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REVIEW ARTICLE

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Laparoscopic living-donor hepatectomy: Review of its current status

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Abstract

The laparoscopic living-donor hepatectomy procedure has been developing rapidly. Although its use has increased worldwide, it is still only performed by experienced surgeons at a limited number of institutions. However, technical innovations have improved the feasibility of more widespread use of laparoscopic living-donor hepatectomy. The advantages of laparoscopic living-donor hepatectomy should not be overemphasized, and the fundamental principle of "living-donor safety first" cannot be neglected. This review aims to summarize the current status of laparoscopic living-donor hepatectomy and to emphasize that, while this procedure may soon be used as a reliable, donor-friendly substitute for traditional open donor hepatectomy, its safety and efficacy require further substantiation first.

KEYWORDS

laparoscopic surgery, liver transplant, living-donor hepatectomy, robotic surgery

1 | INTRODUCTION

Living donor liver transplantation (LDLT) is a treatment that serves as a temporary bridge for endstage liver disease patients in the event a cadaveric donor is unavailable. However, the demand for LDLT is high, especially in countries like Japan where there is a severe shortage of cadaveric donors. The most important disadvantage of LDLT is the significant risk of death incurred by the healthy living donor.[1-5] Therefore, when performing LDLT, donor safety is paramount.

Information sharing, including videos of LDLT procedures, has led to rapid innovation in the technology, instruments, and surgical techniques used for LDLT, innovation that includes laparoscopic hepatectomy. Laparoscopic hepatectomy requires only a small incision and is minimally invasive, which is appealing and beneficial for both the patient and the healthy donor undergoing the procedure.[6,7]

However, laparoscopic hepatectomy is still relatively new and requires special skills to be performed adequately and safely.[8-13] Various techniques, such as robot-assisted surgery, are currently only performed by specialized and experienced surgeons.[9,12,14-20] Indeed, a series of mortalities following the use of laparoscopic hepatectomy at an institute in Japan resulted in a great sense of caution regarding the development and use of laparoscopic hepatobiliary and pancreatic surgery.[11]

In this review, we summarize both the historical development and current status of laparoscopic living-donor hepatectomy.

2 | TECHNICAL DEVELOPMENT IN LAPAROSCOPIC LIVING-DONOR HEPATECTOMY

Similar to the development of open living-donor hepatectomy,[21] laparoscopic living-donor hepatectomy began by using a graft of the left lateral section (LLS) of the liver as was first reported by Cherqui et al in 2002.[22] Information and experience regarding laparoscopic major hepatectomies in nondonor patients accumulated during this

TABLE 1 Pure laparoscopic living-donor right hepatectomies (studies including more than five cases of PLLDRH)

Author	Institution	Country	Year	PLLDRH (n)	Control (open surgery) (n)	Op time (min)	Blood loss (ml)	WIT (min)	Conversion rate	Reasons for conversion
Takahara T	Iwate	Japan	2017	5 (+9 other types)	40 (Hybrid)	455 vs 380	81 vs 239	9.1 ± 2.1	7.1%	Difficulty with hilar dissection (n = 1)
Hong SK	Seoul NU	Korea	2018	26	26	305 vs 202	ND	9.3 ± 2.5	ND	Not mentioned
Samstein B	NY	USA	2018	20 (+31 LLS)	51	429 vs 389	236 vs 405	ND	9.8%	Nonvisual HA (n = 1), parenchymal transection time (n = 2), difficulty with mobilization (n = 2)
Suh KS	Seoul NU	Korea	2018	45	42	331 vs 280	436 vs 338	12.6 ± 4.4	0.0%	None
Lee KW	Seoul NU	Korea	2018	115	ND	321	394	11.0 ± 6.7	ND	Not mentioned
Kwon CHD	Samsung	Korea	2018	54	ND	436	300	6 (2–12)	7.4%	PV stenosis (n = 2), PV injury (n = 1), fatty liver (n = 1)
Park J	Samsung	Korea	2019	91	197	365 vs 326	300 vs 300	ND	5.5%	PV injury (n = 2), PV stenosis (n = 1), Remnant bile duct injury (n = 1), Small remnant volume (n = 1)
Lee B	Seoul NU Bundang	Korea	2019	33	43	434 vs 346	572 vs 559	ND	6.1%	Bleeding (n = 2)
Rhu J	Samsung	Korea	2019	100	205	375 vs 329	299 vs 344	4.5 (1.7–31)	6.0%	PV stenosis (n = 1), PV injury (n = 2), fatty liver (n = 1), Left hepatic duct injury (n = 1), IVC injury (n = 1)
Hasegawa	Iwate	Japan	2019	8 (+3 Left lobe)	ND	387	75	5 (2–10)	9.1%	RHV misfire (n = 1)
Hong SK	Seoul NU	Korea	2019	100	ND	320	ND	11.3 ± 6.2	0.0%	None
Rhu J	Samsung	Korea	2020	103	96	252 vs 301	200 vs 300	3.1 (2.7–4.2)	ND	Not mentioned
Jeong JS	Samsung	Korea	2020	138	187	335 vs 330	300 vs 334	ND	3.6%	PV stenosis (n = 2), PV injury (n = 1), left bile duct injury (n = 1), IVC injury (n = 1)

