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LAPAROSCOPIC AND ROBOTIC HEPATECTOMY IN LIVING LIVER DONORS. CURRENT STATE AND PROSPECTS

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Minimally invasive living-donor hepatectomy is a relatively new surgical technique that can improve donor safety and expedite donor rehabilitation. Following an early stage of research where donor safety was not adequately established, the minimally invasive approach nowadays yields better outcomes when carried out by experienced surgeons. Important factors include donor selection criteria, hospital equipment, and surgeon's learning curve. This review describes the current status of laparoscopic and robotic living-donor hepatectomy, along with the challenges facing the advancement of these surgical techniques.

Key words: liver transplantation, living donation, laparoscopic liver resection, robotic liver resection.

INTRODUCTION

Living-donor liver transplantation (LDLT) became a viable alternative to deceased-donor liver transplantation (DDLT) due to a series of surgical innovations developed in the late 20th century. This was prompted by the rapidly increasing number of liver transplant (LT) candidates in cases of severe organ shortage. In children with end-stage liver disease, especially in their first years of life, reduced cadaveric grafts and split LT are not always feasible due to organ size and technical challenges. In some countries, including the Russian Federation, there are no specific legal prerequisites or well-defined regulations for using children as deceased organ donors [1–2]. Liver grafts from living donors provide comparable or even superior outcomes in terms of graft function and long-term survival, particularly in pediatric recipients, when compared to whole or split LT from deceased donors [3–5]. LDLT offers significant advantages over DDLT, primarily due to the predictable quality of the liver parenchyma by selection and preparation of related donors, and the ability to plan the surgery under optimal conditions. Advancements in hepatobiliary surgery and organ preservation techniques have significantly improved the quality of LDLT grafts, minimizing ischemic and mechanical injury [6–7]. More than 50% of pediatric LT worldwide are performed using LDLT, with relatives being the primary donors [8].

Donor safety during liver donation surgery, specifically hepatectomy, is a significant concern, with complications like biliary problems (bile duct damage, leaks), infections, and vascular issues (bleeding) contributing to donor morbidity. Other factors such as adhesive intestinal obstruction, postoperative hernias and prolonged stay in the operating room may also contribute to donor morbidity [9].

Minimally invasive donor hepatectomy (MIDH) has emerged as a promising technique to reduce donor morbidity. Potential advantages inherent in the minimally invasive technique are better cosmetic results, less postoperative pain, faster recovery, and earlier return to daily activities [10]. MIDH was first described in France by Daniel Cherqui and colleagues, who performed a laparoscopic left lateral sectorectomy on a 27-year-old female donor for transplantation into her child. This pioneering case paved the way for its widespread adoption.

The purpose of this review is to describe the current status of laparoscopic and robotic donor hepatectomy and to identify the barriers to the spread of these surgical techniques.

CURRENT CHALLENGES

In the United States, LDLT peaked in 2001, when it accounted for approximately 10% of all LT [12]. However, following reports of donor complications, the number of LDLT procedures dropped by nearly 40% in subsequent years [12, 13]. As a result, in 2021, when a record 9,234 LT were performed in the United States, only 6.2% of recipients received a graft from a living donor. Most of these were right-lobe grafts [14]. These data contrast with the figures cited for kidney donation. For example, in 2021, related kidney donations accounted for 31.1% of all living-donor kidney transplants in the United States [15].

According to the International Registry of Organ Donation and Transplantation, in Asian countries such as South Korea, Turkey, and Saudi Arabia, living-donor organ transplantation significantly exceeds deceased-donor transplantation. Meanwhile, there is no difference by donated organ [16].

Several meta-analyses and randomized controlled trials have confirmed that minimally invasive laparoscopic

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donor nephrectomy offers lower risks of complications, less postoperative pain, faster rehabilitation, and consequently lower treatment costs [17–19]. Living-donor nephrectomy (LDN) is generally not considered a particularly technically challenging procedure, primarily because the kidney is removed intact, including its capsule, vascular pedicle, and ureter, without needing to transect the parenchyma. On the other hand, MIDH is more technically demanding than living-donor nephrectomy (LDN) because it requires parenchymal transection, and also liver resection is associated with individual anatomical features of each donor [20]. These factors, especially the anatomical complexity and the size (thickness) of the parenchyma, have slowed down progress in the development of this surgical field [21].

Donor safety and rapid postoperative rehabilitation are the two main goals of minimally invasive living-donor graft retrieval [22]. The risk of mortality and morbidity after living-donor liver resection is influenced by three key parameters: physiological status (e.g., comorbidities), volume of liver parenchyma removed, which is directly related to the risk of postoperative liver failure, and intraoperative blood loss and subsequent transfusion need [23]. As a result, in order to minimize the number of complications, surgical teams performing these operations should focus on high-quality donor selection and refinement of surgical techniques. According to the 2021 International Consensus on Minimally Invasive Donor Liver Resection, there is still debate over whether laparoscopic and robotic techniques can fully achieve these goals [21, 23].

However, systematic reviews on laparoscopic graft retrieval in LDLT have provided growing evidence that this technique is safe and effective, particularly when performed by experienced surgeons. The reviews conclude that laparoscopic donor hepatectomy is associated with fewer postoperative complications, lead to less intraoperative bleeding and ensures faster return to normal activities compared to open hepatectomy [24–26]. However, it should be noted that LDLT is fundamentally different from traditional hepatectomy because the vascular pedicles of the resected part must be preserved as carefully as possible throughout [11].

The 2008 International Consensus Conference on Laparoscopic Liver Resection in Louisville highlighted significant concerns about MIDH, particularly regarding donor safety and reproducibility [27]. At the Second International Consensus Conference on Laparoscopic Liver Resections held in Morioka in 2015, it was argued that while MIDH was no longer inferior to open surgery in terms of donor safety, it was not recommended as a standard procedure due to insufficient long-term data on postoperative complications [28]. After publications and reports of positive outcomes, an expert consensus was held in Seoul to make clear guideline for the safe widespread implementation of this minimally invasive technique in living liver donors [29]. The results showed that MIDH yields superior outcomes compared to the open approach when performed in high-volume transplant centers by surgical teams with extensive experience in both transplantation and laparoscopy. Moreover, data from the United States show that donors are more willing to accept surgery when offered a minimally invasive procedure [30].

LAPAROSCOPIC LATERAL SECTIONECTOMY

While minimally invasive liver resection has evolved with different options (hand-assisted laparoscopic surgery, laparoscopic-assisted surgery, pure laparoscopic laparoscopic hepatectomy), the procedure to remove the left lateral sector (LLS) from a living donor was initially demonstrated exclusively as a fully laparoscopic technique. All stages of the operation (mobilization, vascular isolation, parenchymal transection) were performed laparoscopically without manual assistance, and the graft was retrieved through a small suprapubic incision (according to Pfannenstiel) [11]. According to French surgeon Daniel Cherqui, LLS is an ideal structure for fully laparoscopic resection because of its convenient location in the abdominal cavity, high mobility relative to the rest of the liver and few anatomical variations [31]. Following the first successful demonstrations of the feasibility of laparoscopic left lateral sectionectomy (LLLS) in France, Belgium and South Korea, the safety and reproducibility of the procedure were validated by Olivier Scatton [11, 32–35]. In their paper, Scatton et al. analyzed 70 LLLS and noted that after overcoming the learning curve, the median hospital stay gradually decreased, blood loss on average remained around 50 mL, and Clavien–Dindo grade II or higher complications were less frequent. However, it was emphasized that this procedure requires at least two experienced surgeons to complete the necessary learning curve [35]. Soubrane et al. compared not only surgical outcomes but also economic outcomes and concluded that mini-invasive left lateral sectionectomy provides at least equal short-term outcomes compared to laparoscopic nephrectomy [32].

