Comprehensive guide to laparoscope-assisted graft harvesting in live donors for living-donor liver transplantation: perspective of laparoscopic vision

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Abstract

Background A living donor (LD) for liver transplantation (LT) is the best target for minimally invasive surgery. Laparoscope-assisted surgery (LAS) for LDs has gradually evolved. A donor safety rate of 100% should be guaranteed.

Methods We began performing LAS for LDs in June 2012. The aim of this report is to describe the surgical procedures of LAS in detail, discuss various tips and pitfalls, and address the potential for a smooth transition to more advanced LAS.

Results Preoperative planning based on three-dimensional image analysis is a powerful tool for successful surgery. The combination of liver retraction/countertraction and the pressure produced by pneumoperitoneum widens the dissectible/cuttable layer, increasing the safety of LAS. A flexible laparoscope provides excellent magnified vision in both the horizontal view along the inferior vena cava, under adequate liver retraction, and in the lateral view, to harvest left-sided grafts in critical procedures. Intentional omission of painful incisions is beneficial for LDs. Hepatectomy using a smaller midline incision is safe if a hanging maneuver is used. Safe transition from LAS to a hybrid technique involving a combination of pure laparoscopic surgery and subsequent open surgery seems possible.

Conclusion LDLT surgeons have a very broad intellectual and technical frontier.

Keywords Laparoscopic hepatectomy, donor surgery, donor, laparoscopic surgery, laparoscopy

Introduction

Pure laparoscopic surgery (PLS) has been adopted in various fields. PLS is advantageous in that it entails less blood loss, less pain, a lower morbidity rate, earlier postoperative meal ingestion, and a shorter hospital stay compared with conventional open surgery (OS) [1-4]. The benefits to patients are well validated [1-9]. However, in the field of hepatobiliary pancreatic (HBP) surgery in particular, PLS has developed relatively slowly because of technical difficulties, a protracted learning curve, and massive bleeding [1-3,9,10].

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Conflict of Interest: None

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Living-donor liver transplantation (LDLT) requires a healthy individual as a living donor (LD). Perioperative damage should be minimized as much as possible, and an LD for LDLT is the best target for minimally invasive surgery [1,5,7,9,11-14] because he or she inherently requires no invasive surgical procedures. Additionally, a donor safety rate of 100% should be guaranteed [6,7,15,16].

Each country has its own health insurance system. The Japanese government employs a universal health insurance system. Therefore, novel surgical procedures in Japan are not authorized until they are included in the health insurance system's listing by the governmental council. Unfortunately, a few HBP surgeons violated the medical ethics code by ignoring the health insurance system in Japan, and their laparoscopic surgery techniques emerged as a social issue in 2014. However, laparoscopic HBP surgeries potentially have substantial benefits [1-9]. The performance of advanced HBP surgeries should not be compromised by a small number of thoughtless surgeons. Specific regulations and ethical policies for advanced surgeries in LDs should be established for LDLT [15,16], and technological developments should be disseminated worldwide [5,7].

We employ a laparoscope for graft harvesting in LDs and we utilize the concept of laparoscope-assisted surgery (LAS).
LAS is not considered a type of hand-assisted laparoscopic surgery (HALS), but an extension of OS [9,10,12,13,17,18]. Both preoperative imaging techniques and surgical devices are currently well developed [19,20], and hepatectomy procedures via direct vision from a small midline incision are therefore safe [21,22] if a hanging maneuver is used [18,23]. Hence, we herein focus on surgical procedures performed in preparation for a hanging maneuver. We describe our procedures in detail and discuss both tips and pitfalls. In addition, we discuss the potential for smooth transition from LAS to PLS or a hybrid technique (HT).

**Patients and methods**

**Ethical approval**

Skilled surgeons of Nagasaki University, Japan previously provided us with instructions regarding their LAS procedures [21,22,24], allowing us to develop our own LAS technique. The LAS protocol used in our LDLT program has been approved by our institutional review board (Approved No. 991; Ethics Review Committee of Kyoto University Graduate School of Medicine, Kyoto, Japan). LAS for LDs was thus introduced to LDLT procedures in June 2012.