Morbidity (donor) ≧ CD3a	Morbidity (recipient)	30-day mortality (recipient)	Morbidity (recipient) PV/HA/HV	Morbidity (recipient) Bile duct	Reference
21.4%	71.4%[a]	14.3%	7.1%	14.3%	47

(Continues)

TABLE 1 (Continued)

Morbidity (donor) ≧ CD3a	Morbidity (recipient)	30-day mortality (recipient)	Morbidity (recipient) PV/HA/HV	Morbidity (recipient) Bile duct	Reference
7.7%	25.0%	3.3%	11.6%	20.0%	48
12.0%	ND	ND	5.9%	ND	49
2.2%	24.4%	2.2%	11.1%	2.2%	50
2.6%	22.6%	1.7%	6.9%	5.2%	80
16.6%	ND	9.3%[b]	7.4%	31.5%	81
15.4%	46.2%	3.3%	ND	ND	52
9.1%	30.3%	9.1%	12.1%	12.1%	53
15.0%	28.0%	0.0%	8.0%	15.0%	54
9.1%	ND	0.0%	0.0%	27.2%	78
2.0%	27.0%	2.0%	6.0%	9.0%	85
4.9%	56.3%	3.9%	ND	ND	55
11.4%	ND	ND	ND	ND	56

HA, hepatic artery; HV, hepatic vein; IVC, inferior vena cava; LLS, left lateral sectionectomy; ND, not described; NU, national university; NY, New York; PLLDRH, pure laparoscopic living donor right hepatectomy; PV, portal vein; RHV, right hepatic vein; WIT, warm ischemic time.

[a]Cumulative incident ratio.

[b]Graft failure.

