Laparoscopic liver resection: a review of current indications and surgical techniques

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Abstract: Laparoscopic liver resection (LLR) has been the most impressive development in the field of liver surgery in recent two decades. Technical innovations and experience accumulation have made LLR a safe and effective procedure with faster postoperative recovery. Despite the fast spreading of the procedure, details regarding the indications, oncological outcomes and technical essentials were still disputable. To address these issues, two international consensus conferences were hold to update the knowledge in this field. The statements of the both conferences were not conclusive and more high-quality researches are required. In this article, we reviewed the development and the current state of LLR. Indications, outcomes, surgical techniques and devices used in LLR were also discussed.

Keywords: Laparoscopic liver resection (LLR); minimally invasive; indication; technique

Introduction

Radical surgical resection is still one of the most important curative treatments for most liver masses. Attempts at managing diseases of hepato-biliary system through laparoscope was started in 1987, surgeons performed the first case of laparoscopic cholecystectomy (1). Ever since then, laparoscopic approach soon became a wide-adopted standard procedure for patients who need a cholecystectomy. However, as limitations of technique and defects of equipment still remained, it was 4 years later until the first attempt of laparoscopic liver resection (LLR) was made (2). Initial reports of LLR indicated that the outcomes of the patients were comparable to the traditional open approach, which led to positive conclusions that in selected patients, LLR can be a safe and effective treatment. Since then, LLR has become a potentially alternative to traditional open liver resection.

The initial development of LLR was slow, only sporadic cases with local resection were reported (3-6). Left lateral sectionectomy was first reported in 1996, which inspired the interests of surgeons on LLR although the first case was converted to open surgery because of intraoperative massive bleeding (7,8). Since then, with accumulated experience, the cases of LLR increased dramatically around the world, quickly expanding to laparoscopic hemi-hepatectomy, single segmentectomy (not limited to II or III), trisectionectomy (extended or limited anatomical resection), and living donor liver donation (9-11).

The first international experts' consensus conference was held in 2008 to summarize and assess the feasibility and safety of the remarkable development (12). The concept of major liver resections was defined as hemi-hepatectomies,

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trisectionectomies and resections of the difficult posterior segments (IVa, VII, VIII). The conference affirmed that LLR was a safe and effective approach to the management of surgical liver disease in the hands well-trained surgeons with experience in hepatobiliary and laparoscopic surgery. On the other hand, it also listed the concerns of LLR abuse, including inappropriate widened indications and unstable clinical outcomes related to the lack of training standards and credentials. In 2015, the second conference updated consensus, evaluating the status of LLR with recommendations given (13), which mainly focused on the benefits, risks and techniques of LLR and provided references to its development. These two conferences, together with several retrospective studies, supported that LLR was not only not inferior to open procedure for both minor and major hepatic resections in terms of oncological outcomes, but also advantageous in many fields: less blood loss, decreased postoperative morbidity and shorter hospital stay (10,14-18). However, till now, limited conclusions from randomized controlled trials which have been called out worldwide were available, several concerns still remain controversial: what are the appropriate indications and contraindications? How should surgeons perform precise operations? Whether patients can really benefit from the laparoscopic approach and how?

In this review, we will discuss major concerns about LLR together with recent progress in this field which we hope can offer helps to LLR procedure reassessment and standardization.

Patients selection (open or laparoscopic)

As the barcelona clinic liver cancer (BCLC) staging system recommended, resection remains the first-line treatment for 0-A stage hepatocellular carcinoma (HCC) (19,20). For suitable patients selected for LLR, three important factors must be taken into account: the presence of cirrhosis, the location of the mass and the size of the mass. The importance of the latter two factors is different between benign and malignant disease. It is a generally accepted concept that for malignant disease, squeezing the lesion and a poor dissecting margin have a negative influence on long-term outcome. In the discussion below, we will focus mostly on LLR for malignant tumors.

