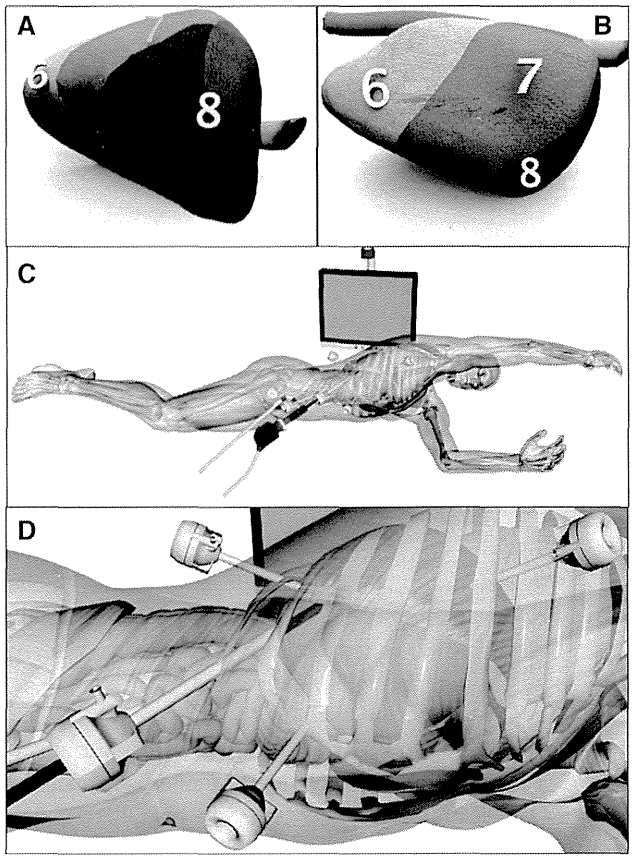

Fig. 3 Laparoscopic liver resection in the semiprone position for tumors in the posterosuperior segment (S7), anterosuperior segment (S8), and right superior portion of the caudate lobe (S1). **a** Right anterior view before the right triangular and coronary ligaments are divided. **b** Right anterior view after the right triangular and coronary ligaments are divided. **c** Semiprone position during surgery. The patient position is almost the same as in Fig. 2. As the surgeon stands on the cranial side to use the intercostal port, the left hand of the patient is moved towards the head. **d** Port sites: an additional intercostal port was inserted at the seventh intercostal space in the anterior axillary line

For resection of S7, S8, and the right superior portion of S1, the laparoscope and ports initially were placed as described above. After hilar dissection and mobilization of the liver, an intercostal port was inserted at about the seventh intercostal space in the anterior axillary line (Fig. 3). The camera was inserted in the anterior axillary line, below the costal margin if necessary. Differential lung ventilation was used when intercostal ports were planned.

Although this patient position is stable, a vacuum mattress and two backboards were used to control rotation and for safety. A carbon dioxide pneumoperitoneum was established and was maintained at 8–15 mmHg. When necessary, such as for parenchymal dissection between the anterior segment and the internal portion of the liver during anterior sectionectomy, S8 segmentectomy, and right hemihepatectomy, the patient was rotated by tilting the left side of the operating table downward by up to 20°–30°. The patient stayed in the semiprone position throughout the procedure (see Video 1, which demonstrates patient position and port sites).

To perform hilar dissection, Rouviere's sulcus (a fissure on the liver to the right of the hilum between S6 and S5) was oriented. The portal pedicles of S6 and the posterior and anterior segments were separated. The portal pedicle of S7 could be visualized after the portal pedicle of S6 was divided. The portal pedicles of segments with tumor visualized on preoperative imaging were divided so that the ischemic area corresponded to the tumor location (see Video 2, which demonstrates hilar dissection).

The right triangular and coronary ligaments were partially divided. The right inferior hepatic vein and short

hepatic vein were also carefully divided. During liver mobilization, the position of the right lobe could be controlled by an assistant using only a 5-mm pledget (see Video 3, which demonstrates mobilization of the right lobe).

The surface of the liver was divided using mainly bipolar scissors fitted with a silicone tube dripping saline to the tip, and the liver parenchyma was transected using bipolar scissors or bipolar forceps such as the BiClamp™ (ERBE, Germany) or LigaSure™ (Covidien, Mansfield, MA) fitted with a saline drip. If parenchymal division of S7, S8, or the right superior portion of S1 was needed, left one-lung ventilation was initiated and an intercostal port was placed, using a balloon to isolate the chest from the abdominal cavity. This port was used by the right hand of the operator (see Video 4, which demonstrates the dual-handling technique of an intercostal port for division of the parenchyma during right hemihepatectomy). The surgical techniques of right hemihepatectomy and posterior sectionectomy in the semiprone position have previously been described in detail [14, 15]. The resected specimen was placed in a plastic bag and extracted through the right lateral trocar site, which was enlarged as needed.

Major resection was defined as hemihepatectomy or right posterior sectionectomy, and minor resection was defined as segmentectomy or tumorectomy. Tumors were defined as deep if they were located >2 cm from the liver surface on preoperative CT.

Laparoscopic liver resection in the supine or semilateral position

Twenty patients underwent laparoscopic liver resection in the supine position. Patient position was carefully adjusted according to tumor location and patient habitus; if necessary, the right side of the patient was tilted upward by up to 45°. The surgical technique has previously been described in detail [5].

Statistical analysis

Outcomes were compared between the supine and semiprone groups. Data are presented as mean (range) or number (percentage). Differences between groups were analyzed using JMP 5.1 software with Fisher's exact test or χ^2 test as appropriate. Continuous variables were compared using Student's t test.

Results

Before the introduction of the semiprone position in February 2010, a total of 7 of 40 patients (17.5 %) with tumors in the anterosuperior and posterior segments underwent laparoscopic liver resection, and after the introduction of the semiprone position, 69 of 120 patients (57.5 %) with tumors in the anterosuperior and posterior segments underwent laparoscopic liver resection. ($P < 0.001$).

Table 1 Indications for laparoscopic liver resection

Type of tumor	Group-S ($n = 20$)	Group-SP ($n = 56$)	P	Total ($n = 76$)
Primary liver tumor	15	30	NS	45
Hepatocellular carcinoma	15	29		44
Cholangiocarcinoma	0	1		1
Metastatic tumor	5	26	NS	31
Colorectal adenocarcinoma	4	26		30
Gastric carcinoid tumor	1	0		1

Group-S supine patients, *Group-SP* semiprone patients, *NS* not significant

The indications for laparoscopic liver resection are given in Table 1. The majority of liver tumors in both groups were hepatocellular carcinoma (HCC).