**Results**

**Preoperative imaging studies**

Volumetric assessment of the hepatic remnant should be performed first to ensure safety for the LD. We use imaging software (HepaVision, MeVis software; MeVisLab, Bremen, Germany) for volumetric analyses of both the hepatic remnant and the graft volume. Precise recognition of the portal vein (PV) and hepatic vein (HV) territories is also important. The predicted territories of portal ischemia due to PV obstruction and venous congestion due to HV sacrifice should be accurately evaluated in both the hepatic remnant and the liver allograft [25].

Anatomical analysis should be performed precisely, especially for LAS. In our institution, detailed analysis is performed by a high-speed three-dimensional (3D) image-analyzing system (Synapse Vincent; Fujifilm Medical, Tokyo, Japan) [19]. Dynamic computed tomography detects the hepatic artery, PV, and HV. Drip infusion cholangiographic computed tomography is performed for analysis of the biliary duct, if needed. Drip infusion cholangiographic computed tomography is more suitable than magnetic resonance cholangiography for creating such 3D images, although it is associated with a higher rate of allergic response to infused agents [26]. Hence, 3D imaging that articulates the vessels and biliary duct in an all-in-one package can be performed if required because drip infusion cholangiographic computed tomography is only performed in selected cases (Fig. 1A).

**Harvest procedure of right-lobe graft (RLG)**

RLG harvesting is performed as follows. The xiphoid process is confirmed. An 8-cm mark is made along the midline starting from a point 2 cm below the xiphoid process (Fig. 1B). Additional 2-cm marks starting from the upper and lower sides of the midline incision are then made to ensure adequate visualization of the HV and hepatic hilum (Fig. 1B, C). A GelPort Laparoscopic System containing a GelSeal cap, Alexis wound protector/retractor, and sterile lubricant is used (Applied Medical Resources Co., Rancho Santa Margarita, CA, USA). The midline incision is protected and retracted by a wound attachment (Fig. 1C). Direct vision alone may provide an inadequate surgical field for further procedures (Fig. 1D). However, the combined use of a laparoscope through the midline incision is an effective solution. Laparoscopic vision provides an excellent magnified field for cutting of the falciform ligament (Fig. 1E), dissection around the right HV (RHV) (Fig. 1F), and detection of the division between the RHV and middle HV (MHV) (Fig. 1G). The 8-cm midline incision is then sealed by a gel-type attachment (Fig. 1H).

A 5-mm camera port is placed at the umbilicus and a 5-mm working port in the right lateral wall (Fig. 1H). The intra-abdominal organs are guarded by hand during port placement (Fig. 2A). The surgeon's left hand, which mainly retracts the liver, is inserted into the abdomen via a sealing port in situations where two assistants (a laparoscopist assistant and a surgical assistant) are present (Fig. 2B). If the assistant surgeon is skillful, his or her right hand is inserted via a sealing port to retract the liver, and a flexible laparoscope is manipulated only by the left hand. If only one assistant is present, he or she assists with surgery and laparoscopy. The right hand of the surgeon maintains close contact with the laparoscope, although the performance of advanced techniques by the assistant is required (Fig. 2C). The right hepatic triangular ligament is cut by a hook-shaped electrode (HSE) under liver retraction (Fig. 2D). The HSE has the advantage of simultaneously cutting and pulling the tissue, creating a safety area in front of the cut tissue. Hence, one working port is usually enough (Fig. 1H). Delicate and detail-oriented retraction/countertraction is performed with the finger, and general and rough retraction/countertraction is performed with the hand (Fig. 2E). The retroperitoneum around the right hepatic triangular ligament, right adrenal gland (RAG), and inferior vena cava (IVC) is cut under countertraction by the fingers and HSE (Fig. 2F, G). The pressure produced by pneumoperitoneum also creates a dissectible and cuttable layer by marked infiltration of carbon dioxide gas. The bare area of the liver is exposed, and the RAG appears as a capsule with its own thin surface membrane (Fig. 2H, 3A). A dissectible/cuttable layer is created by adequate retraction/countertraction with hand or finger assistance and under the pressure of pneumoperitoneum (Fig. 3A). This wide layer is cut as close to the liver side as possible (Fig. 3A, B). Even slightly careless retraction/countertraction may easily result in hemorrhage and/or oozing around the RAG (Fig. 3C, D). Under liver retraction, a horizontal laparoscopic view from the para-IVC (not from Morrison's pouch) provides an excellent view along the IVC (Fig. 3E). The lateral wall of the