In the Russian Federation, the LLLS program was launched in 2016 at the Shumakov National Medical Research Center of Transplantology and Artificial Organs ("Shumakov Center") in Moscow. Gautier et al. reported less blood loss and shorter hospital stay, but longer surgery time with fully LLLS compared to the open approach at the program formation stage [36]. However, as this field developed, the operation time decreased significantly, complications became less in comparison with open surgery, and LLLS gradually became the gold standard method for left lateral sectionectomy [37–43]. Similar results have been reported by other authors worldwide [44–46].

LAPAROSCOPIC LEFT HEMIHEPATECTOMY

With regard to laparoscopic left hemihepatectomy (LLH), no serious complications have been reported at present, however, with limited experience in such surgical procedures, since the left lobe is a very specific graft from the point of view of transplantation in adults, and is used more in pediatric practice [26, 41, 47]. However, Japanese researchers have reported series of left lobe transplants in adults [48–49]. The authors note a lower donor morbidity after these operations, which they attribute mainly to fewer biliary and pulmonary complications. They also believe that the left lobe graft may be a choice for adult patients where the graft-to-recipient weight ratio (GRWR) is greater than 0.8% or between 0.6% and 0.8%, provided that the recipient's MELD (Model for End-Stage Liver Disease) score is less than 15. The main risk of these operations is small-for-size syndrome, which ultimately leads to graft dysfunction in the recipient. However, no high risks have been described specifically for donors.

Similar results have been reported in a multinational multicenter study (France, Japan, South Korea, Spain, USA, Italy), where the authors compared the results of minimally invasive right and left hemihepatectomies [50]. No statistically significant difference in complications and outcomes between right and left lobe donors was reported.

LAPAROSCOPIC RIGHT HEMIHEPATECTOMY

Fully laparoscopic right hemihepatectomy (LRH) in a living donor was first performed in 2010 in South Korea by Korean surgeon Han, but the outcomes were not reported until 2014. This delay in publication led to the general belief that the first documented LRH was performed by French surgeon Olivier Soubrane in 2013 [23]. Nevertheless, LRH in living donors has been successfully developed and implemented primarily in Asian countries like Japan and South Korea, where LDLT is more common than DDLT [26, 51, 52]. However, despite its success, there is significant variation in surgical techniques between hospitals, particularly in trocar placement and the sequence of surgical steps [53, 54].

Although the right lobe of the liver provides an adequate parenchyma volume for the recipient, this approach raises serious concerns about donor safety. Abecassis et al. reported postoperative complication rates of up to 40% [9]. The laparoscopic approach has been advocated in many transplant centers to minimize these complications. Minimally invasive right lobe resection is technically more demanding than left lobe resection due to the deep subdiaphragmatic location of the right lobe and the need for extensive mobilization. [55]. These technical difficulties have slowed the development and widespread adoption of fully LRH for living donors. In its infancy, hybrid techniques (with manual assistance) were used [26, 27, 53]. Even now, experienced surgeons recommend for many centers to use hybrid approaches before moving to fully laparoscopic right lobe resection [27]. Importantly, if the anatomic integrity of the graft is jeopardized, the most appropriate decision is to go for the open option (conversion).

Nevertheless, in Asia, especially in South Korea, performing laparascopic hemihepatectomies in donors is quite common. For example, in 2018, a paper was published reporting the outcomes of 172 right lobe resections in living donors performed in hospitals in South Korea between 2013 and 2017 [56]. In 2021, an article was published reporting 255 completely laparoscopic right lobe resections in a single center [57]. At the same time, the studies compared open and laparoscopic liver resections and demonstrated the high efficiency of minimally invasive techniques in terms of postoperative complications, intraoperative blood loss and length of postoperative hospital stay.

In Russia, Voskanyan et al. were the first to report on the performance of such a surgical operation [54], with the greatest cumulative experience of donor right hemihepatectomies accumulated at Shumakov Center. As of 2022, Monakhov et al. reported 276 laparoscopic donor liver hepatectomies, including 11 cases of completely laparoscopic right lobe resections [41].

DONOR SELECTION

Careful donor selection is considered to be of utmost importance in preparation for MIDH. Preoperative evaluation includes a thorough physical examination. Of particular importance are any concomitant cardiovascular, renal, pulmonary, coagulation-related disorders, and infectious diseases. Many centers exclude patients with arterial hypertension and psychiatric disorders despite the possibility of conservative correction [7, 58, 59]. In addition, standard liver function tests, serologic tests for hepatitis B and C, and chest and abdominal examinations are always used. A contrast-enhanced triple-phase liver CT scan is a critical part of preoperative evaluation for MIDH. It provides essential information for volumetric analysis and vascular assessment of the donor liver.

Magnetic resonance cholangiopancreatography (MRCPG) provides a non-invasive, high-resolution view of the biliary tree, helping to identify anatomical variations and determine the optimal bile duct division point (see Table 1). Misinterpretation of biliary anatomy may require intraoperative cholangiography, but it requires experience, additional costs, and prolongs operative time [60].

Nevertheless, in recent years, indocyanine green fluorescence imaging has been actively used. It helps to visualize bile ducts in more detail when performing laparoscopic liver resection [26, 61]. Methods of using methylene blue to control bile flow have also been reported [46].

Surgeons from different centers define different anatomical criteria for selecting a potential liver donor. For example, Kim et al. considered only donors who had one long right hepatic duct, one artery, and standard portal vein anatomy (Table 1) [62]. They also excluded donors whose right lobe mass exceeded 650 g. Gautier et al. considered the separation of the 2nd and 3rd segment veins as a contraindication for LLS retrieval, as it could cause difficulties during suturing and lead to intraoperative bleeding; however, this ceased to be a contraindication with the accumulation of experience [36, 39]. Rotellar et al. believe that the right lobe graft should have one artery, one portal vein and one bile duct, but, at the same time, variations are acceptable, and each donor should be assessed individually [63].

Anatomical variations of the portal vein (Table 1) were once considered a contraindication for MIDH. However, recent reports suggest that experienced surgical teams can achieve safe and successful outcomes, even in donors with portal vein anomalies [57, 64].

BLOOD LOSS

A strong obstacle in the development of the minimally invasive approach in donor liver surgery has been the difficulty and limitations in approaches when intraoperative bleeding develops. With improvement in technology and surgical technique in the last three decades, it has been possible to significantly reduce blood loss and decrease the frequency of blood transfusion during laparoscopic liver hepatectomies [22, 74, 75].

Gentle parenchymal transection and the pneumoperitoneum effect (i.e., the tamponade effect on the dissected surface due to increased intra-abdominal pressure) play a critical role in reducing blood loss during MIDH.

