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A hybrid method of laparoscopic-assisted open liver resection through a short upper midline laparotomy can be applied for all types of hepatectomies

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Abstract
Background Although hepatectomy procedures should be designed to provide both curability and safety, minimal invasiveness also should be pursued.
Methods We analyzed the data related to our method for laparoscopy-assisted open resections (hybrid method) through a short upper midline incision for various types of hepatectomies. Of 215 hepatectomies performed at Nagasaki University Hospital between November 2009 and June 2012, 102 hepatectomies were performed using hybrid methods.
Results A hybrid method was applicable for right trisectionectomy in 1, right hemihepatectomy in 32, left hemihepatectomy in 29, right posterior sectionectomy in 7, right anterior sectionectomy in 1, left lateral sectionectomy in 2, and segmentectomy in 7 patients, and for a minor liver resection in 35 patients (12 combined resections). The median duration of surgery was 366.5 min (range 149–709) min, and the median duration of the laparoscopic procedure was 32 min (range 18–77) min. The median blood loss was 645 g (range 50–5,370) g. Twelve patients (12 %) developed postoperative complications, including bile leakage in three patients, wound infections in two patients, ileus in two patients, and portal venous thrombus, persistent hyperbilirubinemia, incisional hernia, local liver infarction each in one patient. There were no perioperative deaths.
Conclusions Our method of hybrid hepatectomy through a short upper midline incision is considered to be applicable for all types of hepatectomy and is a reasonable approach with no abdominal muscle disruption, which provides safe management of the hepatic vein and parenchymal resection even for patients with bilobular disease.

Keywords Hepatectomy · Minimally invasive liver resection · Hybrid method · Living-donor hepatectomy · Midline incision

Liver resection is one of the most challenging fields of minimally invasive surgery. In 2007, Koffron et al. [1] reported 300 minimally invasive liver resections (MILR) for hepatic lesions. In their report, they employed three different methods of liver resection: pure laparoscopic liver resection, hand-assisted laparoscopic resection, and laparoscopy-assisted open resection (hybrid) as the MILR. Compared with open hepatic resection, all of their MILR procedures were less invasive and were associated with a shorter operation time, lower blood loss, and shorter hospital stay, with the same rates of local recurrence and complications.

In a worldwide review of laparoscopic liver resection performed in 2009, pure laparoscopic resections were performed in 75 % of cases, hand-assisted laparoscopic resections in 17 %, and a hybrid procedure was done in only 2 % of cases [2]. However, according to the review, the resected area of the liver was a wedge resection in 45 % and left lateral section in 20 %, revealing that only 23 % of procedures were performed for anatomical resections larger than a sectionectomy.

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We have employed hybrid liver resection with hand-assisted laparoscopic liver mobilization and subsequent liver resection with the hanging maneuver [3] and a two-surgeon technique through a short upper midline incision. Our initial data on hybrid liver resection were herein analyzed to clarify the parameters related to their use for various types of hepatectomies.

Patients and methods

Of 215 hepatectomies performed between November 2009 and May 2013 at Nagasaki University Hospital, we employed laparoscopy-assisted open resections (hybrid method) for 102 patients (47 %).

The contraindications for the hybrid procedure were as follows: (1) cases with a previous history of upper abdominal laparotomy; (2) tumor involvement of the diaphragm or a tumor large enough to require an anterior liver resection; and (3) cases with portal or hepatic venous tumor thrombus. The resections for small tumors located in the anterocaudal side of the liver and left lateral sectionectomy were performed under pure laparoscopic liver resection. As a standardized anatomical resection of the normal liver, we chose living-donor left hemihepatectomy for comparison of the surgical outcomes of the hybrid technique and the open procedure.

Among the analyzed patients who underwent hybrid resection, the median age (62 males, 40 females) was 59 years (range 21–85) years (Table 1). The patients' median height was 161 cm (range 145–181) cm, and the median weight was 60 kg (range 37–88) kg. The body mass index (BMI) was 22.8 (range 16.5–31.6).

Table 1 Patient characteristics

Age (years)	59 (range, 21–85)
Sex (M:F)	62:40
Height (cm)	161 (145–181)
Weight (kg)	60 (37–88)
BMI	22.8 (16.5–31.6)
Indications	Number
Hepatocellular carcinoma	32
Metastatic liver tumor	14
Hilar cholangioma	3
Intrahepatic cholangioma	5
Epithelial hemangioendothelioma	1
Hepatic carcinoid	1
Cystoadenoma	1
Caroli's disease	1
Living donor	44

All but one patient had Child-Pugh grade A status; one patient was considered to have Child-Pugh grade B disease. The liver functional reserves were as follows: the indocyanine retention rate at 15 min (ICGR15) had a median of 11 % (range 1–30 %), and the median 99mTc-GSA scintigraphy receptor index [ratio of the liver to heart-plus-liver radioactivity at 15 min (LHL15)] was 0.922 (range 0.826–0.975). The liver functional reserve evaluations, including the ICG retention test and 99mTc-GSA scintigraphy, were not performed for living liver donors.