The preoperative characteristics of the patients are listed in Table 2. Mean patient age, sex, body mass index, history of laparotomy, and preoperative chemotherapy were similar between the two groups. Most patients had underlying liver disease due to hepatitis B or C virus infection or preoperative chemotherapy: 26 patients (33.8 %) had chronic hepatitis, 20 (26.3 %) had liver cirrhosis, and 23 (30.3 %) had received preoperative chemotherapy. Only one patient had Child-Pugh class B liver function, and none had Child-Pugh class C liver function. The preoperative indocyanine green retention rate at 15 min was similar in both groups.

Tumor characteristics are given in Table 3. There were no significant differences in mean tumor size, number of tumors, or location of tumors (surface or deep) between the two groups.

The types of liver resection performed are listed in Table 4. The proportions of patients who underwent major resection were not significantly different between the two groups. In patients who underwent minor liver resection, anatomical resections such as S6 and S7 segmentectomy were performed only in the semiprone group ($P < 0.05$). The proportion of nonanatomical resections of S1, S7, and S8 was also significantly higher in the semiprone group than in the supine group ($P < 0.01$).

Intraoperative and postoperative outcomes are given in Table 5. There were no conversions to open surgery in either group. Of the 24 patients with metastatic colorectal cancer, 12 had undergone previous resection of the primary

Table 2 Preoperative characteristics of patients

Characteristic	Group-S ($n = 20$)	Group-SP ($n = 56$)	P	Total ($n = 76$)
Age	66 (49–78)	66 (39–86)	NS	66 (39–86)
Sex (M/F)	17/3	45/11	<0.05	62/14
BMI	23.1 ± 2.7	23.6 ± 2.9	NS	23.6 ± 2.7
Previous laparotomy [n (%)]	7 (30.4)	28 (50.0)	NS	35 (46.1)
Preoperative chemotherapy	4 (20.0)	19 (33.9)	NS	23 (30.3)
HBsAg (+) (%)	5 (25.0)	7 (12.5)	NS	12 (15.8)
Anti-HCV AB (+) (%)	9 (45.0)	16 (28.6)	NS	25 (32.9)
Liver disease (normal/CLD/LC)	4/7/9	26/19/11	NS	30/26/20
Child-Pugh class (A/B/C)	19/1/0	56/0/0	NS	75/1/0
ICG-R15	17.9 ± 9.54	15.6 ± 10.7	NS	17.6 ± 10.3

Group-S supine patients, *Group-SP* semiprone patients, *NS* not significant, *BMI* body mass index, *HBsAg* hepatitis B surface antigen, *anti-HCV AB* anti-hepatitis C virus antibody, *ICG-R15* indocyanine green retention rate at 15 min

Table 3 Tumor characteristics

Characteristic	Group-S ($n = 20$)	Group-SP ($n = 56$)	P	Total ($n = 76$)
Size (cm)	3.0 ± 1.3	2.5 ± 1.0	NS	2.9 ± 1.3
Number (1/2/3)	18/2/0	42/13/1	NS	60/15/1
Location (superficial/deep)	19/1	45/11	NS	64/12

Group-S supine patients, *Group-SP* semiprone patients, *NS* not significant

Table 4 Types of laparoscopic liver resection

Type	Group-S ($n = 20$)	Group-SP ($n = 56$)	P	Total ($n = 76$)
Major liver resection	4	14	NS	18
Right hemihepatectomy (n)	2	5		7
Right posterior sectionectomy (n)	2	9		11
Minor liver resection	17	54	NS	71
Anatomical liver resection	0	10	<0.05	10
S6 Segmentectomy (n)	0	5		5
S7 Segmentectomy (n)	0	3		3
S8 Segmentectomy (n)	0	2		2
Nonanatomical liver resection	17	44	NS	61
S6 Partial resection (n)	12	13		25
S1 Partial resection (n)	0	1		1
S7 Partial resection (n)	0 (31.2)	14 (70.4)	<0.01	14
S8 Partial resection (n)	5	16		21
Total number of liver resection	21	68		89

Group-S supine patients, *Group-SP* semiprone patients, *NS* not significant

tumor, and 12 underwent simultaneous laparoscopic resection of the primary tumor by low anterior resection ($n = 5$), sigmoid colectomy ($n = 3$), or right colectomy ($n = 1$). One patient in the supine group underwent simultaneous laparoscopic distal gastrectomy for early gastric cancer, which was detected during the preoperative investigation of HCC.

The mean operating time was not significantly different between the semiprone and supine groups. There was less blood loss in the semiprone group (mean 158 g; range

Table 5 Surgical outcomes

Outcome	Group-S ($n = 20$)	Group-SP ($n = 56$)	P	Total ($n = 76$)
Open conversion	0	0		0
Simultaneous combined resection [n (%)]	3 (15.0)	12 (21.4)	NS	15 (19.7)
Rectum [n (%)]	1 (5.0)	6 (10.7)		7 (9.2)
Sigmoid colon [n (%)]	0	4 (7.1)		4 (5.3)
Right colon [n (%)]	0	1 (1.8)		1 (1.3)
Gastrectomy [n (%)]	1 (5.0)	1 (1.8)		1 (1.3)
Spleen [n (%)]	1 (5.0)	1 (1.8)		1 (1.3)
Operative time (min) (range)	344 (99–685)	296 (66–599)	NS	351 (79–881)
Without simultaneous G-I resection[a]	352 (99–685)	272 (79–578)	NS	
Blood loss (g) (range)	889 (120–3,200)	158 (0–1,070)	<0.05	525 (0–3,200)
Without simultaneous G-I resection[a]	1,101 (120–3,200)	98 (0–350)	<0.05	
Blood transfusion	3 (15.0)	3 (5.4)	NS	6 (7.9)
Postoperative complications [n (%)]	4 (20.0)	2 (3.6)	NS	6 (7.9)
Without simultaneous G-I resection[a]	2 (10.0)	0		
Intra-abdominal abscess [n (%)]	2 (10.0)	2 (3.6)		4 (5.3)
Ascites [n (%)]	1 (5.0)	0		1 (1.3)
Bile leakage [n (%)]	1 (5.0)	0		1 (1.3)
Postoperative hospital stay (days) (range)	35 (7–71)	11 (5–23)	<0.05	21.9 (5–71)
Without simultaneous G-I resection[a]	28 (7–71)	9 (5–14)	<0.05	16.2 (5–71)

Group-S supine patients, *Group-SP* semiprone patients, *NS* not significant

Data are presented as median (range) or number (%)

[a] Without simultaneous gastric or colorectal resection

580–1,070 g) than in the supine group (mean 889 g; range 120–3,200 g) ($P < 0.05$), and this difference was greater when patients who underwent simultaneous colorectal or gastric resection were excluded. The mean postoperative hospital stay was shorter in the semiprone group (median 11 days; range 5–23 days) than in the supine group (median 35 days; range 7–71 days) ($P < 0.05$), and this difference was also greater when patients who underwent simultaneous colorectal or gastric resection were excluded.

