Review Article

Insights from Seoul National University Hospital's experience: a systematic review of pure laparoscopic donor hepatectomy progression

Suk Kyun Hong^, YoungRok Choi, Nam-Joon Yi, Kwang-Woong Lee, Kyung-Suk Suh

Department of Surgery, Seoul National University College of Medicine, Seoul, South Korea

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Correspondence to: Kwang-Woong Lee, MD, PhD. Department of Surgery, Seoul National University College of Medicine, 101 Daehakro, Jongrogu, Seoul 03080, South Korea. Email: kwleegs@gmail.com.

Abstract: Following its initial execution in November 2015, pure laparoscopic donor hepatectomy (PLDH) has gained acceptance as a conventional practice at Seoul National University Hospital (SNUH). It is noteworthy that a significant proportion of cases entail full right hepatectomies, which are acknowledged to be technically demanding. As expertise and knowledge have been accrued, the pure laparoscopic technique has been extended to encompass liver recipients as a viable option in SNUH. The aim of this review is to present the developmental progression of PLDH, with a focus on pure laparoscopic donor right hepatectomy (PLDRH), at SNUH. This includes the standardization process, which can be achieved by sharing the hospital's accumulated experience and previous reports. Various types of graft, including full right, left, left lateral section, and monosegment, were procured by pure laparoscopic technique. The criteria for selection were expanded to include donors with variations in the anatomy of the portal vein and bile duct. Additionally, the procedure of PLDRH was determined to be safe and viable for donors with high body mass index and larger graft weight. In conclusion, this review demonstrates the alterations implemented throughout our evolution from restricted to inclusive criteria for donor selection, leading to a complete shift from open surgery to pure laparoscopic procedures in donor hepatectomy and eventually pure laparoscopic living donor liver transplantation (LDLT) in recipient.

Keywords: Donor hepatectomy; laparoscopy; living donor liver transplantation (LDLT); right hepatectomy; minimally invasive

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Introduction

The introduction of pure laparoscopic donor hepatectomy (PLDH) has been aimed at meeting the cosmetic and functional needs of the donor. Initially starting with left lateral sectionectomy (1), PLDH has undergone further development to encompass full left (2) and full right hepatectomy (3), with an increasing number of medical centers adopting this technique. Various studies and international consensus meetings have demonstrated the safety and feasibility of PLDH (4-7). However, limitations in the sample size and the number of centers implementing PLDH, particularly for right hepatectomy, remain significant. Many medical centers continue to face

^ ORCID: 0000-0002-0020-6215.

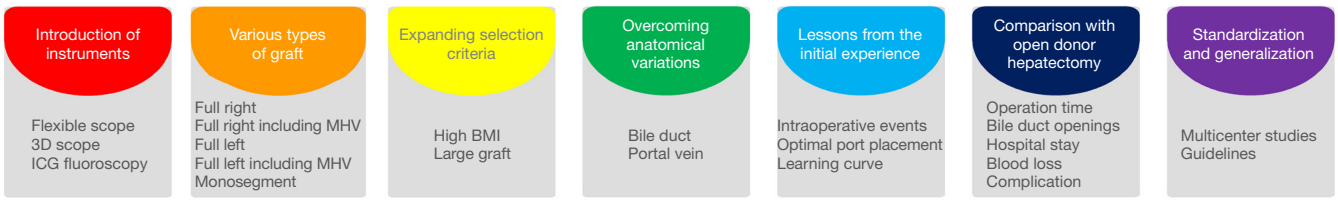

Figure 1 A visual overview of the successive progression of pure laparoscopic donor hepatectomy. 3D, 3-dimensional; ICG, indocyanine green; MHV, middle hepatic vein; BMI, body mass index.

challenges in establishing a secure laparoscopic donor program.

Since November 2015, the Seoul National University Hospital (SNUH) has been implementing a PLDH program (8), which has resulted in the execution of 654 cases up until 2022 (*Figure 1*). Recently about 90% of all donor hepatectomies are performed under pure laparoscopic technique. As PLDH has become stabilized and standardized, pure laparoscopic technique has started to be applied to recipient surgeries as well. SNUH introduced a minimally invasive living donor liver transplantation (LDLT) program in March 2020 (9). SNUH accomplished pure laparoscopic explant hepatectomy and graft implantation through the upper midline incision, and further implemented pure laparoscopic or robotic techniques for both explant hepatectomy and graft implantation, which were successfully performed (10-13). The realization of minimally invasive LDLT has been made possible thanks to the extensive knowledge and experience accumulated through PLDH. The objective of this study is to present our experience and expertise with PLDH, with a focus on pure laparoscopic donor right hepatectomy (PLDRH), through a review of our previous reports. Additionally, we will describe how we have broadened the selection criteria and standardized the procedure.