The primary reasons for the operations were hepatocellular carcinoma in 32, metastatic liver cancer in 14, hilar cholangiocarcinoma in 3, intrahepatic cholangiocellular carcinoma in 5, hepatic epithelial hemangioendothelioma in 1, hepatic carcinoid in 1, cystadenoma in 1, Caroli's disease in 1, and living liver donor in 44 (Table 1). The surgical methods employed were a right trisectionectomy in 1, right hemihepatectomy in 32, left hemihepatectomy in 29, right posterior sectionectomy in 7, left-lateral sectionectomy in 2, and segmentectomy (S5, 6, 7) in 7 patients, and a minor liver resection was performed in 35 patients (combined in 12; Table 2). We evaluated surgical outcomes in the patients who underwent the hybrid procedure. We also compared the surgical outcomes of the hybrid procedure and open procedure for living-donor hemihepatectomy.

The Mann–Whitney U test was applied to compare the groups. $P < 0.05$ was considered to be statistically significant.

Surgical techniques

Patients were placed in the supine position with their arms adducted, and a urinary catheter and arterial and central venous lines were inserted. An 8-cm upper midline laparotomy was made, followed by a 5-mm umbilical incision for the laparoscope. The round, falciform, and coronary ligaments were divided, and a wound retractor was installed. Before starting the laparoscopic procedure, a surgical towel was inserted through the upper midline incision to displace the small intestine and colon away

Table 2 Types of hepatectomies

Types of hepatectomies	Number
Right trisectionectomy	1
Right hemihepatectomy	32
Left hemihepatectomy	29
Anterior sectionectomy	1
Posterior sectionectomy	7
Left lateral sectionectomy	2
Segmentectomy	7
Minor liver resection	35 (combined in 12)

from the surgical site. A GelPort (Applied Medical, CA, USA) was attached to the wound retractor at the 8-cm incision, and a 5-mm trocar was placed in the right lateral upper abdomen under pneumoperitoneum (CO_2 at 8 mmHg; Fig. 1A). This configuration enabled the first assistant surgeon, who stood on the left side of the patient, to use the hand port for liver manipulation. The primary surgeon stood on the right side and used the right lateral 5-mm port for dissection. Using laparoscopic electrocautery and a hand assist, the right lobe of the liver was mobilized until the inferior vena cava (IVC) was recognized for all types of hepatectomies. The IVC does not need to be exposed fully at this stage to avoid incidental massive bleeding.

For patients indicated for left-side hepatectomy, the left triangle ligament also was dissected through the 5-mm port placed through the GelPort (Fig. 1B). After these mobilizations, the midline incision was extended to 10 cm for left-side anatomical resection and 12 cm for right-side anatomical resection, and a wound retractor was applied. For minor partial resections, even for multiple lesions, the 8-cm incision was still used. The wound was retracted and opened with the Omnitract retractor. For a right-side hepatectomy, the short hepatic veins were divided under direct view, and the right hepatic vein was encircled and a 6-mm Penrose drain was placed for a subsequent liver hanging maneuver through a midline incision (Fig. 2A). For an extended left hemihepatectomy, the common trunk of the middle and left hepatic veins was carefully encircled. The left hepatic vein was isolated and encircled in advance of parenchymal resection, when it could be performed safely. A Penrose drain also was placed between the hepatic veins for the liver hanging maneuver for left hemihepatectomies.

When cholecystectomy was necessary, we performed it by an open procedure. Hilar dissection was conducted through the midline incision under direct vision (Fig. 2B).

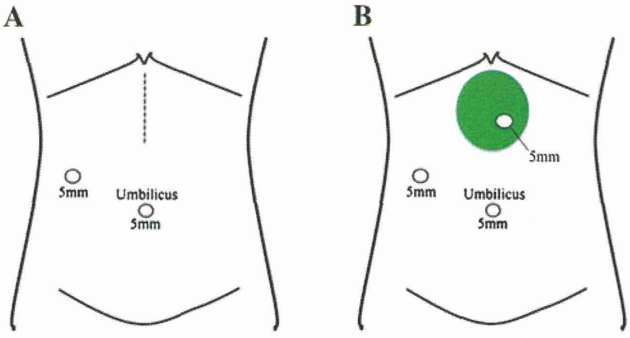

Fig. 1 The trocar placement. **A** *Dotted line* shows the upper midline incision. A 5-mm camera port is inserted from the umbilicus. Another 5-mm trocar is used for dividing the ligaments for mobilization of the right lobe. **B** When mobilizing the left lobe of the liver is necessary, a 5-mm trocar is inserted through a GelPort handport device

By placing surgical towels in the right subphrenic space, the liver can be stabilized in an ideal position by setting the intended transection line in the middle of the incision (Fig. 3).