Table 1

Anatomical variation of the bile ducts and portal vein

Anatomical variation of the bile ducts	
A	Standard bifurcation (57%)
B	Trifurcation (12%)
C	Right anterior (C1, 16%) or right posterior (C2, 4%) ducts draining into the common hepatic duct
D	Right posterior (D1, 5%) or right anterior (D2, 1%) duct draining into the left hepatic duct
E	No hepatic duct confluence (3%)
F	Right posterior duct draining into the cystic duct (2%)
Anatomical variation of the portal vein	
I	Standard bifurcation
II	Trifurcation
III	Right posterior branch as the first branch of the main portal vein
IV	Segment VII branch arising as a separate branch from the right portal vein
V	Segment VI branch arising as a separate branch from the right portal vein

These factors help mitigate venous backflow, which is the primary source of intraoperative bleeding [35]. For instance, Olivier Scatton suggests temporarily increasing the pneumoperitoneum pressure to 14–16 mmHg in order to control and minimize bleeding [35]. The greatest risk of intraoperative bleeding occurs during parenchymal transection. In the minimally invasive approach, this step is performed very precisely and under magnification. Transecting the hepatic vein is also crucial because slippage of the vascular clamp or a defect in the vascular stapler can lead to massive bleeding [39, 76].

Comparative studies have consistently shown that MIDH results in lower [36, 45, 71, 77] or equal [30, 57, 64, 69] blood loss compared to the traditional open approach. However, the studies emphasized that the lack of a statistically significant difference in blood loss was due to small sample sizes [30]. Hence, another advantage of the minimally invasive method can be considered less blood loss compared to the traditional approach.

CONVERSIONS

Any incident that may jeopardize donor safety or graft integrity is an indication for conversion to open surgery. Conversion itself is not a complication but implies that some adverse event occurred during the procedure. The most frequently described reasons for conversion to open access were difficulty in differentiating the anatomy of the bile ducts or porta hepatis and vascular injury resulting in significant bleeding. Also, cases of poor visualization in overweight donors were reported, which also required conversion [50].

Scatton et al. reported 4 conversions (6%) out of 70 operations, of which 69 were LLS retrieval and 1 was left lobe retrieval. The reasons for conversion were injury to the left branch of the portal vein, poor exposure, and uncertainty about biliary tract anatomy. None of the conversions was associated with acute or uncontrolled bleeding or the need for blood transfusion, and all donors recovered without complications [35]. Monakhov et al. reported two conversions (1.2%) out of 164 LLS retrieval surgeries; the conversion cases were associated with occlusion of the left branch of the portal vein by a clip and longitudinal rupture of the left hepatic vein; all donors were also discharged without complications. The outcomes in the recipients were also uneventful [39].

Choi et al. reported a 6.7% conversion rate (4 out of 60 cases) when performing hand-assisted right lobe resections in living liver donors. The primary reasons for conversion were right hepatic vein injury and adrenal vein injury [65].

Soubrane et al. reported a conversion rate of 4.1% (17 out of 412 cases) in MIDH. The primary reasons for conversion were portal vein injury, difficulty mobilizing the porta hepatis and identifying structures in the hepatoduodenal ligament [50].

Rhu reported a 5.0% conversion due to portal vein injury, donor liver steatosis detected during intraoperative biopsy and inferior vena cava injury [57].

LEARNING CURVE AND OPERATIVE TIME

The major obstacle to the global spread of the laparoscopic technique in liver donation is that, apart from technical equipment, it requires considerable experience in both liver surgery and laparoscopic surgery. A multinational study showed that 65.6% of surgeons had performed >50 non-donor laparoscopic hepatectomies and 43.8% had performed >50 open donor hepatectomies before their first minimally invasive donor liver resection [29]. The learning curve for MIDH is primarily influenced by a surgeon's ability to carefully divide liver parenchyma and control intraoperative bleeding. It is also believed that the surgeon spends the most time learning to dissect and mobilize vascular structures [59]. Several reports have emphasized that a minimum of 15–60 procedures are required to achieve optimal outcomes, depending on the liver fragment to be resected [39, 86]. For example, Scatton et al. showed that at least 20 procedures are required to achieve optimal hemostasis and shorten operative time [35]. A similar result was demonstrated by Monakhov et al. in their study [39].

MIDH tends to take longer, especially during the training period of surgeons [39, 45, 62, 69]. Baker et al. found an association between higher body mass index and longer operative time, while Rhu et al. emphasized that after the first 100 operations, surgical time decreased regardless of donor body weight [30, 77].

However, it should be noted that defining a learning criterion for a single surgeon is not possible because experience and outcomes vary between different surgical teams. Rhu et al. reported no change in surgical time from the first to the second quartile over time, but reported a significant decrease from the second to the third quartile and from the third to the fourth quartile. His team was able to meaningfully reduce surgical time after 50 laparoscopic surgeries [77]. To determine the learning curve, Korean surgeon Lee used two variables – intraoperative blood loss and operative time. The learning period was determined based on when these two factors reached a plateau, indicating surgeons had gained proficiency. Significant improvement in surgical outcomes (less blood loss, reduced operative time) was observed after the 15th operation, marking the transition into the "experience accumulation phase" [87].

COMPLICATIONS

As mentioned above, donor safety is the main criterion for living-donor hepatectomies. According to a study conducted at Oxford University, a 30-day postoperative outpatient follow-up is not sufficient; such follow-up underestimates the morbidity of donors after liver resection. A 90-day outpatient follow-up is recommended for donors [66].

The Clavien–Dindo classification, although widely used, tends to consider only the most severe complications and does not consider other less severe complications in the same patient [67]. The new Comprehensive Complication Index method developed on the basis of the Clavien–Dindo classification summarizes all postoperative complications and is the most sensitive tool for assessing the real severity of postoperative complications [68].

The incidence of complications in minimally invasive living-donor hepatectomies ranges from 0 to 40%, with most studies reporting it in the range of 10–26% [50, 57, 69, 70]. The most common complications are wound complications, pleural effusion, biliary effusion or biliary stricture (Table 2).

Most studies comparing MIDH with open hepatectomy found no statistically significant difference in complication rates. However, this lack of statistical significance is likely due to small sample sizes in many studies. Rhu et al. noted an interesting finding that complications were significantly higher in the first quartile of surgeries, suggesting surgeon inexperience during early cases contributes to more complications [57]. Broering also reported that the complication rate decreased from 26.7% to 9.7% after developing appropriate surgical skill [45]. The complication rates did not differ significantly between right and left lobe donors [50]. Also, the complication rate in donors was comparable when comparing surgical outcomes in donors with variant and standard portal vein anatomy [57].

Biliary complications are among the most serious complications following MIDH. Takahara et al. reported three cases of bile leaks even though each bile duct stump was clipped twice and at the end of the operation looked quite normal and there were no signs of biliary leak [71]. The authors suggest that the clips fell off due to necrosis of the bile duct stump with subsequent development of bile leak.