The instruments that facilitated the commencement of PLDH

Since the inception of the LDLT program in January 1999, SNUH has performed more than 1,900 LDLT cases, with the majority of the grafts being right lobe grafts. No donors expired, suffered any disabling morbidities, or necessitated transfusion during surgery. As the number of LDLT procedures has increased, so has the demand for aesthetic and functional results, particularly among young, female donors. Consequently, there has been a surge of interest in minimally invasive donor hepatectomy. Subsequent to the initial two cases of hand-assisted laparoscopic living donor right hepatectomy in 2007 (14), laparoscopy-assisted donor hepatectomy was employed for a limited number of donors who satisfied stringent criteria. However, utilizing conventional laparoscopic hepatectomy proved to be highly demanding technically. One of the primary constraints of conventional laparoscopy is the deficiency of depth perception and tactile feedback. The implementation of 3-dimensional (3D) imaging by 3D scope has overcome the limitation of having a 2-dimensional (2D) view during conventional laparoscopic hepatectomy, allowing for a more realistic and detailed visualization of the surgical field (8). The easy manipulation of a small space was facilitated by the flexible scope, which offered various surgical views including bird's eye, low angle, and lateral views (15). This feature was especially important for liver mobilization. Another essential instrument is indocyanine green (ICG) near-infrared fluoroscopy. The successful application of ICG near-infrared fluoroscopy in delineating the biliary system around the hilar plate and identifying the optimal bile duct division points during PLDH highlights the potential of real-time ICG fluorescence cholangiography as a valuable adjunct to preoperative magnetic resonance cholangiopancreatography (MRCP) (16). The use of ICG fluoroscopy has been demonstrated to be also effective for liver midplane dissection in PLDRH by accurately demarcating the precise midplane of the liver (17). We have quantitatively evaluated the effectiveness of ICG fluoroscopy during liver midplane dissection in PLDRH. Administration of a low dose (0.025 mg/kg) of ICG via a single intravenous injection is adequate for both liver midplane dissection and the identification of bile ducts (17).

Altogether, regarding the surgical setup, we strategically place four monitors in front of the operator: one displaying simultaneous vital signs, another showing preoperative MRCP, a laparoscopic monitor for the operator's reference, and a monitor for the ICG near-infrared fluorescence camera. Additionally, a second laparoscopic view monitor is

positioned on the right side of the donor for easy access by both the assistant and the scopist.

Various types of graft

Our first report of PLDH was right hepatectomy including middle hepatic vein (MHV), which was successfully performed (8). It is important to acknowledge that this approach poses technical challenges and raises concerns about donor safety. As such, including the MHV in the liver graft requires careful consideration. We have provided evidence to support the feasibility and safety of PLDRH with inclusion of the MHV in carefully selected donors and recipients by comparing it to conventional open donor right hepatectomy that includes the MHV and PLDRH that excludes the MHV (18). Although less common than right hepatectomy, left hepatectomy may be necessary considering graft-to-recipient weight ratio (GRWR) and the donor's remnant liver volume. The technical complexity of left hepatectomy with the inclusion of the MHV exceeds that of left lateral sectionectomy, left hepatectomy without the MHV, or occasionally even right hepatectomy. This is primarily due to the deep transection plane taking a sharp turn towards the left above the caudate lobe. Our results suggested that pure laparoscopic donor left hepatectomy is a viable alternative to conventional open donor left hepatectomy, with similar outcomes in terms of donor safety, recipient graft function, and long-term survival (19). Obtaining an anatomical monosegment from a donor is also feasible by pure laparoscopic left lateral sectionectomy and *in situ* reduction with the usage of intraoperative ICG near-infrared fluoroscopy (20).