Six patients (8.6 %) developed postoperative complications, and the complication rate was similar between the two groups. Bile leakage at the cut surface of the remnant liver occurred in one patient with HCC in the supine group. Postoperative symptomatic intra-abdominal fluid collection occurred in one patient with HCC who developed prolonged ascites after minor liver resection, which resolved after administration of diuretics and limitation of water and salt intake. Intra-abdominal abscesses requiring treatment occurred in four patients who underwent simultaneous colorectal resection. In one of these cases, the abscess was adjacent to the partial resection of S8 and was managed by percutaneous drainage and right colectomy. The other patients had undergone low anterior resection, and the abscesses were adjacent to the bowel anastomoses or in the right lower abdomen. No patients required reoperation, and there were no cases of gas embolism, major complication, or perioperative death.

Table 6 Histopathological data

Parameter	Group-S ($n = 20$)	Group-SP ($n = 56$)	P	Total ($n = 76$)
Tumor-free margin [n (%)]	20 (100)	56 (100)	NS	76 (100)
Minimum distance from resection line to tumor tissue (mm) (range)	4 (1–25)	5 (1–30)	NS	4 (1–30)
Weight of resected specimen (g) (range)	142 (7–800)	201 (9–890)	NS	171 (7–890)

Group-S supine patients, *Group-SP* semiprone patients, *NS* not significant

The results of pathological examinations of the surgical specimens are given in Table 6. There were no significant differences between the two groups in tumor-free margin, minimum distance from resection line to tumor tissue, or weight of resected specimens.

Discussion

Laparoscopic liver resection in the semiprone position has a number of advantages over that in the supine position. First, Rouviere's sulcus [16, 17], a fissure on the liver to the right of the hilum, is easily visualized immediately after insertion of the laparoscope. This sulcus is open in 78 % of patients and is recognizable in more than 90 % [18]. The liver stays in position because it is attached to the coronary and right triangular ligaments, but other organs such as the transverse colon and small intestine fall to the lower left. The right hepatic hilum is therefore easily exposed by lifting the edge of the liver or gallbladder. The portal pedicles of the anterior and posterior segments and the segmental pedicles of S6 and S7 can easily be ligated for selective occlusion of the blood supply prior to parenchymal transection.

Second, an intercostal port can be used effectively in the semiprone position. When parenchymal transection is performed using only subcostal ports, transection can be performed from only one direction because the forceps cannot reach the portions of the posterosuperior and anterosuperior segments located adjacent to the diaphragm (Fig. 3). Although it is possible to visualize these areas using a flexible scope or a 30° or 45° laparoscope, it is nearly impossible to operate in this area using only subcostal ports. Partial resection of a posterosuperior or anterosuperior tumor is therefore more difficult than hemihepatectomy or sectionectomy. Right hemihepatectomy involves a relatively small dissection plane and can be performed by approaching the liver from the inferior side at the hepatic hilum, from the front of the IVC. An intercostal port gives access to the abdominal cavity from the seventh intercostal space in the anterior axillary line, passing through the thorax and the diaphragm. This port can be used by the right hand of the operator, allowing the surgeon to approach the liver from both the inferior and the superior aspect to perform partial resection or segmentectomy of S7 and S8. Gayet and co-author [19] used an intercostal port to retract the hepatic veins from a lateral approach. However, as the port was on the left side and the patient was in the supine position, this port could not be used for parenchymal division. The technique they described is clearly different to our procedure [20].

Third, the weight of the liver helps to mobilize it. When the coronary and right triangular ligaments are transected, the right lobe naturally falls to the left, leaving a space under the right side of the diaphragm. This is one of the reasons that an intercostal port can be used and enables division of the blood vessels around the IVC without elevation of the liver by an assistant.

Fourth, the irrigation fluids and blood flow to the lower left side of the abdominal cavity and do not interfere with visualization of the operative field [14, 15].

There was less intraoperative bleeding in the semiprone group than in the supine group for several reasons. The semiprone position enables selective vascular occlusion before parenchymal transection, and the posterior segment is positioned higher than the IVC. We also used an innovative device that had a channel for dripping saline at the tip of a surgical instrument. This device can be attached to various endoscopic bipolar scissors or forceps, including bipolar forceps that can be precisely controlled such as the BiClamp, BiCision, and LigaSure. This equipment is used by some liver surgeons for careful hepatectomy via laparotomy, such as harvesting of a living-donor transplant [21, 22]. However, use of this device in laparoscopic surgery has not been well developed. The saline-dripping channel contains compressed saline or is attached to an infusion pump, and the flow rate can be adjusted from a slow drip to a water jet. Saline dripping prevents adhesion of tissues to the cautery blades by reducing the contact between the electrodes and the tissues, and it washes the blood away. This enables fine parenchymal dissection and careful identification and exposure of the portal pedicles. ENSEAL® (Ethicon Endo-Surgery, Cincinnati, OH) is another modern bipolar device that can coagulate tissues by contact with only one of the jaws [23–25]. This jaw can be used to thinly scoop a portion of hepatic parenchyma before picking up the scooped parenchyma with both jaws and then coagulating and cutting it.

The most common indication for laparoscopic liver resection is HCC in patients with underlying liver disease [7]. Resection of metastatic liver cancer is performed with increasing frequency, but many patients with metastatic cancer have liver damage due to previous chemotherapy [26]. If a sufficient surgical margin can be achieved, partial segmental resection is preferable to segmental resection, and segmental resection is preferable to lobectomy.

The use of innovative techniques and devices enables selective hepatic vascular occlusion and parenchymal division in the semiprone position. This allows us to perform partial resection and anatomical resection of the posterosuperior segments of the right liver with minimal bleeding and ischemic injury.