Table 2

Reported complications of minimally invasive living donor hepatectomy (Clavien–Dindo classification)

I	Fever, gastroenteritis, gastric ulcer, occipital alopecia, pneumothorax without drainage, wound infection, suprapubic hematoma, ileus, arm neuropraxia, atelectasis, transient neutropenia
II	Gastroparesis, pulmonary infection, segment IV infarction, bile duct stenosis, pancreatitis, cystitis, incisional port-size hernia
IIIa	Biliary leakage, fluid collection, bladder injury, portal vein thrombosis or stenosis
IIIb	Abdominal abscess, intra-abdominal bleeding

Regarding wound complications, open resection (especially right lobe resection) in the donor requires a large incision with extensive muscle incision, resulting in pain for several days and discomfort for several weeks [11]. During this incision, sensitive nerve endings (ventral branches of intercostal nerves T8 and T9) are transected, which may result in loss of sensation of the anterior abdominal wall. In contrast, suprapubic incisions are usually well tolerated without sequelae, and postoperative hernias are rare. In addition, they are virtually inconspicuous if located low enough in the pubic hair region [11]. Care must be taken when suturing the abdominal wall closure, as bladder injury may occur [20]. MIDH involves small incisions for trocar placement, which can lead to local ischemia and wound infections. However, these complications occur less frequently in MIDH compared to the open approach [72].

Theoretically, there is a risk of gas embolism due to pneumoperitoneum. However, pneumoperitoneum is created by insufflation of carbon dioxide, a gas with a higher solubility than nitrogen. Several experimental studies have established that absorption of carbon dioxide into systemic circulation is not associated with hemodynamic instability [27].

PAIN SYNDROME

In their works separate and joint studies, Monakhov et. al. and Syomash used an analog scale for pain assessment in donors after open and laparoscopic hepatectomies and reported lower pain syndrome in donors who underwent laparoscopic graft retrieval [26, 39] Kurosaki et al. used less additional analgesia in donors operated mini-invasively compared to patients who underwent open hepatectomy [78]. Reduced dosage or shorter duration of analgesic use has also been shown in a series of studies in donors who underwent minimally invasive hepatectomy [45, 62, 65, 69].

LENGTH OF HOSPITAL STAY AND COST OF TREATMENT

The length of postoperative stay depends largely on the policies of the institution and the health care system. In eastern countries such as Japan and South Korea, the policy is for donors to be hospitalized until they can return to normal daily activities [59]. In addition, some eastern national health care systems do not require patients to be discharged even after they have recovered from surgery [57, 76, 79]. Western countries seem to have an extended recovery protocol. Several reports show no statistically significant decrease in length of stay between the minimally invasive and open approach [30, 80]. However, in most centers, the length of stay was shorter in the minimally invasive graft retrieval group [39, 45, 57].

In terms of treatment costs, the material costs of performing an MIDH were higher. Baker reports that despite the high costs of the surgery itself, these costs were offset by lower costs associated with length of hospital stay [30]. Chinese colleagues report opposite results. In their observational series, MIDH was significantly more expensive than the open procedure [69].

OUTCOMES IN RECIPIENTS

It should be noted that surgical outcomes in donors should not be assessed separately from those in recipients. For example, Troppmann et al. found that laparoscopic donor nephrectomy was associated with delayed graft function and increased acute rejection rates. The reasons for this finding are unclear, but hemodynamic compromise in the renal vasculature due to pneumoperitoneum pressure may be a possible factor [73]. On the other hand, in almost all studies comparing laparoscopic graft retrieval with open donor resection, the authors found no difference between the minimally invasive and conventional approach in terms of vascular and biliary complications, graft survival, and overall recipient survival [26, 36, 39, 45, 46, 63, 94]. The minimally invasive technique did not increase the risks to the recipient even in cases of variant portal vein anatomy [57]. Hong et al. were the only team that observed a higher rate of biliary complications in recipients of grafts from MIDH procedures. The authors believe that most likely this was due to longer warm ischemia time and multiple bile ducts in the graft [64].

ROBOTIC HEPATECTOMY IN LIVING LIVER DONORS

Robotic hepatectomy in living donors is much less common than laparoscopic hepatectomy, but it is considered safe and feasible in the hands of experienced professionals. The first robotic graft retrieval was performed by Italian surgeon Giulianotti and colleagues in 2012. The operation was performed using the da Vinci Robotic Surgical System on a 53-year-old man, from whom the right liver lobe was removed for subsequent transplantation to his 61-year-old brother [26, 81].

Compared to the laparoscopic approach, evolution of the robotic approach has been slow. Potential advantages include an expanded and more stable view as well as better precision of movements. The Da Vinci surgical system can rotate in all directions, allowing a wider range of motion compared to the human hand. This allows manipulation and suturing in the subhepatic space at angles that are not possible with conventional instruments. On the downside, the surgeon has no haptic feedback. Also, the success of the operation depends on the level of training of the assistant who changes the robotic instruments during parenchymal transection [82].

Recent studies have shown that robotic liver resection is feasible and produces similar short-term outcomes as the laparoscopic procedure, but with higher costs, as health insurance does not usually cover such hightech surgeries [70]. Another obstacle to the spread of this technique is the need for high specialization of the medical center and surgical instruments, since only ultrasonic scalpels, hem-o-lok clips and staplers can be used during robotic liver surgery; cavitron ultrasonic surgical aspirators cannot be used [83]. Nevertheless, not only robot-assisted donor resection but also robot-assisted graft implantation has been reported [91].

Two studies comparing robotic living-donor hepatectomy with open hepatectomy found the robot-assisted approach to be just as effective in terms of complications and intraoperative blood loss [83, 84].

Currently, there are no data to suggest that the robotic technique is superior to the open or laparoscopic approach. Troisi et al. did not find any superior outcome to justify the higher cost of the robotic approach compared