Location of the tumor

Considering the poor exposure of the operation area and

difficult bleeding control, it was challengeable to perform LLR for lesions in the posterosuperior part of the liver (21). The Louisville consensus noted that single, no larger than 5 cm lesions located in peripheral liver area (segment II to VI) would be an appropriate indication of LLR (12). As the skills and the experiences accumulated, resection of difficult segments (VII, VIII and IVa) and even caudal lobe was proved to be safe and repeatable. Dulucq *et al.* shared their experience of two isolated laparoscopic resections of the hepatic caudate lobe without eventful postoperative course (22). It is worth mentioning that there was a complication of inferior vena cava (IVC) injury in one case which made the procedure tough even though it did not lead to a conversion. Araki *et al.* proved the feasibility of the approach of caudate lobe resections by analyzing such cases around 14 years from 2000 to 2014 (23). Evidence from multicenter suggested that LLR for posterosuperior parts of the liver was feasible and safe (24-26). In addition, the authors pointed out that surgical techniques must be individualized according to the tumor location and its relationship to the major hepatic vessels. Zheng *et al.* summarized 281 patients who received LLR for lesions located posterosuperior liver segments (I, IVa, VII and VIII), in which the blood loss, complication rate, hospital stay and tumor recurrence was not significantly different comparing with anterolateral (II, III, IVb, V and VI) group, despite longer operation time, higher conversion rate and thinner resection margin (27). Until now, in the experienced centers, location of the tumor may not hamper the laparoscopic approach technically any more if the tumor is assessed resectable in conventional laparotomy.

Size of the tumor

It was well recognized that tumor size is a risk factor in both laparoscopic and open liver tumor resection. Invasion of the important structures which must be conserved in consideration of better inflow and outflow of remnant parenchyma by a large liver tumor is very common, for a LLR, exposing and retracting the tumor would necessarily increase the chance of tumor spread. To avoid the negative influence of the procedure, Louisville statement recommended that tumor measured more than 5 cm is not a good candidate for LLR. Interestingly, in recent years, several reports provided data on LLR for tumor more than 5 cm, the results of which implicated that tumor size may not be a negative risk factor for both short and long-term outcome.

Ai *et al.* conducted a single-center study to evaluate the outcomes of LLR for HCC with a tumor size of 5–10 cm (28). Ninety-seven of 275 included patients received LLR, the others received open procedure. The mean operative time, mean estimated intraoperative blood loss, and blood transfusion rate did not significantly differ. However, shorter postoperative hospital stay and lower postoperative complications were observed in LLR group. The outcomes from follow-up period (median overall follow-up time was 21 months and the median follow-up time of survivors was 23 months) showed no significant difference in tumor recurrence rate. The 1- and 3-year rates of overall survival (OS) time, as well as disease-free survival (DFS) rate, were also not significantly different between the two groups. And this gave positive evidence to response the worries of inadequate resection margin and unsatisfying radical resection rate in LLR for HCC. Another retrospective comparative study was performed between patients who underwent LLR for HCC of ≥5 and <5 cm (29). Outcomes indicated that the conversion rate, operation time, blood loss, postoperative hospital stay, the DFS and OS time (median follow-up time of 37 months) were comparable between the two groups.

Study about LLR for large intrahepatic cholangiocarcinoma (ICC) was also available. Besides the concerns similar to those of HCC (inadequate resection margin, tumor rupture, uncontrollable bleeding and tumor seeding), failure of lymph node dissection under laparoscopy was a problem that can not be neglected. Wei *et al.* analyzed perioperative and long-term outcomes in patients suffered from large (≥5 cm) or multiple (≥2 lesions) ICCs (30). The study drew a conclusion that compared with LLR for small ICCs, LLR for large lesions was technically safe, feasible, and oncologically effective in selected patients. Furthermore, comparisons with open liver resection for large or multiple were made in this study, and no evidence indicated that LLR was inferior in both short and long-term outcomes.

Malignant tumor larger than 10 cm seems no longer an absolute contraindication for LLR nowadays. A study about LLR for colorectal liver metastases showed LLR for tumors with diameter more than 10 cm is safe and effective, thus got the conclusion that tumor size of large colorectal liver metastases should not veto the selection of laparoscopic approach (31). Several LLR cases for huge benign lesion (>10 cm) were published recently (32-34). The procedures showed optimistic outcomes. However, the number of such cases is small and it may not be enough to prove LLR can be widely adopted in this series of patients. On the other hand, the increased operation time required in LLR for huge tumor may add extra risks, such as anesthetic accident, pulmonary infection and nursing problem. These potential problems may add extra worries on application of LLR in patients with big benign masses.

Laparoscopic living liver donation

In the field of living donor liver transplantation (include adult to child and adult to adult), LLR offers safe minimally invasive approach for donors. The report of the first laparoscopic living donor hepatectomy was published in 2002 (11). It was an adult to child case and the procedure was rapidly adopted by followers. Then laparoscopic left or right hepatectomies for adult to adult transplantation were performed (35,36). Laparoscopic living donor left lateral sectionectomy was proved to be safe and repeatable and had become a standard care in experienced centers (37). For the laparoscopic right liver donation, several reports have shown the feasibility of this procedure and it do have advantages in postoperative recovery and cosmetic demands (38,39). On the other hand, much more complicated operation and extremely strict donor screening criteria can not be ignored. Though there were successful cases reported, experts still regarded laparoscopic right donor hepatectomy as an immature technique and more data were required (40).