Expanding selection criteria

Until the safety and feasibility of a novel surgical technique have been confirmed, it is recommended to maintain strict selection criteria. To optimize the outcome for both the donor and recipient, it is advisable to select a donor who possesses desirable attributes in terms of anatomy, volume, and quality of the liver prior to proceeding with PLDH. But at the same time, as experience accumulates, it is also important to safely extend the benefits of PLDH to as many donors as possible. Since March 2016, we have fully embraced the use of ICG cholangiography and ICG demarcation method, eliminating any absolute contraindication for PLDH in cases involving left liver, right liver, or left lateral section grafts, with or without reduction. The conventional open approach was only employed when the patient or their family specifically chose this technique after receiving informed consent and understanding the novelty of PLDH. Additionally, in cases of variant grafts such as right anterior, right posterior, or trisection grafts, the conventional open technique was utilized.

Obesity is recognized as a preoperative risk factor in gastric cancer surgery, and conducting a laparoscopic procedure in obese patients is regarded as challenging (21). In this context, while a body mass index greater than 30 kg/m^2 in potential liver donors is not an absolute prohibition for liver donation, the effects of obesity on the outcome of PLDH may vary compared to other surgical procedures. According to our previous study, there were no statistically significant differences observed in the duration of hospitalization or postoperative complications in donors undergoing PLDRH with a body mass index greater than or less than 30 kg/m^2 (22). Moreover, no significant differences were noted in the outcomes of PLDRH in obese donors compared to open donor right hepatectomy in obese donors (22). Some centers continue to adhere to stringent selection criteria based on graft weight, often specifying a maximum threshold of 700 grams. However, once proficiency is achieved and the procedure is standardized, graft weight alone should not serve as a prohibiting factor for PLDH. Our findings indicated that there were no substantial differences in the incidence of complications among donors, and early and late major complications among recipients, between PLDRH involving graft weights exceeding 1,000 g and those with graft weights below 1,000 g. Moreover, comparable outcomes were noted when comparing PLDRH in graft weight more than 1,000 g to conventional open donor right hepatectomy in graft weight more than 1,000 g (23). At SNUH, neither high donor body mass index (BMI) nor graft weight alone is considered a contraindication for PLDH.

Overcoming anatomical variations

Anatomical features such as a longer and single segment in the right hepatic artery, right portal vein, and right hepatic duct are considered advantageous for PLDRH, and as a result, several centers have adopted selection criteria that favor these anatomical features. According to our experience, PLDRH can be safely performed in a donor with separate right posterior and right anterior hepatic ducts using preoperative MRCP and intraoperative real-

time ICG fluorescence cholangiography (24). There are different techniques for bile duct division, including suture, metal clips, and Hem-O-Lok clips, each with its own advantages and disadvantages (25). Recently, at SNUH, double metal clips or Hem-O-Lok clips have been preferred due to their ease of application and the absence of concerns related to mis-suturing. Nonetheless, suturing technique is still necessary in certain cases, such as a very narrow division point and clip slippage.

When it comes to the control of right portal vein stumps, there are also several distinct methods available: the use of Hem-O-Lok clips, vascular staplers, and suture techniques (24,26-28). In cases where anatomic variations are present in the portal vein, the SNUH technique, which involves the temporary placement of Hem-O-Lok clips, intracorporeal suturing, and subsequent clip removal, has demonstrated safety and utility (26,27). To successfully execute this technique, a high degree of proficiency in laparoscopic suturing of delicate vascular structures is required. Nevertheless, the Hem-O-Lok clips, which serve as a temporary safety mechanism, confer the benefit of reducing the level of suturing-related stress, thereby allowing for more comfortable suturing. Moreover, the SNUH technique has been shown to minimize the risk of torsion more effectively than other methods.

Surgeons should carefully consider the advantages and disadvantages of each method and select the one that best fits their specific needs and preferences. By doing so, they can ensure that they are able to achieve the best possible outcomes for their patients while minimizing any potential risks or complications associated with the chosen method. Ultimately, the decision of which method to use should be based on a thorough assessment of the patient's individual case, as well as the surgeon's own expertise and experience in the field.

Lessons from the initial experience

During our initial period, there were already published reports regarding the preliminary experiences, mostly as case report or case series, with PLDRH, which had demonstrated the feasibility and potential of PLDRH (3,29-31). It is essential to exercise caution since not all intraoperative events necessarily lead to complications, and they may be overlooked or underestimated in studies. We transparently reported the intraoperative events that occurred during the very initial 26 cases of PLDRH (32). These events included incorrect dissection planes at the right upper deep portion of the midplane, portal vein injury during caudate lobe transection, stenosis of the remnant left hepatic duct, angulation of the remnant portal vein due to a different approach angle, arterial damage associated with the use of a laparoscopic energy device, postoperative bleeding due to masking of potential bleeding foci due to intra-abdominal pressure during laparoscopy, and damage to the right liver surface caused by a xiphoid trocar (32).