The 4-0 polypropylene stay sutures were placed at the anterocaudal edge of the liver along the plane of the intended transection. The chief surgeon dissected the hepatic parenchyma from the patient's right side using a Cavitron ultrasonic surgical aspirator (CUSA) system (Integra Life Sciences, Plainsboro, NJ, USA), whereas the assistant surgeon used a saline-linked cautery device (Dissecting Sealer DS 3.5; Salient Surgical Technologies, Portsmouth, NH, USA) from the patient's left side. The occlusion of the hepatic arterial and portal inflow was not performed in any of the cases. The liver parenchyma was dissected with the CUSA, and the intraparenchymal vascular anatomy was defined so that a decision on the hemostatic technique could be made based on the vessel size. The saline-linked cautery device was used to coagulate and divide the dissected vessels that were 3 mm or smaller in diameter. Vessels larger than 3 mm in diameter were ligated with 3-0 or 4-0 synthetic polyester ties and were sharply divided. The few larger vessels were ultrasonically dissected and controlled with 4-0 absorbable monofilament transfixing sutures and were then sharply divided. The traction on the stay sutures was used to separate and to expose the deepening transection plane. During the parenchymal dissection, the upward traction on the tape (hanging maneuver) allowed the surgeon to follow a direct plane and facilitated the exposure and hemostasis of the deeper parenchymal plane in front of the IVC [5, 13]. A closed suction drain was inserted at the conclusion of each procedure.

Preparations for an open hepatectomy were always executed as a backup plan before surgery.

Results

The median length of the operation was 366.5 min (range 149–709) min. The median duration of the laparoscopic procedure was 32 min (range 18–77) min. The median blood loss was 645 g (range 50–5,370) g. There were no macroscopic or microscopic-positive margins seen in any of the patients. No cases were converted to conventional open hepatectomy with subcostal incision. The postoperative complications included surgical site infections in two patients, bile leakage in three patients, ileus in two patients, local liver infarction, portal venous thrombus, incisional hernia, and postoperative hyperbilirubinemia each in one patient. According to the Clavien–Dindo classification [4], the patient with portal venous thrombus and the patient with ileus was a grade III complication, whereas the others

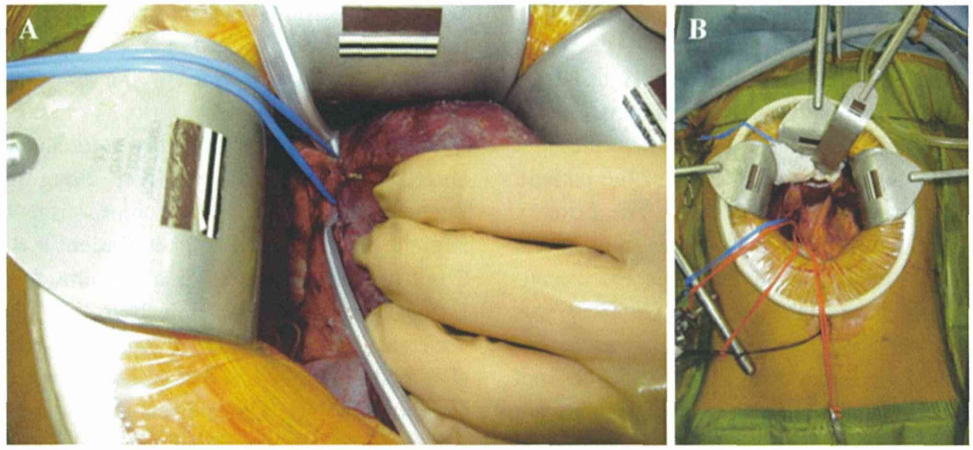

Fig. 2 **A** When mobilizing the right lobe of the liver, the surgeon can manage short hepatic veins, the right hepatic vein, and the inferior vena cava through the upper midline incision with adequate exposure. The *blue vessel loop* is encircling the right hepatic vein, and a Penrose drain also was passed around the right hepatic vein for the later hanging maneuver during parenchymal resection. **B** Hilar dissection under direct vision from the 12-cm upper midline incision. An Omni-tract surgical retractor is useful to maintain a good surgical field (Color figure online)