Cirrhosis

LLR for tumor complicated with underlying liver disease, mostly referring to liver cirrhosis, is controversial. Liver transplantation was regarded as a curative treatment for HCC patients with liver cirrhosis (41,42). Unfortunately, shortage of donor and high costs of the procedure made liver transplantation the last resort for these set of patients. Liver resection remains the first choice of treatment in most circumstances (19,20). The management of cirrhosis liver under laparoscope should be more patient and cautious because it is difficult to identify the important anatomic structures and the liver parenchyma's weakened response to energy equipment. In early period, a number of reports affirmed the safety and feasibility of minor LLR for HCC in patients with cirrhosis (21,43-45). But it was documented that patients with HCC on cirrhotic liver might have a higher transfusion, conversion and complication rate (45). Aiming to further evaluate the procedure, study conducted by Belli *et al.* compared the outcomes between the laparoscopic and open groups in cirrhotic patients (46).

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Laparoscopic surgery had a lower morbidity rate than open surgery, and this might be related to LLR group had a smaller median tumor size than open group and LLR was less extensive. The 1- and 3-year OS rate was 94% and 67% respectively with the median OS of 63 months and the 1 and 3-year DFS rate was 78% and 53% respectively with the median DFS of 38 months. There was no significant difference in OS and DFS rates between laparoscopic and open groups. Similar studies showed LLR for HCC in cirrhotic liver could reduce severe complications and shorten hospital stay. Moreover, these studies offered 5-year OS and DFS rate (47,48). On the basis of similar surgical margin, there was a trend towards better OS rate in LLR group though the data had no statistically difference (70% in LLR group *vs.* 46% in open group). Studies on major LLR for cirrhosis liver were available recently. Yoon *et al.*, Xu *et al.* provided data about major LLR for cirrhosis liver in their centers, respectively (49,50). Their studies may provide higher level evidence by using the propensity score-matched analysis (51). Contrasted with open procedure, LLR for cirrhosis liver required a longer operation time due to difficulty in dissecting liver parenchyma. The blood loss, postoperative complication rate, 2-year OS and DFS were comparable with the open group. All these evidences supported that LLR may be a viable alternative to open procedure even in patients with liver cirrhosis.

Surgical instruments and techniques

The development of LLR was closely related to the adoption of constantly updated surgical instruments (52,53). Generally, instruments can be classified as assistant decision-making parts and concrete operation parts.

Intraoperative ultrasonography (IOUS) and fluorescence imaging system

IOUS is not only useful but indispensable and it promoted the progress of LLR significantly (45,54-56). Several important decision-making parameters, the extent of tumors, relationship to blood vessels and the potential plane of resection can be clearly and readily displayed. as anatomical resection of malignant tumors had been proved with better long-term outcomes (57,58). In anatomical LLR, identification of the hepatic veins and Glissonian system is of vital importance in deciding the transection plane. Careful identification and management of the

branches of these vessels with IOUS can minimize the risk of vascular injury. Another advantage is that IOUS is able to identify the omitted lesions and have significant influence on operation decision-making. The utilize of IOUS in LLR has been recommended in several guidelines (13,59,60).

However, the resection range in the cases of single anatomic segmentectomy can not be marked precisely simply by ultrasound alone. Intraoperative fluorescence imaging techniques using indocyanine green (ICG) is needed for identifying the boundary of segments by laparoscopic fluorescence imaging (61-63). By injecting ICG into the portal branch of target resection segments or adjacent segments after clamping segmental portal pedicle, a liver map of hyperfluorescence or hypofluorescence region appeared under a specific visual system (laparoscopic near-infrared camera system was chosen in the report). The method shared in the reports is considered to be a recommendation for standard anatomic LLR aiming to achieve a better oncological outcome. In the meanwhile, there were experiences indicating that the intraoperative fluorescence imaging techniques in LLR have a potential to provide diagnostic information for malignancy identification as a compensation of limited palpation (64).

Instruments in parenchyma transection

In terms of concrete operation, multitudinous innovative devices were used. in transecting the liver, there is not a conclusion on which device is superior to parenchymal transection yet (13,65).