After gaining initial experience with the procedure, we have determined the optimal location for the port system in performing PLDH (33). While the use of a flexible scope can enhance visibility in the confined surgical area, ensuring the correct placement of ports based on anatomical target points and their intended functions is vital to ensuring safe and successful PLDH outcomes.

Before endorsing the widespread adoption of PLDH, especially PLDRH, a more robust evidence base and a comprehensive understanding of the learning curve associated with its execution are necessary (34). Our utilization of cumulative sum analysis has revealed that the learning curve for PLDRH is roughly 65–70 cases (35). Other surgeons who have experience in executing this standardized procedure may help to minimize the learning curve.

Accumulating experience with PLDRH and comparing it to conventional open donor right hepatectomy

PLDRH can eventually be justified when it is demonstrated that the procedure offers greater benefits and fewer adverse effects than conventional open donor right hepatectomy. In our initial comparative study between PLDRH and conventional open donor right hepatectomy, we found that the total operation time was longer and the percentage of cases with multiple bile duct openings was higher in the PLDRH group (36). However, there was no significant difference between the two groups in terms of the length of postoperative hospital stay, as well as the rate of complications and rehospitalizations (36). In another preliminary comparison study involving 100 cases of PLDRH conducted by a single surgeon, we observed that the recent PLDRH group had a significantly shorter operative time than both the open donor right hepatectomy group and the initial PLDRH group (37). Additionally, the complication rate decreased from the open donor right hepatectomy group to the initial PLDRH group, and further reduced in the recent PLDRH group (37). In

our next comparison study, we conducted 1:1 propensity score matching between PLDRH and conventional donor right hepatectomy, which involved 198 donors in each group (38). We found that the PLDRH group had a longer total operation time, as well as longer time to remove the liver and warm ischemic time. The Δhemoglobin (Hb)%, a measure of real blood loss calculated as ΔHb% = [(preoperative Hb – postoperative lowest Hb)/preoperative Hb] ×100, was significantly lower in the PLDRH group compared to the open group. The Pringle maneuver was not routinely performed. It was only utilized in cases of significant bleeding during parenchymal transection or when persistent oozing hindered the achievement of a clear surgical field, even in situations where the bleeding was not substantial. The rate of complications in donors was similar between the two groups. When examining the recipients, we found that although the rates of other complications were similar between the groups, there were higher rates of both early and late biliary complications in the PLDRH group. We observed that the probability of donors with a preoperative MRCP showing a single bile duct opening having actually multiple bile duct openings was significantly higher in the PLDRH group (38).

One significant advantage of PLDH over open donor hepatectomy relates to the cosmesis of donors, which had not been objectively assessed previously. We utilized a questionnaire to gauge donor satisfaction levels following PLDH and compared them with those of donors who had undergone the conventional open approach (39). Our findings revealed that donors who underwent PLDH exhibited higher levels of satisfaction when compared to their counterparts who had undergone the open approach.

Leading multicenter studies and guidelines

Although laparoscopic liver resections have gained widespread acceptance, the precise status of minimally invasive donor hepatectomy remains somewhat ambiguous and has only been briefly addressed in prior consensus conferences and guidelines on laparoscopic liver surgery (4-6). Consequently, there exists a pressing need to advance the development of minimally invasive donor hepatectomy, particularly in the context of PLDRH, and to establish guidelines that ensure its safe expansion. With vast experience of PLDH, especially PLDRH, we contributed as a leading center to establish multicenter studies and international guidelines (7,40,41). Up to June 2018, the most extensive investigation on PLDH involved five medical centers in Korea (40). The analysis incorporated a total of 545 PLDH cases, consisting of 481 right hepatectomies, 25 left hepatectomies, and 39 left lateral sectionectomies. Ten donors (1.8%) required open conversion, with no fatalities or permanent disabilities reported. A total of 25 patients (4.6%) encountered complications of grade 3 or higher Clavien-Dindo classification (40). As key leaders of the international expert consensus on minimally invasive donor hepatectomy, with a specific emphasis on PLDH, we have made a valuable contribution towards the formulation of a set of clinical guidelines that rely on both clinical expertise and available evidence (7).