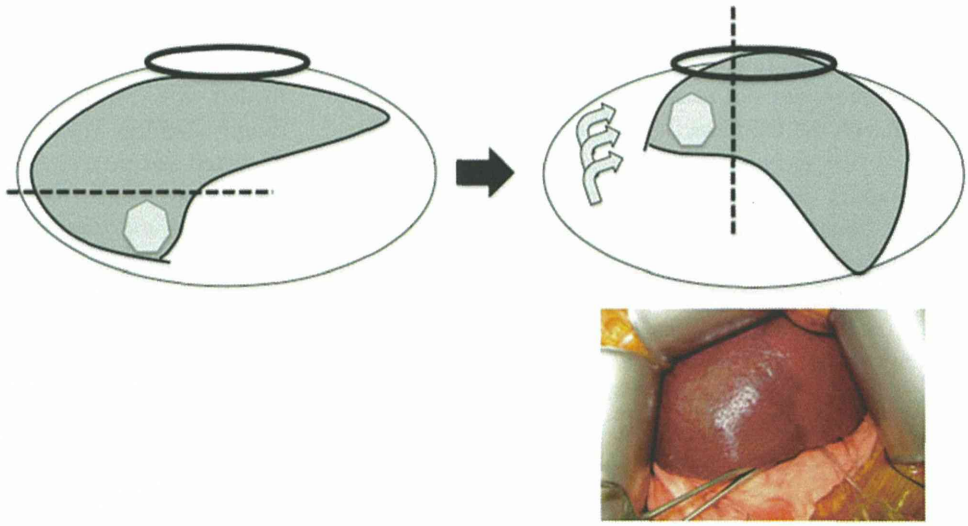

Fig. 3 With sufficient mobilization, the planned resection line can be exposed under an upper midline incision. The *dotted line* shows the planned resection line for a posterior sectionectomy. The photograph shows the demarcation line with control of the inflow to the posterior sector

were grade I. The median hospital stay was 13 days (range 8–123) days.

Comparing the findings for the hybrid technique and the open procedure for living donor left hemihepatectomy ($n = 24$ per group) and right hemihepatectomy ($n = 19$), no significant differences were seen in the duration of the operation [hybrid group: median 440 min (range 282–581) min; open hepatectomy: median 400 min (range 305–636) min]. In donor left hemihepatectomy, the intraoperative blood loss was significantly lower in the hybrid method group [median 510 g (range 50–1,950) vs. 637.5 g (range 250–3,150)]. No significant difference was seen in the intraoperative blood loss between open and hybrid donor right hemihepatectomy [median 625 g (range 320–1,800) vs. 710 g (range 234–2,550); Fig 4].

As a result, a hybrid method was successfully employed even in the cases that needed combined hepatectomy with hemihepatectomy and minor liver resection, or multiple minor liver resections for bilobular lesions, or a right posterior sectionectomy.

Case studies

Case 1

A 56-year-old male with hepatic carcinoid had multiple lesions in the right lobe and a lesion close to the middle hepatic vein. In addition, another tumor was present in the left-lateral section. The patient underwent right hemihepatectomy with local resection of the left-lateral section by a hybrid method. Radiofrequency ablation was performed for the lesion close to the middle hepatic vein with intraoperative ultrasound guidance (Fig. 5).

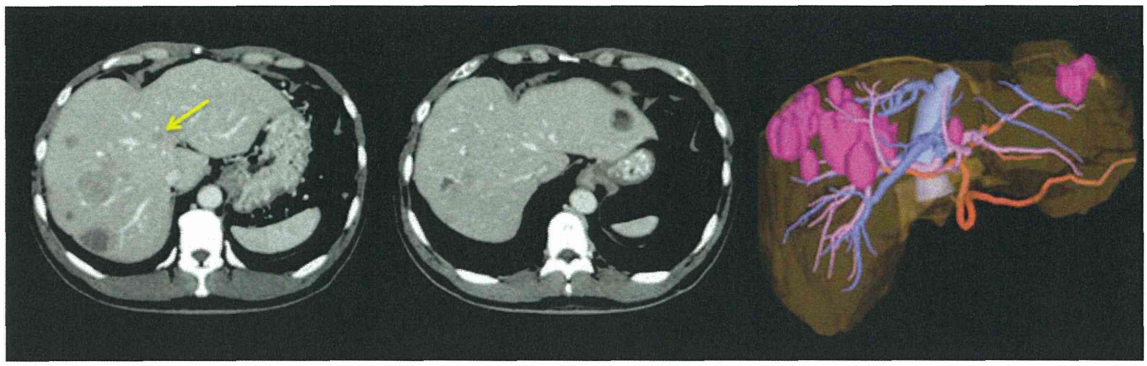

Fig. 4 CT images of multiple hepatic carcinoid tumors treated by hybrid resection, and a lesion treated by radiofrequency ablation (*arrow*). The *right panel* is a 3D reconstructed image made from CT scans obtained by a Synapse Vincent instrument (Fujifilm Medical, Tokyo, Japan)

Case 2

A 75-year-old male with multiple colorectal liver metastases. The tumors were located in segments 4, 6, and 7 (Fig. 6A). Because his hepatic functional reserve was disturbed as a result of the adverse effects of chemotherapy, a right hemihepatectomy was not possible. The patient underwent multiple local resections by a hybrid method through a 10-cm upper midline incision (Fig. 6B).