Ultrasonic scalpel, stapler, cavitron ultrasonic surgical aspirator (CUSA) and water jet were mostly widely mentioned devices used to transect parenchyma while monopolar and bipolar cautery, argon beam coagulator, microwave coagulator were used to manage the cutting surface bleeding. By collecting data of 1499 LLR cases from 10 international centers, Buell *et al.* reported that parenchymal transection using stapler provides advantages of less blood loss and shorter operation time compared to electrosurgical resection (include radiofrequency ablation, tissuelink, ligasure and ultrasonic dissection) (66). However, resections using stapler provided a smaller pathological margin than the electrosurgical technique which leads to oncological concerns.

There was a review indicating that compared with CUSA and blunt dissection water jet had better performance in reducing blood loss and dissection time (67). But while

Table 1 Characters of several liver parenchyma transection instruments

Category	Utility	Advantage	Disadvantage
Ultrasonic scalpel	Separate parenchyma	Wide range of application	Poor performance in separating deep layer parenchyma
Stapler	Cut and suture large tubular structures	Easy to use, save both time and labor	Relatively expensive
CUSA[†]	Separate parenchyma	Less chance to injure vascular wall	–
Water jet	Separate parenchyma	Less chance to injure vascular wall	Easy to blurred the camera
Argon bean coagulator	Hemostasis	–	Increased risk of gas embolism
Mono/bi-polar, microwave coagulator	Hemostasis	–	–

†, cavitron ultrasonic surgical aspirator.

using water jet in parenchymal dissection, camera would be often blurred by the device thus need frequent clean, make the process hard to proceed.

The efficiencies of bipolar compression devices and ultrasonic devices for LLR were evaluated in a retrospective control study (68). The bipolar compression devices were proved to have advantages in reducing transection time. In spite of the lack of significant difference in the estimated blood loss, bipolar compression devices had the tendency to provide better bleeding control. Ultrasonic devices utilized the vibration of its blades to cut and coagulate. Small vessels (≤3 mm) could be easily controlled by ultrasonic devices, bipolar compression devices, on the other hand, enabling the closing of vessels up to 7 mm in diameter (69-71). Moreover, the bipolar compression working principle allows gradual compressing and cauterizing the tissue followed by instant sealing and coagulation. Argon beam coagulator were introduced as an efficient transection plane hemostasis system. Whereas multi-center evidence demonstrated that argon bean coagulator increased the risk of gas embolism, its popularization was limited (13,72,73).

It is worth noting that the surgeons are required to have a comprehensive understanding of the advantages and limitations of their preference to ensure continually safe performance (65). A table of different liver parenchyma transection instruments shows their advantages and disadvantages (*Table 1*). A hand-assisted system was adopted to perform so-called hand-assisted LLR to reduce the degree of difficulty (74,75). With the accumulated experiences from practice, hand-assisted LLR was less frequently reported.

Position and approaches

A reverse Trendelenburg position with or without legs apart is commonly accepted worldwide (13,59). In this position, the blood flow returned to heart is reduced by gravity and the central venous pressure (CVP) is able to maintain in a low level (<5 cmH₂O is recommended). In addition, the transverse colon, small intestine and omentum may keep a distance from the inferior surface of the liver, providing better view and larger operation space. The CO_2 pneumoperitoneum pressure is generally set by 10–14 mmHg. For pure LLR, four, five or more trocars were inserted as needed. Usually a supra- or subumbilical incision was made as observation site, subcostal trocars were used as main operation ports. Most of LLRs are able to perform technically in this way. To handle the small lesions located in antero-superior or posterior part especially for segment VII and VIII, local or single segmentectomy may become a challenge due to a higher risk of insufficient surgical margin and difficult hemostasis. the repeatedly compression of liver tissue to mobilize and expose the lesion also increase the risk of tumor rupture and spread. Therefore, extended resections (resection of right posterior lobe even hemi-hepatectomy) are adopted in cases with the great loss of normal tissue. A novel method of semi-prone position was developed by a Japanese to provide a new visual (76,77). The patient was set in left lateral position with surgeons standing at the left side, after carefully fixed the operating table rotated by 20–25° to from semi-prone position. The utilization of this method increased LLR proportion for patients with lesions in antero-superior and posterior segments in their center (78). Fifty-six patients

performed in semi-prone position were reviewed, compared to traditional supine position, this new approach was safe and showed benefits on reducing blood loss and hospital stay. Besides subcostal ports, an intercostal port is allowed to offer another direction to reduce lesion in hepatic dome. Just like the gravity works in reverse Trendelenburg position, the weight of the liver contributes to mobilization and right hepatic vein control. The posterior segment is positioned above IVC which may potentially reduce venous pressure. Chen *et al.* evaluated LLR with the jackknife position (79). The jackknife position, alike the semi-prone position, aims to deal with the lesions in segment VI, VII and VIII. However, poor exposure of the portal area makes inflow control difficult.