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IVC is exposed, and the short HVs and hepatocaval ligament are then skeletonized (Fig. 3F). As above, even slightly careless retraction/countertraction easily results in hemorrhage and/or oozing around the IVC (Fig. 3F). Employing the many-angled views of the flexible laparoscope, the liver is removed from the diaphragm without injury (Fig. 3G, H). Simultaneous
Figure 3  (A,B) A dissectible/cuttable layer should be created (yellow area). An adequately wide layer is confirmed with a reciprocating hook (purple arrow) and is cut near the liver (red arrow). (C,D) Even slightly careless retraction/countertraction of the liver may easily result in hemorrhage and/or oozing around the right adrenal gland (aqua arrow and areas). (E) Delicate and detail-oriented retraction/countertraction is performed with the finger, and general and rough retraction/countertraction is performed with the hand (blue arrows). The horizontal view via the laparoscope provides an excellent view along the inferior vena cava (green arrows). The surgical field essentially spreads to the foreground via the laparoscope (green lines). (F) The lateral wall of the inferior vena cava is bared, and then short hepatic veins and the hepaticocaval ligament can be skeletonized. Even slightly careless retraction/countertraction will easily result in hemorrhage and/or oozing around the inferior vena cava (black arrow). (G) From an overview provided by laparoscopic vision, the liver is removed from the diaphragm without any injury to the liver or phrenic veins (blue arrows). The bare area of the liver is adequately exposed. The dissectible/cuttable layer is very wide (yellow area) and is intentionally cut as close to the liver as possible (red arrow). (H) The view from underneath also provides an excellent field for cutting a dissectible/cuttable layer (yellow area)

BAL, bare area of the liver; HSE, hook-shaped electrode; IVC, inferior vena cava; RAG, right adrenal gland; SHV, short hepatic vein

retraction/countertraction of the liver and pressure induced by pneumoperitoneum helps to create a dissectible/cuttable layer wide enough for dissection; therefore, this layer should be intentionally traced as close to the liver as possible (Fig. 4A, B). Even blunt dissection by a finger works well (Fig. 4A, B). The walls of the RHV and IVC are carefully detected close to the RHV root (Fig. 4C). The wound-sealing attachment is then removed. Direct vision with focal lighting also provides a preferable surgical field for RHV skeletonization (Fig. 4D-F) if a 2-cm upper extensional incision is made (Fig. 1B, C). The cut ends around the RHV from the right and central sides are connected via laparoscopic vision (direct vision provides only a limited view under the right subphrenic space) (Fig. 4G) [18]. The RHV is skeletonized (Fig. 4H) and then hanged with a Penrose drain (Fig. 5A). An extensional incision is added at the lower side if it appears that subsequent procedures at the hepatic hilum are likely to be difficult (Fig. 1B, C).

Harvest procedure of left-sided graft (LSG)

Laparoscope-assisted removal of the right lobe is performed in the same manner as the procedure described above. The left hepatic triangular ligament is cut (Fig. 5B, C). The cut ends of the membranes from the central and left hepatic triangular ligament sides are connected (Fig. 5D). Simultaneous retraction/countertraction of the liver and pressure induced by pneumoperitoneum widens the dissectible/cuttable layer, and this layer should be intentionally traced as close to the liver as possible (Fig. 5D). The wound-sealing attachment is then removed. Direct vision with an upper extensional incision and focal lighting provides a surgical field for preparation of a hanging maneuver of the left HV (LHV) and MHV (Fig. 5E-G), including dissection around the LHV, MHV, or their common channel (Fig. 5E); detection of the division between the MHV and RHV (Fig. 5F); and skeletonization and subsequent ligation of Arantius’ duct with adequate bareness of the IVC wall on the upper side of Spiegel's lobe. The pinch-burn-cut technique works well [27] (Fig. 5G). Lateral scopic vision provides an excellent magnified field for ligation of the phrenic vein (Fig. 5H), skeletonization and subsequent ligation of Arantius’ duct (Fig. 6A), complete dissection of the connective tissue on the upper side of Spiegel's lobe (Fig. 5H, 6B), and adequate bareness of the IVC wall on the upper side of Spiegel's lobe (Fig. 6C, D).