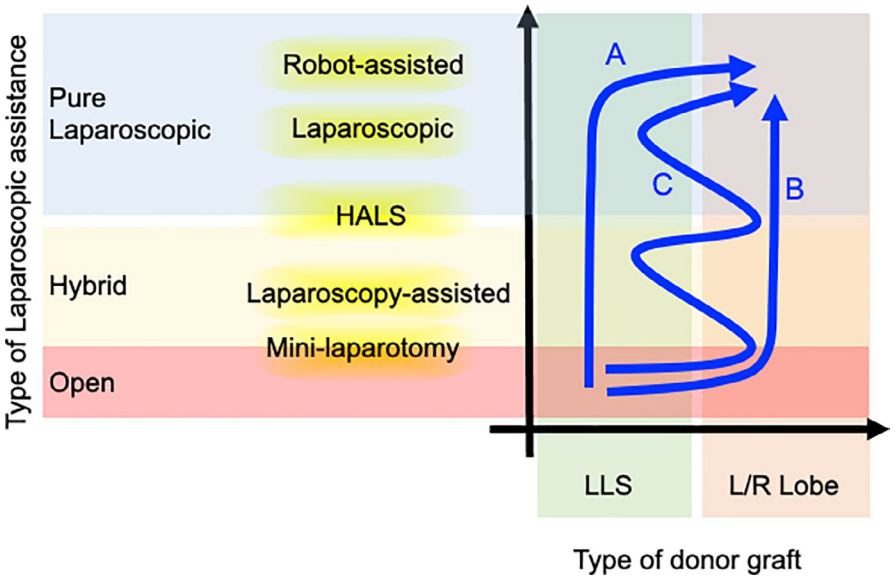

FIGURE 1 Two-dimensional expansion of laparoscopic donor hepatectomy. Laparoscopic donor hepatectomy development has expanded in two dimensions. One dimension is the graft type, progressing from the LLS to the left lobe and the right lobe. The second dimension is the type of laparoscopic assistance used, ranging from open, hybrid hepatectomy to pure laparoscopic procedures. Pure laparoscopic left or right hepatectomy can progress through the A, B, or C pathway. LLS: left lateral section, L/R lobe: left/right lobe

period, and laparoscopic hepatectomy gradually advanced to the point of using a pure laparoscopic approach for right lobectomies in nondonor patients. Hand-assisted laparoscopic surgery (HALS) in nondonor patients was also reported, and both HALS and pure laparoscopic lobectomies were developed concurrently.[8,23,24]

Right lobe hepatectomy in a living donor using HALS was first reported in 2006.[25] However, despite the publication of a few additional studies,[26] HALS hepatectomy has not been widely used after publication of this first report.

Expanding the graft type to include the left or right lobe of the liver using a pure laparoscopic approach in a living donor was not reported until 2013.[27,28] This initiated the first phase of development for pure laparoscopic living donor lobectomies, which was described in multiple case reports that focused primarily on the feasibility of the procedure.[29-46] A second phase followed thereafter that focused mostly on pure laparoscopic living-donor right hepatectomies (PLLDRH). After 2013, many case reports and studies comparing laparoscopic lobectomy with open lobectomy were published.[40,47-57] In reports encompassing more than five cases, comparative studies between PLLDRH and conventional open living-donor right hepatectomy performed at experienced transplant centers were conducted, and the feasibility and safety of this technique were confirmed (Table 1). Among these reports, the largest study, by Jeong et al,[56] used a propensity score matching analysis that determined the incidence of postoperative complications was similar between open donor right hepatectomy and PLLDRH, and less postoperative pulmonary complications, opioid requirements, and hospital stays were required for PLLDRH patients. It is worth noting that there are very few institutions, and most of these in Korea, that have reported on more than five cases of PLLDRH, suggesting that the clinical application of this procedure is still very limited, even within specific high-volume institutions.

At consensus meetings held in Morioka in 2014[9] and in Seoul in 2016,[16] laparoscopic living-donor hepatectomy was discussed, and it was concluded that pure laparoscopic left lateral sectionectomy was a viable and safe procedure; however, pure laparoscopic left or right lobectomies were determined to require further clinical study and these procedures were recommended for use only at experienced transplant centers.[12] A robot-assisted donor hepatectomy was first conducted in 2012,[58] and additional reports regarding this procedure since then have been limited.[59,60]

Parallel to the advancement of pure laparoscopic donor hepatectomy, mini-incision or hybrid donor hepatectomy was also developed and increasingly utilized, mostly in Japan.[6,20,61-71] A left lateral sectionectomy via a mini-incision is feasible without laparoscopy, although laparoscopy does make the procedure easier.[72-74] Furthermore, laparoscopic mobilization is more appropriate for left or right lobectomies due to the enhanced view and increased safety it provides.[6,20,62-65,69,71] In the hybrid technique, laparoscopic mobilization of the liver is performed first and then a small midline incision is used to complete the rest of the procedure as an open surgery. Hybrid hepatectomy and HALS were, therefore, adopted at many centers to ensure donor safety during surgery. Nevertheless, hybrid hepatectomy is not the ultimate goal; rather, it represents an interim method that allows for smaller incisions during donor hepatectomy and results in superior outcomes regarding donor satisfaction.[6]

3 | TWO-DIMENSIONAL EXPANSION AND THE FIVE STEPS OF LAPAROSCOPIC DONOR HEPATECTOMY

Laparoscopic donor hepatectomy has developed in two dimensions (Figure 1). The first developmental dimension involved expanding the graft type that was used and progressed from the LLS to the left lobe to the right lobe. Indeed, the overall technical difficulty associated with this surgery, as well as its incidence of morbidity and mortality, depends on the graft type and is smallest for the LLS but increases with progression to the left and right lobes. The second developmental dimension involved the type of