Table 3

Results of laparoscopic hepatectomy at different transplant centers

Author	Number of operations (n)	Retrieved liver fragment	Operation time (minutes, range)	Blood loss (milliliters)	Conversions (n, %)	Learning curve (number of operations)	Complications (C–D, number)	Hospital stay (days, range)
Soubrane et al., 2006 [32]	16	LLS	320 ± 67	18.7 ± 44.2	1 (6.25%)	not assessed	I – 2 IIIb – 1	11.0 ± 2.7
Kim et al., 2011 [34]	11	LLS	330 ± 68	396 ± 72	0	not assessed	0	6.9 ± 0.3
Yu et al., 2012 [88]	15	LLS	331.3 ± 63	410.0 ± 71.2	0	not assessed	0	7.1 ± 0.8
Scatton et al., 2015 [35]	70	LLS – 69 LL – 1	308 (180–555)	50 (10–500)	4 (6%)	20	I – 9 II – 2 IIIa – 4 IIIb – 1	4
Soubrane et al., 2015 [20]	124	LLS	308 (180–555)	50 (10–500)	4 (3.2%)	faster operation time	I – 6 II – 15 IIIa – 6	6.3 (2–18)
Broering et al., 2018 [45]	72	LLS	293 (192–420)	100 (50–600)	3 (4.8%)	15	I and II – 3 IIIa – 1	4.1 ± 1.33
Gautier et al., 2018 [37]	37	LLS	277.9 ± 16.3	96.8 ± 16.5	0	faster operation time	IIIb – 1	4 ± 0.4
Semash [26]	100	LLS	262 ± 60	85 ± 68	1 (1%)	faster operation time	II – 1 IIIa – 1 IIIb – 1	4.5 ± 1.6
Monakhov et al., 2021 [39]	164	LLS	227.5 (140–400)	50 (20–400)	2 (1.2%)	37	II – 2 IIIa – 2 IIIb – 1	5 (2–14)
Kwon et al., 2018 [56]	54	RL – 41 ERL – 10 LL – 3	436 (294–684)	300 (10–850)	4 (7.4%)	20	I and II – 9 IIIa – 6 IIIb – 3	10 (7–27)
Takahara et al., 2017 [71]	54	RL	454.93 ± 85	81.07 ± 52.78	1 (1.9%)	40	I and II – 6 IIIa – 4	8.43 ± 1.65
Park et l, 2019 [89]	91	RL	345 ± 225	300 ± 200	5 (5.5%)	30	I and II – 2 IIIa – 11 IIIb – 3	10 ± 3
Rhu et al., 2021 [57]	255	RL	261 (230–325)	200 (150–300)	5 (2%)	not assessed	I – 7 II – 20 IIIa – 11 IIIb – 4	8.87 ± 3.00
Soubrane et al., 2022 [50]	412	LL – 164 RL – 248	424 (240–850)	410 (10–3550)	17 (4.1%)	faster operation time	I and II – 70 III and IV – 38	10 (2–50)
Seo et al., 2022 [90]	376	RL	260.9 ± 66.1	257.8 ± 194.6	not described	faster operation time	I and II – 10 IIIa and IIIb – 19	7.2 ± 2.4

Note: LLS, left lateral sector; LL, left lobe; RL, right lobe; ERL, extended right lobe; C–D, Clavien–Dindo classification.

Table 4

Results of robot-assisted living-donor hepatectomy at different transplant centers

Author	Number of operations (n)	Retrieved liver fragment	Operation time (minutes, range)	Blood loss (milliliters)	Conversions (n, %)	Learning curve (number of operations)	Complications (C–D, number)	Hospital stay (days, range)
Chen et al., 2016 [92]	16	RL	596 (353–753)	169 (50–500)	0	15	IIIa – 1	7 (6–8)
Broering et al., 2020 [83]	35	RL	504 ± 73.5	250 (100–800)	0	15	I and II – 2	5.3 (3–12)
Binoj et al., 2020 [93]	51	RL	536.8 ± 73.4	530.39 ± 222.72	0	not described	not described	8.27 ± 3.0
Rho et al., 2020	52	RL	493.6	109.8	2 (3.8%)	faster operation time	I and II – 8 IIIa and IIIb – 2	
Broering et al., 2020 [95]	175	LLS – 61 LL – 34 RL – 80	424 (177–693)	138.1 (20–1000)	2 (1.14%)	not assessed	I and II – 12	4.3 (2–22)
Troisi et al., 2021 [85]	25	LLS	290	100	0	15	0	3 ± 0.3

Note: LLS, left lateral sector; LL, left lobe; RL, right lobe; ERL, extended right lobe; C–D, Clavien–Dindo classification.

with the laparoscopic method [85]. They also emphasized that conversion in robotic resection takes longer than in the laparoscopic approach. Therefore, it is crucial to apply all laparoscopic techniques to stop unexpected bleeding before conversion.

Regarding the learning curve in robotic donor surgery, Broering et al. argue that robotic hemihepatectomy takes a short learning curve, with the mastery phase reached in 15 procedures [83]. Chen et al. took a more measured approach to learning and divided the learning curve into three phases – novice surgeon (1–15 procedures), trained surgeon (15–25 procedures), and experienced surgeon (25–52 procedures). The effect of training was demonstrated by a reduction in surgery time and donor hospital stay after phase 1 of training. Blood loss decreased after phase 2 of training. The authors also note that the presence of dual robot control consoles offers a safe form of training, as the supervisor (instructor) can assist the surgeon during surgery and take over control if necessary [84, 92].

The most extensive experience with robot-assisted living-donor hepatectomy is currently available at the King Faisal Specialist Hospital & Research Centre (KFSHRC) in Saudi Arabia. Surgeons at this hospital reported retrieval of 61 LLS, 34 left lobes and 80 right lobes [95]. The cumulative worldwide experience is summarized in Table 4.

In any case, the robotic method is still very limited in geographic distribution and requires much more experience than laparoscopy. The upcoming introduction of new robotic systems that support haptic feedback or cavitron ultrasound-guided surgical dissectors will facilitate further spread of robotic living-donor hepatectomy.

PROSPECTS FOR FURTHER DEVELOPMENT

The main obstacles to the development and widespread adoption of minimally invasive living-donor surgery include lack of material and technical resorces at hospitals, surgical skill gap and institutional barriers and resistance. Also, there is no uniform and standardized surgical protocol, each transplant center follows a different approach [53]. Establishing an international registry for minimally invasive living-donor hepatectomies and implementing standardized surgical techniques will help in training surgeons worldwide.

Also, new techniques are constantly being introduced into medicine. One of the new technologies that are already beginning to be applied in laparoscopic surgery, including hepatobiliary surgery, is augmented reality (AR) technology. The surgeon, using special AR spectacles, can see in the monitor not only the operating field, but also vascular structures that are loaded using multislice CT scan data and virtual reality technology. Prototypes already exist and are being tested [96–98].

CONCLUSION

Living donation contributes significantly to the expansion of the organ donor pool. Minimally invasive hepatectomies have the potential to increase the number of transplants from living donors due to a number of advantages. These advantages include lower intraoperative blood loss, less pain, faster rehabilitation, and minimized complications. In the hands of experienced surgeons, this approach is safe not only for donors, but also for recipients, as graft quality does not become worse after the procedure. This direction is promising, but not all transplant centers can perform such operations. The main obstacles to the development of minimally invasive living-donor hepatectomies are lack of advanced equipment and resources, as well as conservatism among surgeons. When launching a minimally invasive hepatectomy program, ensuring surgeon expertise and proper mentorship is critical for safety and success.