These procedures, which ensure adequate exposure of the IVC wall, are important for LSG (Fig. 5G, H; 6B-D). The common channel of the LHV and MHV, or LHV, is adequately skeletonized (Fig. 6E). The common channel of the LHV is then hanged with a Penrose drain (Fig. 6F). The lateral laparoscopic view through the midline incision provides excellent magnified vision and works well for harvesting during LSG. An extensional incision at the lower side is added if further procedures at the hepatic hilum are difficult (Fig. 1B, C).

Our procedures for other types of allografts

Our LAS can be applied to other graft types, such as monosegmental grafts [28], RLG with the MHV [29], or right posterior grafts [26]. Although this may be technically difficult and high-risk in that the cutting surface is set to an 8-cm midline incision, a hanging maneuver of the HV enables a safe hepatectomy even via a smaller midline incision [18,23].
Currently, in our institution, the rough removal of the liver is achieved by pneumoperitoneum rather than the open method. Here, based on our surgical procedures of PLS for hepatectomy in patients undergoing HBP surgery, we verified and validated the potential for a smooth transition from LAS to an HT or PLS in LDs [9,18,30,31]. Specialized gauze (Deltagauze; Osaki Medical Co., Nagoya, Japan) (Fig. 6G) and an articulated fan-shaped retractor (Fig. 6H) allow for adequate retraction/countertraction without any slippage (Fig. 7A). Additionally, advanced devices for PLS are available (Fig. 7A, B). Laparoscopic Medical Co., Nagoya, Japan) (Fig. 6G) and an articulated fan-shaped retractor (Fig. 6H) allow for adequate retraction/countertraction without any slippage (Fig. 7A). Additionally, advanced devices for PLS are available (Fig. 7A, B). Laparoscopic
coagulating shears (Harmonic Ace, Ethicon; Johnson & Johnson, Tokyo, Japan) serve as a useful scalpel that provides reliable hemostasis (Fig. 7A). A button-shaped electrode with suction used in conjunction with a soft-coagulation system (VIO; Erbe, Tübingen, Germany) is an effective tool for secure hemostasis (Fig. 7B). A self-irrigating monopolar electrode (IO advanced, Erbe) is also useful for hemostasis. The assistant surgeon removes the liver using two forceps/retractors (Fig. 7C).

Under liver retraction, the lateral wall of the IVC is bared by laparosonic coagulating shears (Fig. 7D), and short HVs (SHVs) and the hepatocaval ligament are then skeletonized (Fig. 7E), as the horizontal view from the para-IVC provides an excellent magnified view along the IVC via the flexible laparoscope (Fig. 7F). This view represents one of the advantages of using a laparoscope (Fig. 3E, 7E, F). The laparoscopic surgical field then essentially spreads to the foreground, and suture closure of unexpected injuries, including bleeding, should therefore be made from the front and bottom sides, making the best use of the front safety area (Fig. 7G).

Discussion

We consider our LAS as an extension of OS [9,12,13,17,18], though HALS is considered an extension of laparoscopic surgery [10]. Essentially, our LAS is an optional extension of OS, making the best use of scopic vision [9,18,21,24]. The concepts of LAS and HALS are distinct from each other [9,10,28]. Although HALS abandons the advantages of PLS or HT [9,23], our LAS benefits LDs. Though it is unrealistic to expect any procedure to have no complications, actual complications greater than grade III according to the Clavien–Dindo classification were not observed in our LAS in live donors.