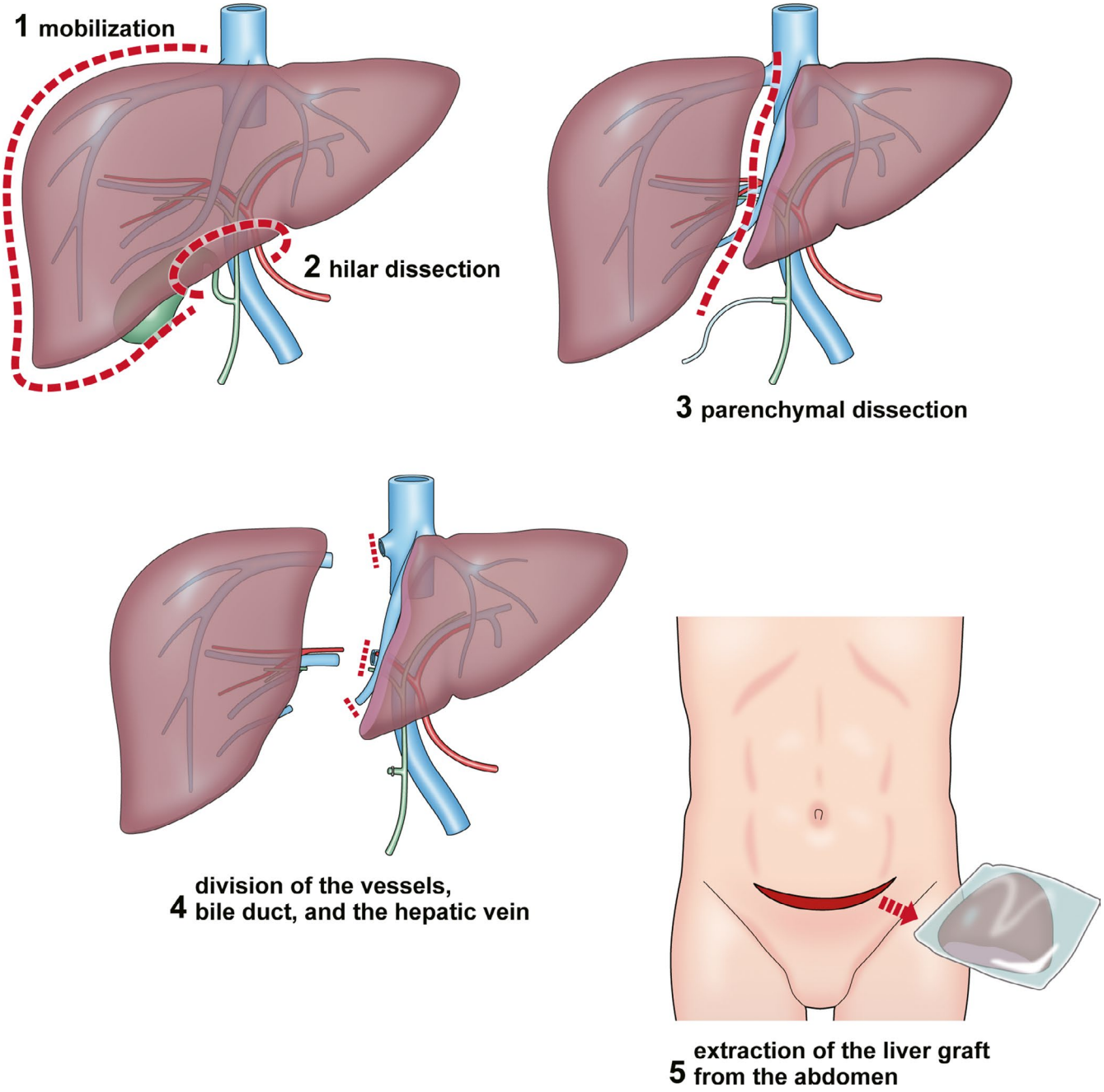

FIGURE 2 Five steps of laparoscopic donor hepatectomy for a right hepatectomy. The technical steps of living-donor hepatectomy can be divided into five steps: (1) mobilization; (2) hilar dissection of the artery, portal vein, and bile duct; (3) parenchymal dissection; (4) division of the vessels and bile duct, and division of the hepatic vein; and (5) extraction of the liver graft from the abdomen. Copyright: MEDICAL EDUCATION INC