The semiprone position has some inherent disadvantages. When the laparoscope is initially introduced into the abdominal cavity, the positions and relationships of structures are unfamiliar. Rotation of the camera can help to achieve a more familiar orientation. It is important for surgeons learning this technique to familiarize themselves with the visual field and the locations of organs in this position. For tumors of the hepatic dome, resection is performed from the lower aspect to the upper aspect, even when using an intercostal port. Even if the operator is right-handed, parenchymal dissection should be performed mainly using the left hand while supporting the portion of the liver containing the tumor using the right hand.

We experienced one case of the tracheal tube becoming dislodged. Fortunately, this did not have serious consequences because the anesthesiologist responded immediately. Care must be taken to avoid blindness due to prolonged pressure on the eye, as has been reported in patients who underwent esophagectomy in the prone position.

Three surgeons are now performing hepatectomy in the semiprone position at our institution, and the indications for pure laparoscopic hepatectomy have expanded rapidly since the introduction of this technique. The technique is also being used at a number of other institutions in Japan. We believe that use of this technique has resulted in expansion of the indications for laparoscopic resection of tumors in the anterosuperior and posterior segments and has improved outcomes, irrespective of number of surgical experience of surgeon.

In conclusion, introduction of the semiprone position allowed us to perform laparoscopic liver resection in patients with tumors of the anterosuperior and posterior segments, without increasing the proportion of patients undergoing major hepatectomy. This method is safe and minimally invasive and can reduce intraoperative bleeding and shorten the postoperative hospital stay compared with resection in the supine position.

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Revisiting the Safety of Living Liver Donors by Reassessing 441 Donor Hepatectomies: Is a Larger Hepatectomy Complication-Prone?

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Donor safety is of paramount importance in performing living donor liver transplantation (LDLT). We retrospectively reviewed donor medical records to confirm whether larger donor hepatectomy is absolutely complication-prone. A total of 441 living donor hepatectomies were performed between October 1996 and July 2012 in our institute, which were divided into three eras (Era I, October 1996 to March 2004; Era II, April 2004 to March 2008; Era III, April 2008 to July 2012) and the incidences of postoperative complications were compared among the three types of hepatectomy—right hepatectomy (RH), left hepatectomy (LH) and left lateral segmentectomy (LLS). Although severe complications (Clavien's grade 3 or more) frequently occurred in RH in Eras I and II (15.4% and 10.7%, respectively), the incidence in Era III decreased to the comparable level observed in LH and LLS (5.4% in RH, 2.3% in LH and 5.3% in LLS). The incidence of postoperative complications did not relate to the type of hepatectomy selected in the latest era. Since most complications after hepatectomy were considered preventable, step-by-step meticulous surgical procedures are a prerequisite for further assuring donor safety irrespective of the type of hepatectomy selected.

Keywords: Clinical liver transplantation, donor risk, hepatic resection, living donor transplantation, postoperative complication

Abbreviations: LDLT, living donor liver transplantation; LH, left hepatectomy; LLS, left lateral segmentectomy; PT-INR, prothrombin time-international normalized ratio; RH, right hepatectomy; TB, total bilirubin

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Introduction

Since the initial cases of living donor liver transplantation (LDLT) were performed (1,2), more than 20 years have already passed and LDLT has become one of the standard therapeutic modalities for patients with end stage liver disease (3–6) as well as hepatocellular carcinoma (7–9). The safety of living liver donors is of paramount importance and this issue has been aggressively discussed so far (10–16). Although the liver has a capacity to regenerate, it is generally believed that the larger the resected liver parenchyma is, the more frequently postoperative complications will occur (13,14,17,18). We implemented the LDLT program in 1996 and have performed more than 400 LDLTs so far. In our experience, as observed in other transplantation centers, the incidence of postoperative complications after right hepatic donation was higher than that of left-sided hepatic donation (13,18). That is, a larger hepatectomy was considered complication-prone. Moreover, the recipient survival after left hepatic grafting was comparable to that after right hepatic grafting (13,18). We had strongly advocated the use of left-sided hepatic grafts for the sake of donor safety. Perioperative managements and operative procedures of living liver donors seemed to be established with cumulative experience. In this paper, we revisited the safety of living liver donors from the experience of more than 400 LDLTs focusing on postoperative complications after donor hepatectomy.

Methods

The medical records of 441 living liver donors who underwent a donor hepatectomy in our institute between October 1996 and July 2012 were retrospectively reviewed. All LDLTs were performed after obtaining approval from the Ethics and Indications Committee for LDLT. The donors were divided into the following three eras mainly according to Japanese year terms which begins on April 1: Era I, between October 1996 and March 2004; Era II, between April 2004 and March 2008; Era III, between April 2008 and July 2012. Donors who underwent a posterior sectionectomy were excluded from the study because of the small number (n = 6). All the donors were followed for at least 1 year. The incidences of postoperative complications, intraoperative blood losses of the three types of hepatectomy—right hepatectomy (RH), left hepatectomy (LH) and left lateral segmentectomy (LLS)—were compared in each era. The levels of total bilirubin (TB) and prothrombin time-international normalized ratio (PT-INR), the lengths of postoperative hospital stays were compared among the three types of

hepatectomy in Era III. Postoperative complications were graded according to the Clavien's classification (19).

Psychiatric complications, such as delirium, depression or alopecia areata, were not discussed in the current study because of the difficulty in grading these complications. All superficial wound problems, such as wound dehiscence, wound infection or keloid, were regarded as grade I, even though some donors with such problems underwent repair surgery under local anesthesia later. Transient hyperbilirubinemia and prolongation of prothrombin time were not considered morbidity. Bile leaks were graded according to the international study group of liver surgery (20).

The hepatectomy procedures and perioperative managements were the same ways as previously described (12,13,21). Our strict criterion for performing donor RH was that preoperative volumetric analyses confirmed the remnant liver volume was estimated to be no less than 35% of the total liver volume. Donors had to have normal transaminase levels in preoperative evaluations. Candidate donors whose transaminases were beyond the normal ranges were rejected. Most of these abnormalities were caused by steatosis of the liver. We offered the rejected candidate donors a diet program in order to normalize transaminase levels.

Prevention of venous thromboembolism was provided through the use of intermittent pneumatic compression and compression stockings and through encouraging early ambulation.

NCSS 2007 software (22) was used for statistical analyses. Proportions were compared using chi-square test, while numerical measures were compared by one-way analysis of variance (ANOVA) or t-test. A p-value of less than 0.05 was considered to be statistically significant.