Liver allografts should be harvested without subtle injuries because even a subtle injury may result in intractable complications in the LDLT recipient [11,18]. Hence, a certain incision is required for graft harvesting, although LDLT surgeons try to minimize this incision [18,21,24]. LAS is advantageous in terms of inducing less damage to the abdominal wall and allowing for faster postoperative recovery [18,21,22]. Surprisingly, 30% to 50% of complications in LDs are related to abdominal wall damage and include incisional hernia, bowel obstruction, and chronic discomfort [5]. Moreover, 60% of LDs develop wound-related symptoms, such as a tightened wound, paresthesia, or a hypertrophic scar even at 1 year after OS, and 35% of them continue to have complaints thereafter [18]. In LAS, an upper middle incision is preferable for minimizing abdominal muscle damage [18,21,22,24], and this incision could allow access to all segments [18,21,22,24]. Skillful surgeons have gradually expanded their surgical indications for LDs, in the order of OS, LAS or HT, and PLS [9,18,21,22,30,31]. Subsequently, interestingly enough, they have reported informative results that intentional omission of a transverse or subcostal incision surely benefited patients after surgery, and that unexpected injuries during HT occurred in patients with a questionable omission of midline incision [18,21,22]. We agree that such omission of the midline incision is risky [9,18,21,22], although intentional omission of the transverse or subcostal incision is very beneficial [21,22]. Although a subcostal incision is painful, this incision provides an adequate surgical field [9,18]. It is reasonable that less analgesic action enables a shorter time to hospital discharge and earlier social reintegration [18,21,22]. On the other hand, a scar that is concealable within a bikini line is cosmetically advantageous in some countries with long seashores and nice beaches [5,31]. However, if the skin incision is far from the upper abdomen, one of the advantages of LAS...
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In comparison with our PLS, our LAS can provide a dissectible/cuttable layer with a width that makes it unlikely to
suffer injury by the best use of simultaneous use of retraction/countertraction by a hand or finger and marked infiltration of carbon dioxide gas (Fig. 3G, H, 4A, B). Even a lower pressure of pneumoperitoneum is enough to create this layer in LAS. The sufficient width of this layer enables simple cutting by the HSE (Fig. 2E-G, Fig. 3A-D, H, 4C, 5D). Based on this high degree of surgical safety, we intentionally omitted the transverse incision, which is required only for liver removal from the diaphragm [23]. This omission has a great advantage, especially for LDs undergoing RLG, because a longer transverse incision is required in an OS for RLG rather than for LSG [23,33].

For HV hanging in RLG, it is important that bareness of the RHV wall is established and dissection at the RHV/MHV division is performed before creation of pneumoperitoneum (Fig. 1F, G). For HV hanging in LSG, combined use of the laparoscope via an even smaller midline incision is effective. The lateral view via a flexible laparoscope provides an excellent magnified field during PLS, even on the right side from the esophagus (Fig. 7H). Under this view, a direct approach for important procedures involving HV hanging can be performed simply and rapidly (Fig. 5H, 6-D).

Current laparoscopic instruments are well developed, but each instrument should be used in the correct manner [9,34]. Many devices are available, and surgeons should follow the manufacturers’ instructions to avoid any malfunctions [9,34]. Surgeons must also make sure that their knowledge of how to use these devices is regularly updated [34]. In HV reconstruction, a margin of graft HV is important to ensure reliable anastomosis and excellent outflow [35]. The HV margin may be shortened during PLS because the HV will be cut by an endostapler. We employ a specialized device for our LAS [Proximate TX (TX30V), White cartridge (XR30V); Ethicon, Johnson & Johnson], and this device facilitates proper placement of the stapler on the tissue without cutting. This device only closes the side of the donor IVC; it never cuts the graft HV. Hence, the HV margin of the graft is preserved. We cannot apply this device via a laparoscopic port, which is why we make a midline incision in the upper abdomen and why we did not challenge PLS in LDs.