laparoscopic assistance used and progressed from open hepatectomy to hybrid hepatectomy to pure laparoscopic hepatectomy. Figure 1 provides a visual representation of the various developmental processes that have occurred. Developmental process A focuses on the LLS, starting with open surgery and then expanding into laparoscopic and robot-assisted surgery before progressing to a left or right donor hepatectomy. In contrast, developmental process B first expands into open left or right donor hepatectomy before proceeding to pure laparoscopic hepatectomy. Processes A and B represent extreme examples and, in reality, the hepatectomy developmental process resembles process C, a process that moved back and forth between graft type and the laparoscopic assistance used. There are substantial gaps in the technical skill required for hepatectomies based on the sought-after graft type and/or the laparoscopic assistance used.

The technical steps of living-donor hepatectomy can be divided into five steps: (1) mobilization; (2) hilar dissection of the artery, portal vein, and bile duct; (3) parenchymal dissection; (4) division of the vessels and bile duct, and division of the hepatic vein; and (5) extraction of the liver graft from the abdomen (Figure 2).

The type of laparoscopic assistance used can be defined in terms of the five steps required for a living-donor hepatectomy. Hybrid hepatectomy utilizes laparoscopy for the mobilization of the liver (step 1), but hilar and parenchymal dissection, and division of the vessels (steps 2–5) are performed via direct visualization as an open surgery. Many experienced liver transplant programs quickly adopted the hybrid hepatectomy procedure because it is similar to open surgery through a small midline incision. Furthermore, laparoscopic liver mobilization is not difficult, making the hybrid technique easy to introduce. Regarding safety, this technique is more reliable than other laparoscopic procedures and has therefore been implemented in several Japanese transplant programs.[9,11]

For HALS, the entire surgery is performed laparoscopically with the surgeon's hand inside the abdominal space; this requires the skin incision to be large enough for a hand.[25] Pure laparoscopic procedures are considered the primary goal of minimally invasive surgery because the skin incision required for extraction of the graft can be restricted to a free site, usually a supra-pubic incision in the form of a Pfannenstiel incision.[36] Robotic surgery is often included as a type of pure laparoscopic surgery.

A magnified laparoscopic view is a distinct advantage when performing steps 2 and 3 (hilar dissection of the artery, portal vein, and bile duct, and parenchymal dissection). However, unexpected bleeding and anatomical disorientation during laparoscopic procedures, including robot-assisted procedures, are the main safety concerns.[48] Unexpected bleeding and/or unintended organ injury are easier to avoid during a hybrid procedure than they are during HALS or pure laparoscopy because a hybrid procedure allows for better tactile sensation and anatomical orientation. Creating effective countermeasures for these safety concerns is the most difficult and technically demanding challenge when executing a pure laparoscopic procedure.[6]

To avoid anatomical disorientation in a laparoscopic view, augmented reality (AR) support systems are being developed but have not yet been proven to be sufficient.[75-77] Anatomical recognition during step 4 of a purely laparoscopic living-donor hepatectomy, and the devices used to cut vessels are the major safety concerns. A technical error might occur during this step, although the risk is very low. Indeed, the risk at step 4 during an open procedure is extremely low, as we have never once experienced such an error here.

4 | CURRENT STATUS OF LAPAROSCOPIC DONOR HEPATECTOMY

Energy devices such as ultrasonic dissectors, soft coagulation systems, and laparoscopic surgical staplers have increased the ease of performing laparoscopic procedures, even for less skilled surgeons. Furthermore, surgical monitors have advanced extensively to allow for visualization in 4K and 8K resolution, and can even provide a 3D view in some cases. Application of robotic surgery using the da Vinci system has made a significant advance in this field, especially with the use of multijoint laparoscopic instruments and a 3D view. These developments in surgical devices and systems will facilitate pure laparoscopic hepatectomy becoming a mainstream approach in the future, even for living-donor hepatectomy. However, further careful evaluation of the safety and efficacy of these new techniques is still required.