Results

Postoperative complications of the three types of hepatectomy in each era

Postoperative complications frequently occurred after RH in Eras I and II (Figure 1). However, the incidence dramatically dropped in Era III. The incidences of postoperative complications in Era III were comparable among the three types of hepatectomy. We did not encounter any Clavien's grade IV or V complications throughout our entire experience. When we defined Clavien's grade III or more as a severe morbidity, the incidence of postoperative severe morbidity after RH gradually decreased (15.4% in Era I, 10.7% in Era II, 5.4% in Era III). The details of postoperative complications are summarized in Table 1. Clavien's grade III complications consisted mainly of bile leak and biliary stricture. Complications related to upper gastrointestinal tract, such as gastric stasis and duodenal ulcer were frequently observed after LH, while pleural cavity-related complications, such as pneumothorax and pleural effusion, occurred only after RH.

Biliary complications and treatments

Biliary complications and treatments are summarized in Table 2. A total of 19 donors suffered a biliary complication. There were 16 bile leaks and 3 biliary strictures. Grade A bile leaks were treated only by postponing drain removal. Grade B bile leaks needed percutaneous drainage. Grade C bile leaks were treated by surgical repair under general anesthesia. There were three biliary strictures in the current study. The incidence dramatically decreased in Era III.

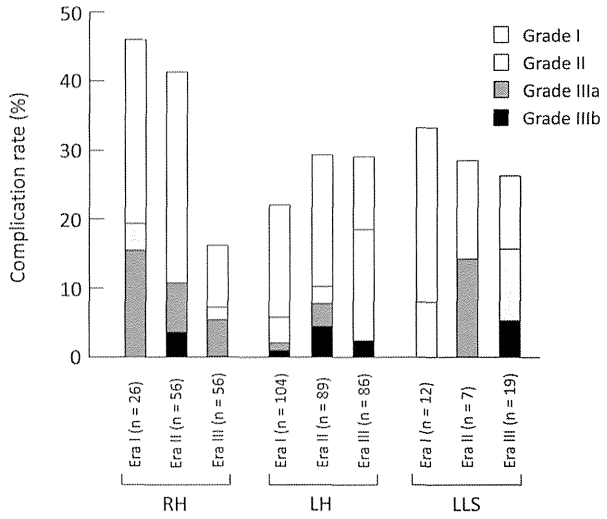

Figure 1: The incidences of postoperative complications of each era in each graft type. Postoperative complications were graded according to Clavien's classification system. When a donor had two or more complications, only the complication with the highest grade was counted. LH, left hepatectomy; LLS, left lateral segmentectomy; RH, right hepatectomy.

Intraoperative blood losses of the three types of hepatectomy in each era

As shown in Figure 2, the intraoperative blood losses had decreased with the cumulative experience. The decrease in Era III was notable. The decrease was mainly attributed to the use of intermittent Pringle maneuver during liver transection as previously reported (12,23).

Kinetics of total bilirubin and prothrombin time-international normalized ratio after three types of hepatectomy

There were transient increases of TB after RH compared to LH and LLS (at days 3, 5 and 7; $p < 0.001$) (Figure 3). The peak level was observed at postoperative day 3. The levels of TB gradually decreased and returned to normal until 1 month after operation.

The increases of PT-INR were observed not only after RH, but also after LH and LLS. The levels of PT-INR at days 1, 3, 5 after RH were significantly higher than those after LH or LLS at each time point ($p < 0.001$; Figure 4). The levels of PT-INR after LH were comparable to those after LLS throughout the observed period.

Comparisons among the three types of hepatectomy in Era III

The donor characteristics and operative results were compared in the latest era (Era III). The data are summarized

Table 1: Details of postoperative complications of each type of hepatectomy in each era

		RH			LH			LLS		
Grade	Complication	Era I (n = 26)	Era II (n = 56)	Era III (n = 56)	Era I (n = 104)	Era II (n = 89)	Era III (n = 86)	Era I (n = 12)	Era II (n = 7)	Era III (n = 19)
I	Superficial wound problem	4 (15.4)	15 (26.8)	4 (7.1)	17 (16.3)	14 (15.7)	9 (10.5)	2 (16.7)	–	2 (10.5)
	Bile leak—grade A[1]	3 (11.5)	1 (1.8)	–	–	1 (1.1)	–	1 (8.3)	–	–
	Pleural effusion	1 (3.8)	–	–	–	–	–	–	–	–
	Edema	–	–	–	–	1 (1.1)	–	–	–	–
	Refractory abdominal pain	–	–	–	–	–	–	–	1 (14.3)	–
	Intra-abdominal abscess	–	–	–	–	–	–	–	–	1 (5.3)
	Hoarseness	–	1 (1.8)	1 (1.8)	1 (1.0)	1 (1.1)	1 (1.2)	–	–	–
	Numbness in the upper extremities	1 (3.8)	–	–	1 (1.0)	2 (2.2)	1 (1.2)	–	–	–
II	Intra-abdominal abscess	1 (3.8)	–	–	–	–	–	–	–	1 (5.3)
	Duodenal ulcer	–	–	–	2 (1.9)	1 (1.1)	2 (2.3)	–	–	–
	Gastric stasis[2]	–	–	–	1 (1)	1 (1.1)	11 (12.8)	1 (8.3)	–	1 (5.3)
	Ileus	–	–	–	1 (1)	–	1 (1.2)	–	–	–
	Gastroenteritis	–	–	1 (1.8)	–	–	–	–	–	–
IIIa	Pleural effusion requiring thoracentesis	1 (3.8)	–	1 (1.8)	–	–	–	–	–	–
	Bile leak—grade B[1]	2 (7.7)	–	–	1 (1.0)	3 (3.4)	–	–	1 (14.3)	–
	Biliary stricture requiring percutaneous transhepatic cholangioplasty	1 (3.8)	–	–	–	–	–	–	–	–
	Pneumothorax	–	2 (7.7)	1 (1.8)	–	–	–	–	–	–
	Iatrogenic hydrothorax	–	1 (3.8)	–	–	–	–	–	–	–
	Intra-abdominal abscess	–	1 (3.8)	1 (1.8)	–	–	–	–	–	–
IIIb	Biliary stricture requiring surgical repair	–	–	–	1 (1.0)	–	–	–	–	–
	Biliary stricture requiring endoscopic stenting under general anesthesia	–	1 (1.8)	–	–	–	–	–	–	–
	Abdominal incisional hernia	–	1 (1.8)	–	–	2 (2.2)	1 (1.2)	–	–	–
	Intra-abdominal bleeding requiring relaparotomy	–	–	–	–	1 (1.1)		–	–	–
	Bile leak—grade C[1]	–	–	–	–	1 (1.1)	1 (1.2)	–	–	–
	Refractory abdominal pain requiring adhesiolysis	–	–	–	–	–	–	–	–	1 (5.3)

Complications were graded according to the Clavien classification (19). Some donors had two or more complications.
Figures before the parentheses are the number of donors in each complication. Figures in the parentheses are the incidence of each complication expressed as percentage in each graft type in each era.
LH, left hepatectomy; LLS, left lateral segmentectomy; RH, right hepatectomy.
[1]Bile leaks are graded according to the International Study Group of Liver Surgery (20).
[2]Gastric stasis is caused by narrowing of the gastric outlet resulted from upward distortion of the stomach into a dead space created by LH.