Case 3

A 74-year-old female with solitary hepatocellular carcinoma in segment 7 underwent an extended posterior sectionectomy by a hybrid method (Fig. 7).

Discussion

We herein reported the largest case series of hepatectomies performed by hybrid methods. To date, two other large case series employing hybrid methods have been reported [1, 5]. Our data further support the safety, feasibility, and efficacy of the hybrid approach for anatomical liver resection.

Although the term "hybrid method" is becoming common, there are some differences among institutions in terms of the following procedures: the location of the incision, the trocar locations, the extent of hand-assist procedures, etc. At our institution, we have adopted an upper midline incision for both the hand access and the open procedure. The hybrid method with an upper midline incision can be performed irrespective of the type of resection. Even posterior sectionectomies (S6 + 7) were consistently performed through the upper midline incision after hand-assisted right lobe mobilization. The benefits of anatomical resection for HCC have been reported [6, 7]. Hepatic parenchymal resection under direct vision in hybrid method can achieve meticulous and accurate resection with exposing vessels as well as conventional open procedure.

In addition to the effective application of the hybrid method for anatomical liver resections, we consider that a multiple partial hepatectomy is a good indication for the hybrid technique. Bilobular multiple liver tumors can be consistently managed through the short upper midline incision after the sufficient mobilization of the liver.

The upper midline incision contributes to the effective hand assist compared with access through a subcostal incision as a result of the wider working space. In terms of ergonomics, a hand-assist through the upper-midline incision may be more natural, because the rotation of the liver and the hand movement of the first assistant go in the same direction. Furthermore, the midline incision offers easy access to bilobular lesions. By using a GelPort hand device in place of trocar insertion, less port surgery can be achieved.

Hand-assisted procedures performed during the management of the area around the IVC and hepatic veins guarantees that there can be rapid emergency management of incidental massive bleeding. We consider that dividing the short hepatic veins and the subsequent encircling of the right hepatic vein or the common trunk of the middle hepatic vein and left hepatic vein can be more securely performed under direct vision compared to by a laparoscopic procedure. Once the right lobe is mobilized, the liver can be rotated to the left of the midline and retracted; therefore, the surgeon can easily approach the IVC and the right hepatic vein even through a minilaparotomy with a short upper midline incision. Because the IVC and hepatic hilum are basically located in the middle of the abdomen, the surgeon can approach these areas without stress through the midline under the exposure provided by the wound retractor and surgical retractor. The safety guaranteed by the hand-assist procedure seems to be superior to the magnification effect obtained during laparoscopy.