Future safety and efficacy evaluation should focus on two aspects: first, donor outcomes including morbidity, bleeding, operative time, and living donor satisfaction. Most previous research on pure laparoscopic left and right lobectomies has shown these procedures are viable in terms of donor safety. The second aspect to focus on is recipient outcome; this aspect requires significant further investigation.

When analyzing donor outcomes, there are several major concerns during laparoscopic surgery, including: (a) anatomical disorientation; (b) parenchymal transection; (c) the length of the hepatic vein; (d) the cut point of the bile duct; (e) ischemic time from inflow occlusion to graft-out through the small incision; and (f) unexpected complications such as uncontrollable bleeding or organ injury. Most previous reports did not assess these points and only compared the incidence or severity of postoperative morbidities. If any negative outcomes are revealed, even during the development phase of laparoscopic donor hepatectomy, this new technique should not be accepted. Fortunately, thus far, all results of these comparative studies between laparoscopic and conventional open donor hepatectomy have concluded that the outcomes of laparoscopic procedure are not significantly worse than for conventional open donor hepatectomy.[40,47-56,78]

The effects in transplant recipients are also an important measure for evaluating laparoscopic procedures. Park et al[79] and several other studies,[47-50,52-55,78,80,81] which mainly described donor outcomes, also reported on outcomes for the recipients and found they were similar to those for conventional open donor hepatectomy. However, these results should not be interpreted as demonstrating that laparoscopy is as effective as conventional open procedures. Recipient outcomes can be influenced by many more factors than the slight differences seen with donor hepatectomy; as such, detailed investigations of long-term recipient outcomes are necessary.

The limitations of laparoscopic procedures have been described in many articles and primarily focus on restrictions in motion, visualization, and tactile sensation.[82] Hong et al reported the differences between laparoscopic and conventional open surgeries.[48] They highlighted the difficulty in recognizing the right plane for parenchymal transection, the relatively horizontal cutting axis for the right portal vein and right hepatic duct, and the difficulty in determining the correct cutting point for these vessels. In this specific case, the patient experienced portal vein injury, thermal injury of the hepatic artery, and surface damage to the liver during mobilization caused by a trocar. All these issues were rectified during the surgery and caused no complications postoperatively. Further difficulty is caused by the need to manage anatomical variations. Small hepatic ducts[52] and other anatomical anomalies[48,54,81] can cause an increase in morbidities following pure laparoscopic procedures. This indicates that such incidents are potential problems, which may cause severe

complications postoperatively; however, very few of these anomalies have been reported.

Another concern is warm ischemic time (WIT), defined as the time from inflow occlusion to graft removal and flushing with a cold preservation solution. This time is longer for laparoscopic procedures than it is for conventional open procedures, and ranges from 3.1 to 12.6 min laparoscopically (most commonly about 10 min) (Table 1). Results regarding graft survival after transplantation in recipients have been reported in several studies; longer WIT seems to have no influence on graft function or survival. However, marginal situations, such as a small-for-size grafts or fatty liver combined with prolonged WIT, might reveal an adverse effect on graft outcomes.

Mid-surgery conversion from a laparoscopic to an open procedure is also a matter of concern. The reported rate of conversion is approximately 6%–7%, ranging from 0%–9.8% (Table 1). Most conversions resulted from unexpected injuries to major vessels (Table 1). This rate is not unexpectedly high when compared to that of nondonor major hepatectomy[83,84]; however, it should be noted that rescue conversions to open surgery were necessary in patients with near-miss events. We should be aware that laparoscopic procedures carry these potential risks and we should work to minimize them. It is very important to communicate the approaches to prevent the complications, and share the reasons for conversion and to determine criteria for conversion during the safety validation phase of pure laparoscopic procedures.