Table 2: Summary of biliary complications and treatments

Era	Type of hepatectomy	Type of complication	Treatment
I	RH	Bile leak—grade A	Postponement of drain removal
		Bile leak—grade A	Postponement of drain removal
		Bile leak—grade A	Postponement of drain removal
		Bile leak—grade B	Percutaneous drainage
		Bile leak—grade B	Percutaneous drainage
		Biliary stricture	Percutaneous transhepatic cholangioplasty
	LH	Bile leak—grade B	Percutaneous drainage
		Biliary stricture	Surgical repair
	LLS	Bile leak—grade A	Postponement of drain removal
II	RH	Bile leak—grade A	Postponement of drain removal
		Biliary stricture	Endoscopic stenting
	LH	Bile leak—grade A	Postponement of drain removal
		Bile leak—grade B	Percutaneous drainage
		Bile leak—grade B	Percutaneous drainage
		Bile leak—grade B	Percutaneous drainage
		Bile leak—grade C	Surgical repair
	LLS	Bile leak—grade A	Postponement of drain removal
		Bile leak—grade B	Percutaneous drainage
III	LH	Bile leak—grade C	Surgical repair

Bile leaks are graded according to the International Study Group of Liver Surgery (20).
LH, left hepatectomy; LLS, left lateral segmentectomy; RH, right hepatectomy.

in Table 3. The mean age of donors who underwent LLS was the youngest among the three types of hepatectomy. Most of the LLS donors were the father or the mother of a small recipient. Donors who underwent LH were male-dominant. LH resulted in the most increased blood loss among the three types of hepatectomy. The mean blood loss in Era III was 390 mL. We evaluated the risk factors for blood loss of more than 400 mL regarding all 161 donors of Era III, which revealed that "male donor" was a statistically significant risk factor for blood loss of more than 400 mL (χ^2 8.29, $p < 0.01$) while "LH" was not (χ^2 1.44, $p = 0.23$).

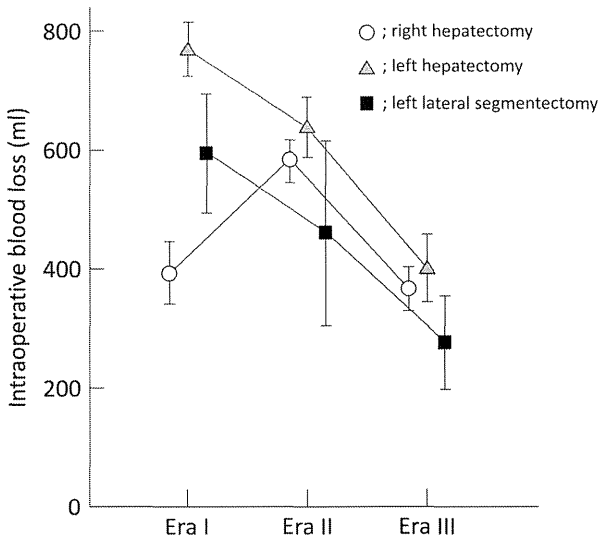

Figure 2: Intraoperative blood losses of each graft type in each era.

There were no statistical differences among the three types of hepatectomy with regard to operation times. The mean lengths of postoperative hospital stays of the three types of hepatectomy were almost equal. Furthermore, there were no statistically significant differences in the incidences of postoperative complications among the three types of hepatectomy. There was no relationship between the postoperative complications and the intraoperative blood losses.

Discussion

The current study clearly showed that the incidence of postoperative complications after RH had decreased to the same level as observed in LH and LLS donors in the latest era probably because of cumulative experiences of surgical procedures and perioperative managements. Although the blood tests showed the burden of losing large liver parenchyma in RH was larger compared to LH or LLS as shown in Figures 3 and 4, the test results rapidly returned to the normal levels. Now that RH has become a safe procedure with regard to the incidence of postoperative complications, a smaller hepatectomy (LH and LLS) should not be considered safer in living liver donation. In reviewing the medical records, most complications were preventable by step-by-step meticulous surgical procedures.

"Gastric stasis" occurs when the stomach is distorted into the dead space created by LH. Donors with gastric stasis complain of abdominal discomfort and abdominal fullness caused by partial obstruction of the gastric outlet. For ulcer prevention, lansoprazole or omeprazole was routinely used during perioperative periods. These drugs were

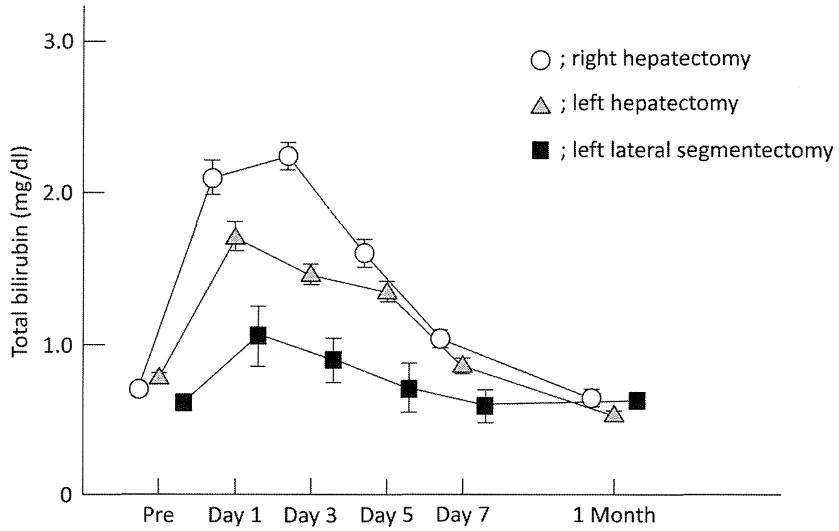

Figure 3: Kinetics of total bilirubin after the three types of hepatectomy. Pre, preoperation.

administered to the donors approximately for 1 month after operation. The five donors suffered from duodenal ulcers after cessation of these drugs. The exact reason why duodenal ulcers occur predominantly after LH has not yet been elucidated. One presumed reason is that after LH the stomach is distorted upward and attached to the raw cutting surface of the liver, which impairs blood circulation around the pylorus causing the development of duodenal ulcer. Hepatobiliary surgeons occasionally encounter such phenomena after LH for a malignant hepatic tumor as well. We applied Seprafilm™ (Kaken Pharmaceutical Co., Ltd., Tokyo, Japan) over the stomach in order to prevent the adhesions. In addition, the dead spaces were filled with the greater omentum in order to prevent the distortion of the stomach. However, these means have not yet proven to be effective. If we can lessen the incidence of these complications, the safety of living donors will further increase.