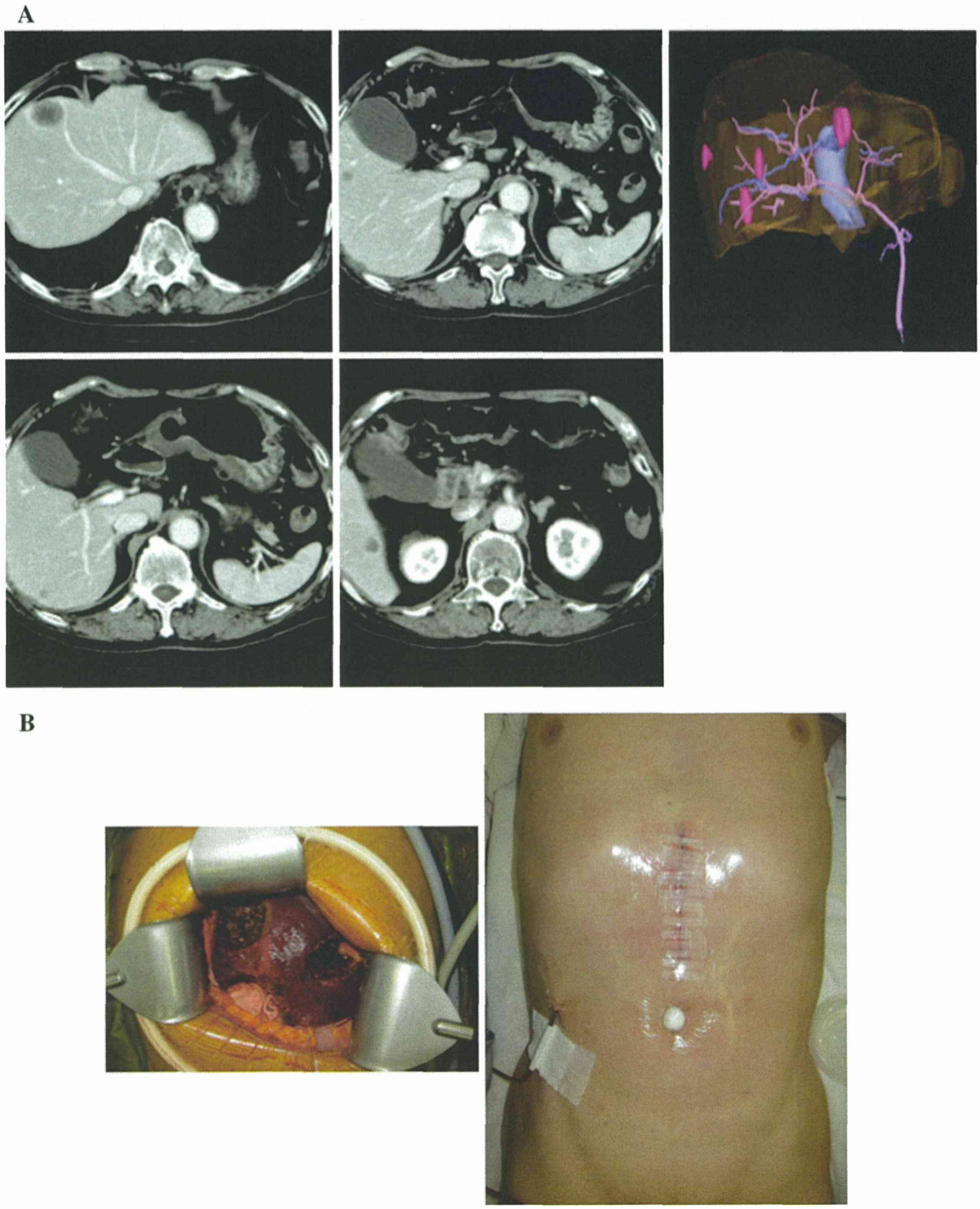

Fig. 5 **A** CT images of multiple colorectal metastases treated by a hybrid method. The *right panel* is a 3D reconstructed image made from CT scans obtained by a Synapse Vincent instrument (Fujifilm Medical, Tokyo, Japan). **B** Local resection was performed for four lesions because of insufficient liver functional reserve for major hepatectomy. A 10-cm upper midline incision was made for the hybrid method

Reducing blood loss is one of the goals of liver surgery, and several technical inventions have been introduced to achieve this, including the Pringle maneuver [8, 9] and selective vascular occlusion [10], among other techniques. Regarding surgical devices, the CUSA has contributed to the safety of hepatectomies by making it easy to identify the vessels during parenchymal transections. However, because the CUSA cannot seal tissues, meticulous ligation is required to avoid bleeding or bile leakage from the cut surface of the liver. Saline-linked electric cautery (SLC) is

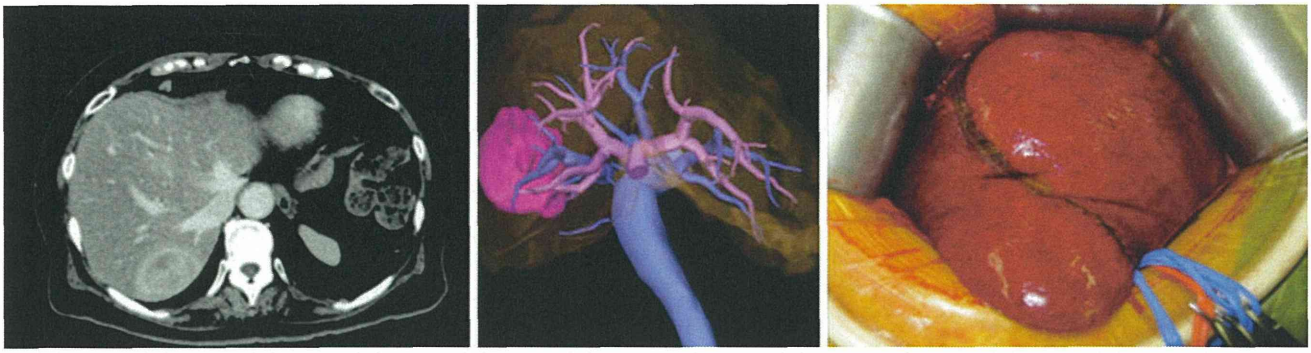

Fig. 6 Contrast-enhanced CT scan showed a mass lesion in segment 7 of the liver. The *middle panel* is a 3D reconstructed image made from CT scans obtained by a Synapse Vincent instrument (Fujifilm Medical, Tokyo, Japan). The intraoperative photograph shows the line of resection for the posterior sectionectomy