The difficulty of LLR varies with the range of resection. Besides partial hepatectomy in marginal area, laparoscopic left lateral section (LLLR) is considered as a simple and practicable method for beginners (80). Agreement was reached on considering LLLR as a standard of care in the first international conference (12). Although there has not been a procedure of precise standardized surgical technique for LLLR, laparoscopically stapled left lateral sectionectomy were commonly adopted in many centers as a result of minimizing blood loss and operation time (81-84). Two endoscopic liner staplers act as the key part of the procedure to separate pedicles of left lateral lobe and the left hepatic vein safely. Besides the two structures, there are seldom important large vessels or bile duct lied in the left side of the falciform ligament, which ensures a confident transection.

The major LLR is still a challenge through decades and should be performed only by experts (10,14). Mobilization of the right posterior segments, identification of intrahepatic anatomic variation, proficient of suture and ligation with laparoscopic apparatus as well as operation precisely and constantly for hours make the major LLR hard to master. The conventional approach of right liver resection needs mobilization of the right liver and control of right hepatic vein before transecting the parenchyma. For those large lesions located in right lobe of the liver, morphological disorder, surrounding structures adhesion and unstable tumor status make the conventional approach difficult to implement and the same is true in LLR. An anterior approach was introduced in the 1990s as an alternative to the conventional one. The method optimized the order of the procedure, putting parenchyma transection at first while mobilization in the end, and was frequently used in opening

right hepatectomy as its various superiorities (85-87). Soubrane *et al.* conducted a similar caudal approach in LLR (13,88). The procedure started with intrafascial dissection of the right portal pedicle, the Cantlie line, the edge of IVC and the middle hepatic vein (MHV), which are important landmarks guiding the parenchyma resection. Unlike the conventional approach, MHV was firstly controlled, not until the resection reached the end could MHV be stapled. A retrospective comparative study, together with several case reports, verified the safety and feasibility of the caudal approach (89-92). Compared with the conventional approach, the caudal approach provides similar postoperative outcomes and benefits of reduced conversion rate.

In order to meet various situations, other novel approaches were also introduced. Yamashita *et al.* introduced a total transthoracic approach (93). In this case report, the patients previously received 3 major abdominal surgery. The transthoracic approach allowed the resection of liver tumor to perform smoothly by avoiding managing the great chaos in the abdominal cavity. A left-side approach was conducted by Cai *et al.* to provide convenience to anatomic caudal resection (94). The left-side approach had advantages especially for lesions arose from Spiegel's lobe with or without spreading to right part of the caudate lobe, since most of these approaches were reported with limited cases, further studies are needed to prove their repeatability.

Massive blood loss and requirement of transfusion in liver resection have close relationship to the perioperative complications and malignancy recurrence (95,96). Bleeding control is one of the main concerns of all LLR. As previously discussed, LLR do have advantages in reducing blood loss and transfusion rate. An appropriate balance between pressure of CO_2 pneumoperitoneum and CVP would be essential to decrease venous bleeding and maintain a stable hemodynamics (97). The pressure of pneumoperitoneum was commonly set as 10–14 mmHg and adjustment according to parameters of airway, CVP gradient was needed to reduce risks of gas embolism (98-100). In the meanwhile, surgeons must realize that meticulous hemostasis of transection plane is necessary because bleeding from small veins may stop temporarily by the effects of positive abdominal pressure. Low CVP (<5 cmH$_2$O) is essential of bleeding control. Reverse Trendelenburg position, limited fluid infusion and short-term shutoff of mechanical ventilation in emergency offer helps.

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Difficulty scoring/classifying system and learning curve of LLR

As previously mentioned, the difficulty of procedure varies greatly from type to type. A difficulty scoring or classifying system is necessary for preoperative preparation, especially for the beginners. Ban *et al.* came up with a difficulty scoring system based on several critical factors (resection extent, tumor size & location, proximity to important tubular structures and liver function). The system divided difficult index into three levels which gave guidance to surgeons (80). Although there were limitations, this novel difficulty system was widely adopted. Another similar difficulty classifying method presented by Kawaguchi simplified the evaluation steps (101). However, judging difficult levels merely based on operational related factors would not be able to meet the needs of precisely and individualized treatment. An international survey of potential factors which may add difficulty to operation from up to 80 experienced surgeons suggested that patient's overall conditions should also be considered (102). These factors included BMI, history of chemotherapy, repeated liver resection and concurrent procedures. Hasegawa put forward a new model to predict surgical difficult of LLR. In this model obesity and platelet count were included.