Pleural cavity-related complications such as pneumothorax and pleural effusion occurred only after RH, probably resulting from rotating the right lobe by dissecting the right triangular and coronary ligament. Pleural effusion might have resulted from deprivation of large hepatic parenchyma after RH.

Severe complications (Clavien's grade III) consisted mainly of biliary stricture and bile leak. Three donors suffered biliary stricture in the current study. One donor required reoperation to release the stricture caused by excessive suturing near the right hepatic duct after LH. One biliary stricture was treated only by percutaneous transhepatic cholangioplasty. One donor required repeat endoscopic cholangioplasty under general anesthesia. The biliary stricture of this donor was considered to be caused by excessive skeletonization of the bile duct during the hepatic artery isolation, leading to biliary ischemia. Biliary stricture caused

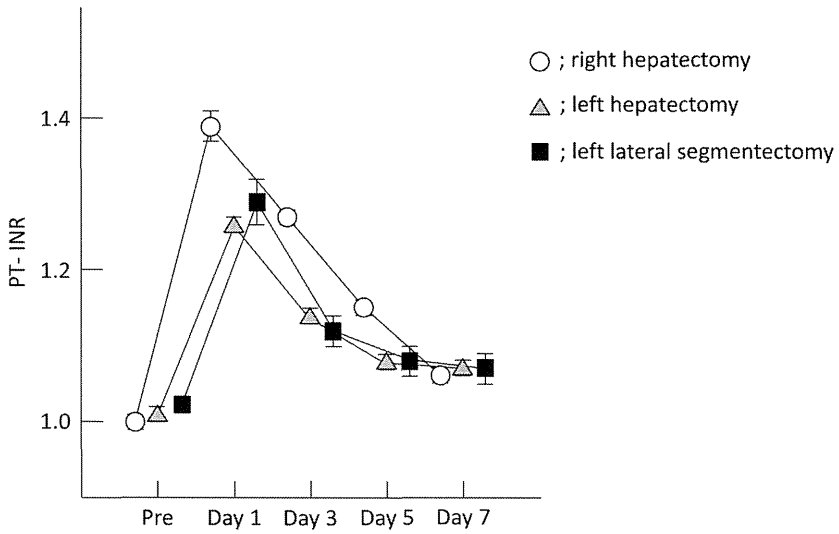

Figure 4: Kinetics of prothrombin time-international normalized ratio (PT-INR) after the three types of hepatectomy. Pre, preoperation.

Table 3: Donor characteristics and surgical results of the three types of hepatectomy in Era III

	Type of hepatectomy		
Factors	RH	LH	LLS
Number	56	86	19
Male/female	24/32[1]	62/24[1]	7/12[1]
Age	38.4 ± 1.4	36.2 ± 1.1	31.7 ± 2.4
Estimated remnant liver volume (%)	39.3 ± 0.6[2]	62.7 ± 0.5[2]	75.4 ± 1.0[2]
Intraoperative blood loss (mL)	366 ± 32[2]	431 ± 26[2]	276 ± 54[2]
Operation time (min)	413 ± 11	421 ± 9	347 ± 19
Postoperative hospital stay (day)	12.7 ± 0.5	12.5 ± 0.5	12.6 ± 0.9
Complication rate (%)[3]			
Grade I	8.9	10.5	10.5
Grade II	1.8	16.3	10.5
Grade IIIa	5.4	0	0
Grade IIIb	0	2.3	5.3
Total	16.1	29.1	26.3

LH, left hepatectomy; LLS, left lateral segmentectomy; RH, right hepatectomy.
Values are expressed as a mean ± SEM.
[1]Statistically significant by chi-square test ($p < 0.001$).
[2]Statistically significant by one-way ANOVA ($p < 0.001$).
[3]Complication was graded according to Clavien's classification (19). When a donor had two or more complications, only the complication with the highest grade was recorded.

by ischemia is considered refractory and may lead to secondary cholestatic liver disease. Extensive skeletonization of the common hepatic or bile duct should be avoided in order to prevent devastating biliary complications (12). We introduced real-time cholangiography using a C-arm in dividing the right or left hepatic duct in the middle of Era II (12). Real-time cholangiography had enabled surgeons to keep the remnant biliary system intact by cutting the hepatic duct under direct vision, which resulted in no biliary stricture in Era III. Meticulous closure of small Glisson branches during transection of liver parenchyma is a prerequisite for preventing bile leakage. Also, excessive use of electrocautery around bile ducts on the cutting surface in an attempt to stop bleeding should be avoided. In order to prevent exposure of relatively large intrahepatic bile ducts on the cutting surface, which may increase the possibility of major bile leaks, it is far more important to transect the liver along the precise border between the left and right hemilivers.

Several surgeons documented the accepted lower safety margin of donor remnant liver volume might be 30% of the total liver volume in LDLT (24–27). Transplant surgeons have to set strict limitation for the safety margin of remnant liver volumes. Otherwise, a tragedy caused by an extremely small remnant liver would occur. As shown in Figures 3 and 4, metabolic and productive burdens of remnant livers proved by blood tests after RH were large compared to those after LH or LLS, even though we set the limit on remnant liver volume at 35%. There have been devastating consequences after living liver donation around the world, most of which occurred after right hepatic donation (28–32). Enthusiasm for the use of extensive RH grafts has been recently dampened in many transplant centers since those devastating reports were published. When a small remnant liver cannot sustain metabolic or productive demand of the body, the consequence will be donor mortality. Nobody can exactly know how much remnant liver is absolutely safe. However, setting the limit of remnant liver volume at 35% of the total liver volume is absolutely safer than setting the limit at 30%. Furthermore, our policy in performing RH is that an RH graft does not include the middle hepatic vein. Losing the middle hepatic vein from the remnant liver will result in congestion of the segment IV, which may further worsen the function of the remnant liver and increase the possibility of donor mortality. Although there is concern about blood congestion of the anterior sector of RH grafts without the middle hepatic vein after reperfusion in recipients, technical advancements have enabled surgeons to safely reconstruct the drainage veins of the anterior sector in such grafts (33,34). The major drawback of setting the limitation at 35% is the fact that the more the limitation is raised, the more candidate donors are rejected. In fact, approximately one of every 10 candidate donors for RH was rejected in our institute because his/her preoperative volumetric analysis revealed the remnant liver volume was less than 35% of the total liver volume. Volumetric analyses were done by students in our graduate school who were given only minimum clinical information (35,36). Even a candidate donor whose estimated remnant volume was 34.9% was rejected. Although our strict criterion for donor RH may result in death of a candidate recipient who eventually cannot undergo LDLT, the safety of healthy living liver donors is the top priority in our LDLT program.