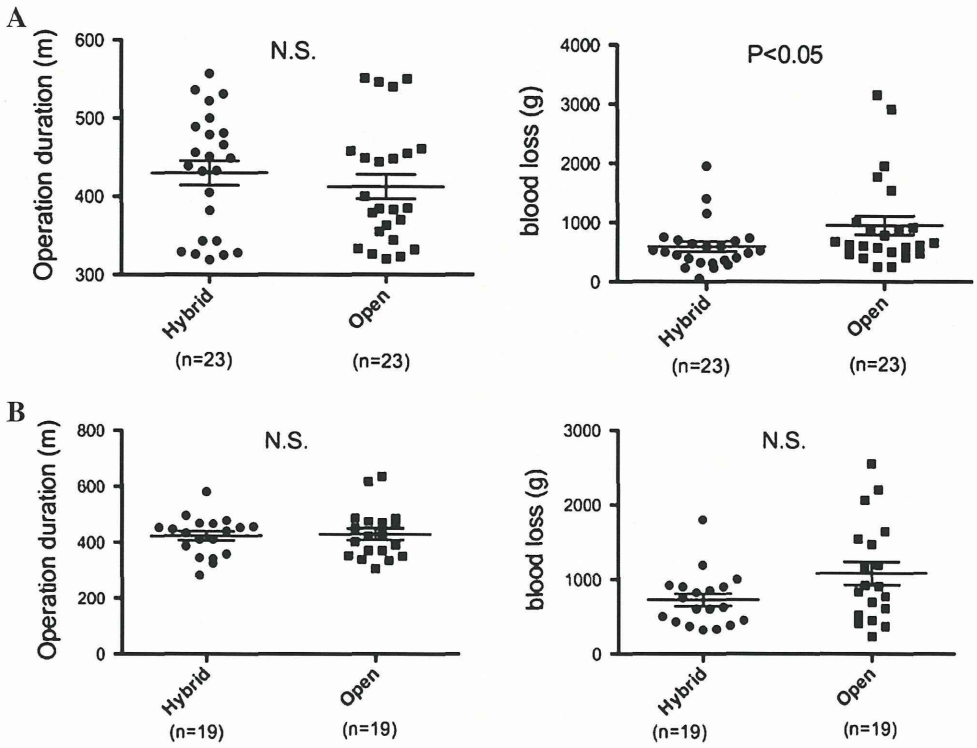

Fig. 7 Comparing the surgical outcomes of the hybrid procedure and open procedure for **A** living-donor left hemihepatectomy and **B** right-donor left hemihepatectomy

another novel device that contributes to reducing the need for ligation during liver parenchymal transections, because it can be used for tissue sealing [11]. Aloia et al. [12] introduced a two-surgeon technique for hepatectomies to resect neoplasms in adults, and demonstrated promising results. Palavecino et al. [13] demonstrated that the mean intraoperative blood loss was significantly decreased after the introduction of the two-surgeon technique compared with other techniques (stapling alone, ultrasonic dissection alone, saline-linked cautery alone, and the clamp-crush technique). We previously demonstrated that SLC could be adapted safely for living liver donor surgery without injuring either the graft or the remnant liver [14]. With the introduction of the liver hanging maneuver, which brings the transection line to just beneath the upper midline incision with pulling up of the liver [5, 15], to the hybrid method, parenchymal transection with the two-surgeon technique can be conducted as well as during open procedures. As a result, parenchymal transection can be successfully completed through the 10- to 12-cm upper midline incision without additional stress for the surgeon.

The upper midline incision that we adopted for the hybrid procedure is considered to have several advantages compared to the right subcostal incision, which was previously reported for the hybrid method. The upper midline can avoid muscle disruption and disturbing the sensory nerve dominating the abdominal wall. Jain et al. [16] reported the presence of persistent numbness of the

abdominal skin between the subcostal incision and the umbilicus in patients who had undergone liver transplantation. Surprisingly, 100 % of the patients ($n = 101$) had persistent numbness up to 9 years following liver transplantation. Five percent of these patients developed thermal injuries or blunt trauma complications. According to the results of a randomized, double-blind trial concerning midline versus transverse incisions in major abdominal surgery, although no relevant differences between midline and transverse incisions were observed for pulmonary complications, the median length of hospital stay and incidence of incisional hernias after 1 year was higher, and patients showed more wound infections, in the transverse group ($P = 0.02$) [17]. Given the development of the above-mentioned postoperative complications, the upper midline incision seems to be a more reasonable approach.

Some authors have reported previously the feasibility of major hepatectomy using a midline incision, including living donor hepatectomy [18, 19]. Lee et al. concluded that the procedure after an upper midline incision was more difficult in male donors with large fatty livers and deep truncal cavities. Without randomized, controlled trials, we presently cannot show objective data comparing our procedure and midline hepatectomy without laparoscopy. However, laparoscopic mobilization of the liver under pneumoperitoneum has been reported to be a safe and effective procedure with a good multidirectional surgical view and a wide working space [1, 20]. Hence, this virtue of laparoscopic procedure would allow for mobilization of the liver even in patients with deep truncal cavities, irrespective of the length of the midline incision. The influence of each patient's constitution on our technique seems to be smaller than that on midline major hepatectomy without a laparoscopic procedure. In this study, 17 patients (17 %) had a BMI >25, which is the cutoff value between normal and overweight. Among these patients, four had a BMI >30, which is considered obese. We therefore considered that our procedure can be applied in almost all patients, except those with morbid obesity accompanied by an extremely thick abdominal wall.