Discussion

Since its inception in 2002 (1), PLDH has gained significant recognition, with a marked increase in its application to donor major hepatectomy from the middle of 2010, largely influenced by the experience of PLDRH gained at SNUH. Based on our cumulative experience, the shorter hospital stays and reduced blood loss in donors compared to open donor right hepatectomy, with comparable complications in both donor and recipient, make it justifiable to actively expand the application of PLDH, including PLDRH. As experience accumulates, the reduction in operation time, blood loss, and hospitalization period even in the long-term is an encouraging factor that supports the active promotion of PLDRH (42). With the accumulation of experience, one of the initial drawbacks of PLDRH, which was a longer operative time compared to open donor right hepatectomy, has been minimized (43). In fact, our recent study limited to a single surgeon showed even shorter operative times in PLDRH compared to open donor right hepatectomy (37). It is particularly noteworthy that these results were achieved without the use of any selection criteria for PLDRH. By sharing our experience and surgical details, as well as adapting and modifying the surgical method to fit individual needs, the learning curve for performing a safe PLDH program can be further minimized.

There are still some things to keep in mind. Surgical standardization involves the standardization of the surgical procedure, instruments, room setup, and the surgical team, and not just the skills of a single surgeon. It is crucial to have a high level of proficiency in maneuvering a flexible scope and to establish clear communication and collaboration between the surgeon and scopist (15). Additionally, expertise in both donor and recipient surgery is mandatory for the safe and feasible implementation of PLDH in LDLT, as it

involves both the donor and recipient. After analyzing the recipients, it was found that the rates of other complications of grade 3 or more, including intra-abdominal bleeding, intra-abdominal fluid collection, wound problem, hepatic artery problem, portal vein problem, hepatic vein problem, cardiac problem, pulmonary problem, gastrointestinal problem, bone problem, neurologic problem, and sepsis, were comparable across the groups (38). However, the PLDRH group exhibited higher rates of both early and late biliary complications (38). While additional research investigating other factors that may contribute to biliary complications is necessary, the elevated occurrence of such complications is probably linked to the extended warm ischemic time and the multiple bile duct openings during the operation (38). We have implemented external biliary drainage (EBD) in some cases as a measure to prevent biliary complications in transplant recipients. Based on our preliminary observations, the implementation of EBD has demonstrated efficacy in reducing the occurrence of biliary leakage following LDLT involving a graft obtained via the PLDRH and duct-to-duct biliary anastomosis (44). Nevertheless, to establish the safety and effectiveness of this method in the current era of PLDH, further randomized studies are ongoing and necessary to provide solid conclusions. Furthermore, advanced techniques and technologies that offer a clearer view of biliary anatomy without the need for extensive dissection around the bile duct, as typically required for ICG cholangiography, would be very helpful. These advancements would also offer the added benefit of providing a spatial relationship between the artery and portal vein, which can be incredibly beneficial. Additionally, the adoption of new narrow, concise, and intact clips can potentially ensure sufficient length of the bile duct in the graft side, where 0.5 mm matters, and this could significantly contribute to the reduction of biliary complications.

Given the anticipated short and intricate vascular stump in the PLDRH group, we anticipated that it would have an effect on the duration of bench surgery. The quality of the graft is a critical factor in LDLT procedures. The need for additional trimming or bench-surgery procedures to ensure graft quality can significantly impact the duration of bench surgery. We revealed that the bench surgery duration was lengthier in the PLDRH group when compared to the open group, irrespective of whether the vascular network was reconstructed (45). Additionally, the estimated graft weight did not differ significantly between PLDRH and open donor right hepatectomy. However, given that the actual graft weight tended to be lower in the PLDRH group, this should be taken into consideration during pre-surgical planning (46). In summary, the attainment of safety and feasibility in PLDRH procedures requires not just the proficiency of the donor surgeon, but also the competence and experience of the entire surgical team in both bench surgery and recipient surgery.

Conclusions

This review demonstrated that PLDH can be an alternative to open donor hepatectomy and even be a more basic and standardized method with sharing our experience and know-how. With the aim of reducing the burden placed on donors who sacrifice for the benefit of liver transplant recipients, it is hoped that PLDH, especially PLDRH, will be able to assist and benefit more donors. This, in turn, may provide greater comfort and relief to liver transplant recipients, who may otherwise struggle with feelings of guilt associated with receiving such a significant gift.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-23-239/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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