The donors were allowed to leave the hospital when they felt confident about living their homes themselves. Their decisions for discharge were completely voluntary. The

lengths of postoperative hospital stays were comparable among the three types of hepatectomy in Era III, which indicated that systemic recovery was almost equal among the three types of hepatectomy.

Confirmation of true safety of living liver donors needs long-term evaluation. Living liver donation is one of the major abdominal operations and considerable adhesions and large operation scars in the upper abdomen are inevitable. Donors may suffer a malignant disease in the stomach, in the biliary tree, or in the liver itself in the future. Undergoing donor operation may decrease curability of such future diseases. Adhesions in the abdomen may increase the incidence of miscarriage among young female donors. Large operation scars may impair activity of daily life. These long-term impacts of living liver donation have yet to be elucidated. Personnel who participate in LDLT programs have to take responsibility for following living donors long after liver donation in order to confirm the true safety.

The management styles for living liver donors have not changed since the implementation of our LDLT program. However, there was a considerable replacement of staff surgeons at the beginning of Era II, which might have related to the ironical increase of donor complications in LH in Era II. However, the most important result in this paper is that the incidence of postoperative complications after RH had steadily decreased with the cumulative experience. Although the replacement of surgical staffs might have led to the increase of complications in LH, the complication rates in RH had decreased nonetheless. At least two donor surgeons who had sufficient experience in hepatectomy attend donor operations in our department because surgical skills in donor operations critically affect the incidence of surgical complications after donor hepatectomy. The most important thing is that staff surgeons for donor operations have to hand down their surgical skills to younger surgeons. Trainees for living donor hepatectomy, who have already had the experience of sufficient hepatobiliary surgeries, first attend donor operations as the second assistant. Then, they become the first assistant with the aid of an experienced second assistant. Finally, they become an operator with the aid of experienced first and second assistants.

In conclusion, the incidence of postoperative complications after donor RH was comparable to those after donor LH and LLS in the latest series. We believed that this was probably because of our strict criterion for RH in which a donor hepatectomy was performed only when the estimated remnant liver volume is no less than 35% of the total liver volume. Although the safety of RH was confirmed by the current study, we will continue to advocate the use of LH grafts whenever possible for the sake of donor safety. Meticulous surgical procedures are needed in order to decrease donor morbidity, because most of the complications we encountered were not related to the small volume of a remnant liver but to the step-by-step surgical procedures.

Disclosure

The authors of this manuscript have no conflicts of interest to disclose as described by the *American Journal of Transplantation*.

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Clinical Transplantation

Evaluation of graft stiffness using acoustic radiation force impulse imaging after living donor liver transplantation

Ijichi H, Shirabe K, Matsumoto Y, Yoshizumi T, Ikegami T, Kayashima H, Morita K, Toshima T, Mano Y, Maehara Y. Evaluation of graft stiffness using acoustic radiation force impulse imaging after living donor liver transplantation.

Abstract: Acoustic radiation force impulse (ARFI) imaging is an ultrasound-based modality to evaluate tissue stiffness using short-duration acoustic pulses in the region of interest. Virtual touch tissue quantification (VTTQ), which is an implementation of ARFI, allows quantitative assessment of tissue stiffness. Twenty recipients who underwent living donor liver transplantation (LDLT) for chronic liver diseases were enrolled. Graft types included left lobes with the middle hepatic vein and caudate lobes (n = 11), right lobes (n = 7), and right posterior segments (n = 2). They underwent measurement of graft VTTQ during the early post-LDLT period. The VTTQ value level rose after LDLT, reaching a maximum level on postoperative day 4. There were no significant differences in the VTTQ values between the left and right lobe graft types. Significant correlations were observed between the postoperative maximum value of VTTQ and graft volume-to-recipient standard liver volume ratio, portal venous flow to graft volume ratio, and post-LDLT portal venous pressure. The postoperative maximum serum alanine aminotransferase level and ascites fluid production were also significantly correlated with VTTQ. ARFI may be a useful diagnostic tool for the noninvasive and quantitative evaluation of the severity of graft dysfunction after LDLT.

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Key words: acoustic radiation force impulse – graft function – graft stiffness – living donor liver transplantation

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Living donor liver transplantation (LDLT) has emerged as a critical surgical option for patients with end-stage liver disease of various etiologies (1). However, problems related to graft size have been found, and small-for-size (SFS) syndrome remains a major complication after adult-to-adult LDLT (2). Previous reports have demonstrated that SFS syndrome can lead to severe graft dysfunction and decrease recipient survival rates after transplantation (3, 4). The use of SFS grafts (graft-to-recipient weight ratio [GRWR] of <0.8–1.0% or graft volume-to-recipient standard liver volume [GV/SLV] ratio of <30–40%) has been a risk factor for SFS syndrome (5). Moreover, multiple factors related to both donors and recipients influence the occurrence of this syndrome (6). The mechanisms of SFS syndrome have been investigated, and it has been found that increased portal venous flow (PVF) and hypertension are the important etiologic factors leading to the development of SFS syndrome (7, 8). Shear stress caused by transient portal hypertension is thought to induce damage to sinusoidal endothelial cells, which leads to the subsequent process of hepatocyte injury (9).

Acoustic radiation force impulse (ARFI) imaging is a new ultrasound-based modality to evaluate tissue stiffness using short-duration acoustic pulses in the region of interest selected on a conventional B-mode image (10). An acoustic push pulse transmitted by the transducer toward the tissue produces shear waves that propagate into the tissue. Virtual touch tissue quantification (VTTQ) measures the velocity of the shear wave propagation, which allows quantitative assessment of tissue stiffness. VTTQ is the first available implementation of ARFI (11). ARFI has been applied to determine the elasticity of various tissues such as liver,