Furthermore, quick celiotomy and closure of the abdomen also were benefits of the upper midline incision [21]. The additional duration of the preparation for laparoscopic procedure was offset by the rapid opening and closing of the abdominal incision.

Although the long-term outcomes should be carefully evaluated, given the aforementioned advantages, in addition to the safety and feasibility, we consider that our technique should become more widely accepted as a standard hybrid method. Moreover, this method does not require expert laparoscopic surgical skills.

Disclosures Drs. Akihiko Soyama, Mitsuhisa Takatsuki, Tomohiko Adachi, Amane Kitasato, Yasuhiro Torashima, Koji Natsuda, Takayuki Tanaka, Izumi Yamaguchi, Shiro Tanaka, Ayaka Kinoshita, Tamotsu Kuroki, and Susumu Eguchi have no conflict of interest or financial ties to disclose.

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Reply

We thank Dr Li and colleagues for their interest in our study.

There are data[1] supporting race as a risk factor for stroke and mortality after carotid endarterectomy, the risk being higher in persons of black race compared with white. The risk of complications for other races is unclear. Although it may be premature to generalise these findings to a mixed vascular surgery population and cardiac complications, it would have been interesting to assess the association between race and cardiac outcome. Unfortunately, data regarding race are not available in the study population.

Preoperative anaemia and blood loss are well-accepted risk factors for cardiac events after vascular surgery[2]. We adjusted for preoperative anaemia in multivariable analysis. However, blood loss is an intraoperative event and is therefore impossible to incorporate in preoperative cardiac risk stratification, which is the focus of our study. Furthermore, the amount of perioperative blood loss is unlikely to be influenced by the presence or absence of diabetes mellitus, making it unlikely as a confounding factor.

As pointed out by Li et al, intraoperative hypotension and tachycardia are undoubtedly influential on the risk of ischaemic myocardial injury. However, as stated above, preoperative cardiac risk assessment will have to rely on data available preoperatively. Therefore we chose not to include data on intraoperative haemodynamics.

Routine troponin measurements were performed three times a week during admission (or whenever clinically indicated). We agree with Li et al that this may have led to an underestimation of the risk of cardiac events. However, this effect is likely to be equally present in diabetics and non-diabetics and is therefore unlikely to limit the validity of the study.

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APRV in patients with atelectasis after liver transplantation

Atelectasis frequently occurs after living donor liver transplantation (LDLT)[1] and it is a risk factor for hypoxaemia and pneumonia. Airway pressure release ventilation (APRV), a mode providing two levels of airway pressure (P_{high} and P_{low}) during two set time periods (T_{high} and T_{low}), is one method that can be used to treat atelectasis. As far as we know, no studies have evaluated the impact of APRV on atelectasis and the hepatic blood-flow after LDLT.

After obtaining institutional ethics approval (013-0199), we compared the outcomes of patients who were ventilated with APRV after LDLT between January and December 2008. During this study period, APRV was used in patients who were more than 12 years old, with atelectasis confirmed on a chest X-ray within two days of LDLT. For each APRV patient we chose a similar historical control patient who was ventilated by synchronised intermittent mandatory ventilation (SIMV) after LDLT between October 2003 and December 2007. The ventilator settings and level of sedation were adjusted so that the PaO_2 was >100 mmHg, the $PaCO_2$ was 40±5 mmHg and the Richmond Agitation Sedation Scale was between -3 and 0, during either SIMV or APRV ventilation. The exclusion criteria included: 1) reoperation, 2) bilateral thoracentesis and 3) intolerance to APRV for at least 12 hours.

The weaning method consisted of continuous positive airway pressure or continuous positive airway pressure with pressure support in both groups, and the endotracheal tube was removed when the patients met all the following criteria: 1) stable liver function, 2) no haemodynamic instability, 3) PaO_2 to FiO_2 ratio of >200, 4) positive end-expiratory pressure of <5 cmH_2O and 5) pressure support of <5 cmH_2O.

During the study period, nine patients were treated with APRV (mean age=46.0 ± standard deviation 13, 4 male/5 female, body mass index=25.9±3.5, Model for End-Stage Liver Disease score=18.7±11.9 and duration of surgery=949.1±156.1 minutes) and they were compared to 27 historical controls subjects who had similar characteristics. The average APRV settings were P_{high} of 14.1±3.6 cmH_2O, P_{low} of 2.1± 2.7 cmH_2O, T_{high} of 5.2±2.9 seconds, T_{low} of 1.1±0.3 seconds, with a mean airway pressure (MAP) of 13.6±4.7 cmH_2O. The atelectasis score was significantly better after