Experience alone is insufficient for achieving safety in laparoscopic surgery [3,34,36]. Preoperative anatomical analysis based on 3D imaging is critical for successful HBP surgeries, including LAS, HT, and PLS (Fig. 1A). Preoperative anatomical analysis also enables both precise evaluation of the liver remnant and graft volume, and efficient planning of the actual operative procedures [19,37], if the surgeons themselves create simulation images [34]. It is reasonable that the graft volume never involves the caudate lobe, because the PV and/or biliary duct branches of the caudate lobe are usually ligated during surgical procedures around the hepatic hilum. Moreover, the SHVs that drain the caudate inflow are also ligated. Although LAS provides an excellent view around the IVC, removal of the whole caudate lobe with ligation of the hepatocaval ligament and all SHVs will require a longer operative time (Fig. 3F, 7E, F). If the graft harvest is delayed, a longer waiting time, which incorporates an anhepatic phase during LDLT, will cause severe problems, including coagulopathy and hemodynamic instability in the LDLT recipient. During LDLT, the donor surgery should proceed without any delay. Thus, preoperative evaluation of the graft volume without the caudate lobe is a realistic way to precisely predict the functional graft volume, a stable course during the recipient surgery, and a smoother process of our LAS.

The required surgical techniques for OS and PLS are completely distinct [1-3,10]. Surgical procedures in PLS should be carefully considered and well established [1,3,9,11,15,16], and we should consider that PLS commonly requires a longer operative time than OS [10]. Some researchers have reported advantageous points of PLS for LDs, such as less blood loss, less pain, a shorter hospital stay, and earlier social reintegration [3,5,6,14]. We also understand that many LDLT surgeons wish to attempt PLS for LDs [1,5,7,9,11,14]. Some LDLT surgeons have actually documented PLS for RLG and LSG [5,7,14]. Advanced devices are dependable (Fig. 6G, H, 7A, B), and flexible laparoscopes provide an excellent magnified view (Fig. 7D-F, H). However, surgeons should become technically familiar with PLS [3,9,38]. A key to this procedure is to expose the bare area of the liver in the right subphrenic area, where two working ports are placed as far as possible toward the lateral-dorsal side (Fig. 1H) and as far as possible toward the head side along the upper midline (Fig. 1B) [38]. The assistant surgeon should adequately retract the liver during the surgical procedure (Fig. 7C, D) to maintain excellent laparoscopic vision along the IVC (Fig. 7E, F). Unexpected bleeding from vessels during donor surgery is a nightmare for surgeons because blood transfusions should be avoided. In OS, a suture placed at the far side of the bleeding point and subsequent grasping of this suture immediately improves this situation. On the other hand, the laparoscopic surgical field essentially spreads to the foreground; therefore, the needle to insert a suture for hemostasis should enter from underneath toward the foreground during PLS (Fig. 7G). In PLS, the rubbing of a bleeding vessel or oozing tissue by a button-shaped electrode with suction with a soft-coagulation system is a key technique for reliable hemostasis (Fig. 7B), since efficient bleeding control is so important in PLS [9]. A self-irrigating monopolar electrode (IO advanced, Erbe) is also useful for hemostasis, especially for sure hemostasis on the cut surface of the liver.

Although there are no definitive studies on optimal drain placement after heptectomy by PLS, we usually place a closed drain only in the early postoperative period. The bilirubin and amylase levels in the drain discharge may be informative for clinical decisions after PLS. Drains should be placed automatically, and we believe that short-term placement of a drain via a stab wound for the laparoscopic port is not invasive but is effective for the patient’s postoperative course after PLS.

A protracted learning curve under excellent teaching is required for a procurement of prestigious laparoscopic surgeon. Board-certified and well-educated laparoscopic surgeons may employ an HT for LDs without any delay [9,31], and such surgeons in our own institution allow the further stepwise introduction of advanced laparoscopic surgeries [2,3]. Considering the current status of our institution, careful progression from LAS to an HT is our current goal, because we agree that both an HT and HALS can function as a bridge to PLS in the future [10]. Although we are not ready for PLS in LDs [15,16], an HT, which is a combined surgery involving PLS until the preparation for a...
hanging maneuver and subsequent OS with a direct approach using a laparoscope, seems to be a safe possibility. Where should LDLT surgeons head in the next decade? LDLT surgeons have a very broad intellectual and technical frontier.

References