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REFERENCES

1. *Gautier SV, Monakhov AR, Tsirulnikova OM, Latypov RA, Dzhanbekov TA, Mescheryakov SV et al*. Split liver transplantation: a single center experience. *Almanac of Clinical Medicine*. 2020; 48 (3): 162–170. https://doi.org/10.18786/2072-0505-2020-48-031.
2. *Ghobrial RM, Amersi F, Busuttil RW.* Surgical advances in liver transplantation. Living related and split donors. *Clin Liver Dis*. 2000; 4 (3): 553–565. https://doi.org/10.1016/s1089-3261(05)70126-4.
3. *Austin MT, Feurer ID, Chari RS, Gorden DL, Wright JK, Pinson CW*. Survival after pediatric liver transplantation: why does living donation offer an advantage? *Arch Surg*. 2005; 140 (5): 465–470; discussion 470–471. https://doi.org/10.1001/archsurg.140.5.465.
4. *Bourdeaux C, Darwish A, Jamart J, Tri TT, Janssen M, Lerut J et al*. Living-related versus deceased donor pediatric liver transplantation: a multivariate analysis of technical and immunological complications in 235 recipients. *Am J Transplant*. 2007; 7 (2): 440–447. https://doi.org/10.1111/j.1600-6143.2006.01626.x.
5. *Kasahara M, Umeshita K, Inomata Y, Uemoto S; Japanese Liver Transplantation Society.* Long-term outcomes of pediatric living donor liver transplantation in Japan: an analysis of more than 2200 cases listed in the registry of the Japanese Liver Transplantation Society. *Am J Transplant*. 2013; 13 (7): 1830–1839. https://doi.org/10.1111/ajt.12276.
6. *Semash K, Janbekov T, Akbarov M, Usmonov A, Gaibullaev T.* Stages of preparation and examination of related liver donors and their perioperative management. *Coloproc.* 2023; (1): 41–54. https://doi.org/10.56121/2181-4260-2023-1-41-54.
7. *Semash KO, Dzhanbekov TA, Akbarov MM, Usmanov AA, Povlonniezov KhG.* Prizhiznennoe donorstvo fragmentov pecheni. Rekomendatsii po selektsii i obsledovaniyu rodstvennykh donorov fragmenta pecheni. Tashkent, 2023; 24. https://search.rads-doi.org/project/10145/index (date of access: 13.02.2024). https://doi.org/10.61726/4427.2024.11.78.001.
8. *Quirino L, Jan PL.* Living-Related Liver Transplantation. Progress, Pitfalls, and Promise. *Regen Med Appl Organ Transplant*. 2014: 283–298. https://doi.org/10.1016/B978-0-12-398523-1.00021-5.
9. *Abecassis MM, Fisher RA, Olthoff KM, Freise CE, Rodrigo DR, Samstein B et al.* A2ALL Study Group. Complications of living donor hepatic lobectomy – a comprehensive report. *Am J Transplant*. 2012; 12 (5): 1208–1217. https://doi.org/10.1111/j.1600-6143.2011.03972.x.
10. *Novitsky YW, Litwin DE, Callery MP.* The net immunologic advantage of laparoscopic surgery. *Surg Endosc*. 2004 Oct; 18 (10): 1411–1419. https://doi.org/10.1007/s00464-003-8275-x.
11. *Cherqui D, Soubrane O, Husson E, Barshasz E, Vignaux O, Ghimouz M et al*. Laparoscopic living donor hepatectomy for liver transplantation in children. *Lancet*. 2002 Feb 2; 359 (9304): 392–396. https://doi.org/10.1016/S0140-6736(02)07598-0.
12. Organ Procurement and Transplantation network [Internet]. Liver Donors Recovered in the U.S. by Donor Type. (date of access: 13.02.2024). https://optn.transplant.hrsa.gov/data/view-data-reports/national-data/.
13. *Ghobrial RM, Freise CE, Trotter JF, Tong L, Ojo AO, Fair JH et al.* A2ALL Study Group. Donor morbidity after living donation for liver transplantation. *Gastroenterology*. 2008 Aug; 135 (2): 468–476. https://doi.org/10.1053/j.gastro.2008.04.018.
14. *Kwong AJ, Ebel NH, Kim WR, Lake JR, Smith JM, Schladt DP et al*. OPTN/SRTR 2021 Annual Data Report: Liver. *Am J Transplant*. 2023 Feb; 23 (2 Suppl 1): S178–S263. https://doi.org/10.1016/j.ajt.2023.02.006.
15. *Lentine KL, Smith JM, Miller JM, Bradbrook K, Larkin L, Weiss S et al*. OPTN/SRTR 2021 Annual Data Report: Kidney. *Am J Transplant.* 2023; 23 (2 Suppl 1): S21–S120. https://doi.org/10.1016/j.ajt.2023.02.004.
16. International Registry in Organ Donation and Transplantation [Internet]. Final Numbers in 2022. (date of access: 13.02.2024) https://www.irodat.org.
17. *Nanidis TG, Antcliffe D, Kokkinos C, Borysiewicz CA, Darzi AW, Tekkis PP, Papalois VE.* Laparoscopic versus open live donor nephrectomy in renal transplantation: a meta-analysis. *Ann Surg*. 2008 Jan; 247 (1): 58–70. https://doi.org/10.1097/SLA.0b013e318153fd13.
18. *Yuan H, Liu L, Zheng S, Yang L, Pu C, Wei Q, Han P.* The safety and efficacy of laparoscopic donor nephrectomy for renal transplantation: an updated meta-analysis. *Transplant Proc*. 2013 Jan-Feb; 45 (1): 65–76. https://doi.org/10.1016/j.transproceed.2012.07.152.
19. *Nicholson ML, Kaushik M, Lewis GR, Brook NR, Bagul A, Kay MD et al*. Randomized clinical trial of laparoscopic versus open donor nephrectomy. *Br J Surg*. 2010 Jan; 97 (1): 21–28. https://doi.org/10.1002/bjs.6803.
20. *Soubrane O, de Rougemont O, Kim KH, Samstein B, Mamode N, Boillot O et al*. Laparoscopic Living Donor Left Lateral Sectionectomy: A New Standard Practice for Donor Hepatectomy. *Ann Surg*. 2015 Nov; 262 (5): 757–761; discussion 761–763. https://doi.org/10.1097/SLA.0000000000001485.
21. *Cherqui D, Ciria R, Kwon CHD, Kim KH, Broering D, Wakabayashi G et al*. Expert Consensus Guidelines on Minimally Invasive Donor Hepatectomy for Living Donor Liver Transplantation From Innovation to Implementation: A Joint Initiative From the International Laparoscopic Liver Society (ILLS) and the Asian-Pacific Hepato-Pancreato-Biliary Association (A-PHPBA). *Ann Surg*. 2021 Jan 1; 273 (1): 96–108. https://doi.org/10.1097/SLA.0000000000004475.
22. *Semash KO, Dzhanbekov TA, Akbarov MM, Usmanov AA, Povlonniezov KhG.* Prizhiznennoe donorstvo fragmentov pecheni. Taktika vedeniya rodstvennykh donorov fragmenta pecheni v usloviyakh statsionara, a takzhe

ambulatorno posle rezektsii pecheni. Tashkent, 2023; 21. https://search.rads-doi.org/project/10146/index (date of access: 15.02.2024). https://doi.org/10.61726/7507.2024.31.90.001.