Several articles describe an improvement in the results of the procedure according to a learning curve.[48,53,55,80,85] Hong et al[48,85], Rhu et al[55], and Lee et al[80] reported that an expert HBP surgeon with sufficient experience in open donor right lobectomy requires 50–60 cases of PLLDRH for technique stabilization. Lee et al[53] reported that experience with more than 70 cases of pure laparoscopic right lobectomies should be recommended before starting PLLDRH.

Donor safety should be a top priority.[3] Thus, any mortality or sequelae following laparoscopic surgery may influence the development and restrict the expansion of this approach unless the causes are fully disclosed and countermeasures are sufficiently established.

5 | ROBOT-ASSISTED LIVING-DONOR HEPATECTOMY

The performance of robot-assisted major hepatectomy has rapidly spread worldwide, due to the well-established da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA). The advantage of robotic surgery lies in the combination of laparoscopic technique with a magnified 3D view and less restricted surgical manipulation. However, proficiency in using the device is essential and requires intense training.[59,60,86]

Robot-assisted living-donor hepatectomy was first reported by Giulianotti et al in 2012, which described a case of robot-assisted living donor right lobectomy subsequent to the performance of over 90 robotic minor and major hepatectomies.[58] However, few articles on robot-assisted living-donor hepatectomy are available as of yet. Chen et al reported a series of 13 robotic living donor right hepatectomies and compared these with 54 open living donor right hepatectomies.[59] Liao et al described a case of robotic living-donor left lateral sectionectomy.[60] Recently, Troisi et al reported that robotic LLS for donor hepatectomy is a safe procedure, with results comparable to laparoscopy in terms of donor morbidity and overall recipient outcomes when the procedure is performed by experts.[87]

Therefore, robot-assisted living-donor hepatectomy seems to be a minimally invasive approach that overcomes the difficulty of restricted movement experienced during "conventional" laparoscopic procedures. However, this technique is still new and should be carefully introduced in accordance with the required learning curve of the surgeons and staff involved in surgery.

6 | JAPANESE EXPERIENCE IN LAPAROSCOPIC LIVING-DONOR HEPATECTOMY

In Japan, the circumstances surrounding the development of laparoscopic procedures are different than that of other countries. Insurance coverage for laparoscopic hepatectomies was not implemented until in 2010 with laparoscopic minor hepatectomies (partial liver resection and left lateral sectionectomy). Furthermore, two different incidents where a cluster of mortalities occurred in patients who underwent laparoscopic hepatectomy in academic hospitals in Japan were widely broadcast.[11] These events revealed the failure of local hospitals to safely manage laparoscopic surgery and, since their occurrence, have reinforced restrictions on laparoscopic hepatectomy implemented by the Japanese government.

In 2016, laparoscopic major hepatectomy was included in insurance coverage; however, as of 2020, insurance does not currently cover laparoscopic living-donor hepatectomy in Japan. Therefore, this procedure has never been performed in most of the hospitals in Japan, resulting in the development of hybrid donor hepatectomy instead and the publication of multiple studies.[6,61,63,65,66,69,71,74] We demonstrated that living donors, especially young donors, strongly desire to have a smaller skin incision, and all the donors decided to undergo hybrid surgery rather than conventional open surgery.[6]

This approach provides a temporary solution that considers the current social circumstances in Japan. However, the goal is not to perform hybrid donor hepatectomy, but pure laparoscopic or robotic donor hepatectomy is the true target.

7 | FUTURE PERSPECTIVES

Both technical innovations and the sharing of surgical experiences will promote the safety and efficacy of pure laparoscopic and robot-assisted living-donor hepatectomy. However, the safety of these procedures has not yet been established thoroughly enough for them to be applied as standard techniques at all transplant centers. This is especially true for right and left lobectomy, which is currently

recommended to be performed only at centers with adequate expertise and experience in both pure laparoscopic or robot-assisted living-donor hepatectomy and open living-donor hepatectomy. Educational methods are also rapidly developing, and surgical practices in various institutions will improve through the sharing of knowledge and practices via scientific meetings, extensive Internet access to video clips of surgical procedures, and so on. Pure laparoscopic and robot-assisted living-donor hepatectomy will likely be one of the most quickly developing fields of surgical innovation in the next decade.

CONFLICT OF INTEREST

The authors declare no conflicts of interest for this article.

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