For now, consensus had been reached that resection extent and lesion location were two main factors. left lateral sectionectomy and hemihepatectomy were regarded as two watersheds for the beginners, advanced learners and proficient. Unfortunately, none of the present difficult systems was fully satisfied. Thus, new ideas, which may at least include liver cirrhosis, were always welcome. On the other hand, another independent system—the learning curve may be useful for reference.

The learning curve describes the operation acquisition process of a settled team using cumulated sum or risk-adjusted cumulated sum analysis which regarding total operation time and total intraoperative blood loss as main observation indexes. According to literature reports, the learning curve of major hepatectomy was around 45 cases, the mean operation time was around 250–350 min and mean blood loss was around 300–500 mL (103-107). The result shows that surgeons may get stable outcomes after nearly 45 cases training under the premise of expertly performing open hepatectomy and simple LLR. As the LLR performed more and more worldwide, valuable experiences accumulated continuously. The learning curve of sophisticated LLR may become steeper which means that less cases are required. It is

suggested that surgeons should start with wedge resection and do not take risk to try difficult LLR unless they can perform left lateral sectionectomy very well. Actually, mastering major LLR is a challengeable work indeed, recommendations are given that surgeons should perform major LLR with great cautiousness even though they have been quite familiar with laparoscopic surgery.

Robot hepatectomy

Robotic system is another minimally invasive approach which has been widely used in gastrointestinal, urinary and gynecological surgeries (108). It was applied for liver surgery in early 2010s, the initial experiences showed that robotic system can be used not only minor but also major liver resection (109,110). Recent reviews summarized the half-decade development of robotic liver surgery (111,112). Not limited to similar efficiency compared to conventional laparoscopic approach, its unique advantages of facilitating suturing under laparoscope allow it to provide more possibilities in the future. But on the other hand, a comparison conducted by Tsung showed that robot hepatectomy might not as perfect as we expected (113). What is more, higher cost of the robotic liver surgery probably makes it less appealing to patients, limited devices availability, relative fixed patient position and compromised assistant aiding would be also influence the choice of surgeons when confounding a difficult case.

Postoperative recovery

A concept of enhanced recovery after surgery (ERAS) was introduced by Kehlet in 1997 (114). ERAS is focused on optimizing perioperative management aiming to improve recovery, reduce postoperative morbidity and overall cost. The common strategies include preoperative education, individualized nutrition support, early oral intake and mobilization, appropriate analgesia etc. Achievements reached in many other surgical fields motivated ERAS to be applicated in liver surgery (115). A randomized control study, conducted to evaluate ERAS in LLR, verified these advantages (116). The patients underwent ERAS program benefited from lower morbidity rate, higher living quality and less cost. Among the various strategies, perioperative patient education, early postoperative mobilization, reduced drainage tubes, enhanced pain control, intravenous fluid restriction and oral nutrition played the essential part and also recommend by ERAS guideline for liver surgery (117).

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Cost

The cost of treatment is a financial problem concerned by both medics and patients. LLR serves as a minimally invasive approach, kinds of high-tech laparoscopic equipment and instruments are indispensable and may increase the operation expense. However, surveys from multiple centers showed that, in most cases, total in-hospital cost of LLR was no higher than conventional open approach (118-121). This result probably related to shorter postoperative hospital stay and faster recovery when receive laparoscopic approach. Moreover, as the development of LLR goes faster, new low-cost techniques can be adopted without compromising surgical outcomes. And this gives an optimistic view of the future of LLR.

Conclusions

In conclusion, with the effort of both liver surgeons and medical engineers in recent two decades, LLR has become a technically practicable treatment for liver disease. Indications of LLR has expanded from local resection to difficult cases, even living donor allograft donation. with a learning curve of 45–60 cases, surgeons are able to perform continual high-quality operations of LLR (105). It was estimated that over 9,000 LLRs has been performed worldwide up to 2015, and the number is still in exponential growth. Even though few RCT is available at present, under the circumstance of quickly accumulated cases, many important questions regarding the oncological, cost-effective and technical aspects are about to get conclusions.

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Footnote

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