23. *Soubrane O, Perdigao Cotta F, Scatton O*. Pure laparoscopic right hepatectomy in a living donor. *Am J Transplant*. 2013 Sep; 13 (9): 2467–2471. https://doi.org/10.1111/ajt.12361.
24. *Nguyen KT, Marsh JW, Tsung A, Steel JJ, Gamblin TC, Geller DA*. Comparative benefits of laparoscopic vs open hepatic resection: a critical appraisal. *Arch Surg*. 2011 Mar; 146 (3): 348–356. https://doi.org/10.1001/archsurg.2010.248.
25. *Ciria R, Cherqui D, Geller DA, Briceno J, Wakabayashi G*. Comparative Short-term Benefits of Laparoscopic Liver Resection: 9000 Cases and Climbing. *Ann Surg*. 2016 Apr; 263 (4): 761–777. https://doi.org/10.1097/SLA.0000000000001413.
26. *Semash KO*. Laparoskopicheskoe iz''yatie levogo lateral'nogo sektora pecheni u prizhiznennogo donora: dis. … kand. med. nauk. M., 2020; 113. https://doi.org/0.61726/5567.2024.63.97.001.
27. *Buell JF, Cherqui D, Geller DA, O'Rourke N, Iannitti D, Dagher I et al*. World Consensus Conference on Laparoscopic Surgery. The international position on laparoscopic liver surgery: The Louisville Statement, 2008. *Ann Surg*. 2009 Nov; 250 (5): 825–830. https://doi.org/10.1097/sla.0b013e3181b3b2d8.
28. *Wakabayashi G, Cherqui D, Geller DA, Buell JF, Kaneko H, Han HS et al*. Recommendations for laparoscopic liver resection: a report from the second international consensus conference held in Morioka. *Ann Surg*. 2015 Apr; 261 (4): 619–629. https://doi.org/10.1097/SLA.0000000000001184.
29. *Rotellar F, Ciria R, Wakabayashi G, Suh KS, Cherqui D*. On behalf of the WS-MIDH collaborative group. World Survey on Minimally Invasive Donor Hepatectomy: A Global Snapshot of Current Practices in 2370 Cases. *Transplantation*. 2022 Jan 1; 106 (1): 96–105. https://doi.org/10.1097/TP.0000000000003680.
30. *Baker TB, Jay CL, Ladner DP, Preczewski LB, Clark L, Holl J, Abecassis MM*. Laparoscopy-assisted and open living donor right hepatectomy: a comparative study of outcomes. *Surgery*. 2009 Oct; 146 (4): 817–823; discussion 823–825. https://doi.org/10.1016/j.surg.2009.05.022.
31. *Cherqui D*. Laparoscopic liver resection. *Br J Surg*. 2003 Jun; 90 (6): 644–646. https://doi.org/10.1002/bjs.4197.
32. *Soubrane O, Cherqui D, Scatton O, Stenard F, Bernard D, Branchereau S et al*. Laparoscopic left lateral sectionectomy in living donors: safety and reproducibility of the technique in a single center. *Ann Surg*. 2006 Nov; 244 (5): 815–820. https://doi.org/10.1097/01.sla.0000218059.31231.b6.
33. *Troisi R, Debruyne R, Rogiers X*. Laparoscopic living donor hepatectomy for pediatric liver transplantation. *Acta Chir Belg*. 2009 Jul-Aug; 109 (4): 559–562. https://doi.org/ 10.1080/00015458.2009.11680486.
34. *Kim KH, Jung DH, Park KM, Lee YJ, Kim DY, Kim KM, Lee SG*. Comparison of open and laparoscopic live donor left lateral sectionectomy. *Br J Surg*. 2011 Sep; 98 (9): 1302–1308. https://doi.org/10.1002/bjs.7601.
35. *Scatton O, Katsanos G, Boillot O, Goumard C, Bernard D, Stenard F et al*. Pure laparoscopic left lateral sectionectomy in living donors: from innovation to development in France. *Ann Surg*. 2015 Mar; 261 (3): 506–512. https://doi.org/10.1097/SLA.0000000000000642.
36. *Gautier S, Monakhov A, Gallyamov E, Tsirulnikova O, Zagaynov E, Dzhanbekov T et al*. Laparoscopic left lateral section procurement in living liver donors: A single center propensity score-matched study. *Clin Transplant*. 2018 Sep; 32 (9): e13374. https://doi.org/10.1111/ctr.13374.
37. *Monakhov A, Semash K, Tsiroulnikova O, Djanbekov T, Khizroev K, Kurtak N, Gautier S*. Laparoscopic left lateral sectionectomy in living liver donors: from the first experience to routine usage. *Transplantation.* 2020 Sep; 104 (S3): S241. https://doi.org/10.1097/01.tp.0000699664.06418.8f.
38. *Gautier SV, Monakhov AR, Gallyamov EA, Zagaynov EV, Tsirulnikova OM, Semash KO et al*. Laparoscopic Approach in Liver Harvesting from Living Donors for Transplantation in Children. *Annaly khirurgicheskoy gepatologii = Annals of HPB Surgery*. 2018; 23 (1): 13–18. (In Russ.). https://doi.org/10.16931/1995-5464.2018-1-13-18.
39. *Monakhov A, Gautier S, Tsiroulnikova O, Semash O, Latypov R, Dzhanbekov T et al*. Living donor left lateral sectionectomy: Should the procedure still be performed open? *Journal of Liver Transplantation*. 2021; 1: 100001. https://doi.org/10.1016/j.liver.2020.100001.
40. *Monakhov A, Semash K, Khizroev K, Tsiroulnikova O, Voskanov M, Gallyamov E et al*. Laparoscopic living donor hepatectomy: a new standard for left-sided grafts? *Transplantation.* 2022; 106 (8S): 139–139.
41. *Monakhov A, Semash K, Boldyrev M, Mescheryakov S, Gautier S*. Laparoscopic donor hepatectomy in settings of pediatric living donor liver transplantation: single center experience. *Korean J Transplant*. 2022; 36 (Supple 1): S354. http://doi.org/10.4285/ATW2022.F-4979.
42. *Monakhov A, Gautier S, Tsiroulnikova O, Semash K, Khizroev K, Gallamov E et al*. 332.3: Laparoscopic hepatectomy in living liver donors for transplantation in children: From implementation to routine use. *Transplantation.* 2019; 103 (11S): S82. https://doi.org/10.1097/01.tp.0000612032.55662.25.
43. *Gautier SV, Gallyamov EA, Monakhov AR, Khizroev HM, Zagainov EV, Semash KO*. Laparoscopic removal of liver fragments from a living donor for transplantation to children. *Russian Journal of Transplantology and Artificial Organs*. 2017; 19 (S): 90–91.
44. *Samstein B, Griesemer A, Halazun K, Kato T, Guarrera JV, Cherqui D, Emond JC*. Pure Laparoscopic Donor Hepatectomies: Ready for Widespread Adoption? *Ann Surg*. 2018 Oct; 268 (4): 602–609. https://doi.org/10.1097/SLA.0000000000002959.
45. *Broering DC, Elsheikh Y, Shagrani M, Abaalkhail F, Troisi RI*. Pure Laparoscopic Living Donor Left Lateral Sectionectomy in Pediatric Transplantation: A Propensity Score Analysis on 220 Consecutive Patients.

Liver Transpl. 2018 Aug; 24 (8): 1019–1030. https://doi.org/10.1002/lt.25043.
46. *Kim WJ, Kim KH, Cho HD, Namgoong JM, Hwang S, Park JI, Lee SG.* Long-Term Safety and Efficacy of Pure Laparoscopic Donor Hepatectomy in Pediatric Living Donor Liver Transplantation. *Liver Transpl*. 2021 Apr; 27 (4): 513–524. https://doi.org/10.1002/lt.25910.
47. *Semash KO, Monakhov AR, Khizroev HM, Dzhanbekov TA, Meshcheryakov SV, Boldyrev MA et al.* Laparoscopic hemihepatectomy in a living liver donor. *Russian Journal of Transplantology and Artificial Organs*. 2021; 23 (S): 65.
48. *Taketomi A, Kayashima H, Soejima Y, Yoshizumi T, Uchiyama H, Ikegami T et al*. Donor risk in adult-to-adult living donor liver transplantation: impact of left lobe graft. *Transplantation*. 2009 Feb 15; 87 (3): 445–450. https://doi.org/10.1097/TP.0b013e3181943d46.
49. *Iida T, Ogura Y, Oike F, Hatano E, Kaido T, Egawa H et al*. Surgery-related morbidity in living donors for liver transplantation. *Transplantation*. 2010 May 27; 89 (10): 1276–1282. https://doi.org/10.1097/TP.0b013e3181d66c55.
50. *Soubrane O, Eguchi S, Uemoto S, Kwon CHD, Wakabayashi G, Han HS et al*. Minimally Invasive Donor Hepatectomy for Adult Living Donor Liver Transplantation: An International, Multi-institutional Evaluation of Safety, Efficacy and Early Outcomes. *Ann Surg*. 2022 Jan 1; 275 (1): 166–174. https://doi.org/10.1097/SLA.0000000000003852.
51. *Han HS, Cho JY, Yoon YS, Hwang DW, Kim YK, Shin HK, Lee W.* Total laparoscopic living donor right hepatectomy. *Surg Endosc*. 2015 Jan; 29 (1): 184. https://doi.org/10.1007/s00464-014-3649-9.
52. *Lin NC, Nitta H, Wakabayashi G.* Laparoscopic major hepatectomy: a systematic literature review and comparison of 3 techniques. *Ann Surg*. 2013 Feb; 257 (2): 205–213. https://doi.org/10.1097/SLA.0b013e31827da7fe.
53. *Semash KO, Gautier SV*. Review of surgical techniques for performing laparoscopic donor hepatectomy. *Russian Journal of Transplantology and Artificial Organs*. 2020; 22 (4): 149–153. https://doi.org/10.15825/1995-1191-2020-4-149-153.
54. *Voskanyan SAe, Artem'ev AI, Zabezhinskiyi DA, Shabalin MV, Bashkov AN*. Laparoscopic donor right hemihepatectomy (first experience in Russia). *Endoscopic Surgery*. 2017; 23 (3): 37–40. (In Russ.). doi: 10.17116/endoskop201723337-40.
55. *Suh KS, Yi NJ, Kim T, Kim J, Shin WY, Lee HW et al*. Laparoscopy-assisted donor right hepatectomy using a hand port system preserving the middle hepatic vein branches. *World J Surg*. 2009 Mar; 33 (3): 526–533. https://doi.org/10.1007/s00268-008-9842-z.
56. *Kwon CHD, Choi GS, Kim JM, Cho CW, Rhu J, Soo Kim G et al*. Laparoscopic Donor Hepatectomy for Adult Living Donor Liver Transplantation Recipients. *Liver Transpl*. 2018 Nov; 24 (11): 1545–1553. https://doi.org/10.1002/lt.25307.
57. *Rhu J, Kim MS, Choi GS, Kim JM, Kwon CHD, Joh JW.* Laparoscopic Living Donor Right Hepatectomy Regarding the Anatomical Variation of the Portal Vein: A Propensity Score-Matched Analysis. *Liver Transpl*. 2021 Jul; 27 (7): 984–996. https://doi.org/10.1002/lt.26050.
58. *Gautier SV, Monakhov AR*. Evaluation, selection and preparation of living donor for partial liver transplantation in children. *Russian Journal of Transplantology and Artificial Organs*. 2015; 17 (1): 134–146. (In Russ.). https://doi.org/10.15825/1995-1191-2015-1-134-146.
59. *Marubashi S, Wada H, Kawamoto K, Kobayashi S, Eguchi H, Doki Y et al*. Laparoscopy-assisted hybrid left-side donor hepatectomy. *World J Surg*. 2013 Sep; 37 (9): 2202–2210. https://doi.org/10.1007/s00268-013-2117-3.
60. *Ausania F, Holmes LR, Ausania F, Iype S, Ricci P, White SA.* Intraoperative cholangiography in the laparoscopic cholecystectomy era: why are we still debating? *Surg Endosc*. 2012 May; 26 (5): 1193–1200. https://doi.org/10.1007/s00464-012-2241-4. Epub 2012 Mar 22.
61. *Kim YS, Choi SH.* Pure Laparoscopic Living Donor Right Hepatectomy Using Real-Time Indocyanine Green Fluorescence Imaging. *J Gastrointest Surg*. 2019 Aug; 23 (8): 1711–1712. https://doi.org/10.1007/s11605-019-04217-w.
62. *Kim KH, Kang SH, Jung DH, Yoon YI, Kim WJ, Shin MH, Lee SG.* Initial Outcomes of Pure Laparoscopic Living Donor Right Hepatectomy in an Experienced Adult Living Donor Liver Transplant Center. *Transplantation*. 2017 May; 101 (5): 1106–1110. https://doi.org/10.1097/TP.0000000000001637.
63. *Rotellar F, Pardo F, Benito A, Zozaya G, Martí-Cruchaga P, Hidalgo F et al*. Totally Laparoscopic Right Hepatectomy for Living Donor Liver Transplantation: Analysis of a Preliminary Experience on 5 Consecutive Cases. *Transplantation*. 2017 Mar; 101 (3): 548–554. https://doi.org/10.1097/TP.0000000000001532.
64. *Hong SK, Tan MY, Worakitti L, Lee JM, Cho JH, Yi NJ et al*. Pure Laparoscopic Versus Open Right Hepatectomy in Live Liver Donors: A Propensity Score-matched Analysis. *Ann Surg*. 2022 Jan 1; 275 (1): e206–e212. https://doi.org/10.1097/SLA.0000000000003914.
65. *Choi HJ, You YK, Na GH, Hong TH, Shetty GS, Kim DG.* Single-port laparoscopy-assisted donor right hepatectomy in living donor liver transplantation: sensible approach or unnecessary hindrance? *Transplant Proc*. 2012 Mar; 44 (2): 347–352. https://doi.org/10.1016/j.transproceed.2012.01.018.
66. *Egger ME, Ohlendorf JM, Scoggins CR, McMasters KM, Martin RC 2nd.* Assessment of the reporting of quality and outcome measures in hepatic resections: a call for 90-day reporting in all hepatectomy series. *HPB (Oxford)*. 2015 Sep; 17 (9): 839–845. https://doi.org/10.1111/hpb.12470.
67. *Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD et al*. The Clavien–Dindo classification of surgical complications: five-year experience. *Ann Surg*. 2009 Aug; 250 (2): 187–196. https://doi.org/10.1097/SLA.0b013e3181b13ca2.
68. *Slankamenac K, Graf R, Barkun J, Puhan MA, Clavien PA.* The comprehensive complication index: a novel continuous scale to measure surgical morbidity. *Ann Surg*. 2013 Jul; 258 (1): 1–7. https://doi.org/10.1097/SLA.0b013e318296c732.

69. *Zhang X, Yang J, Yan L, Li B, Wen T, Xu M et al*. Comparison of laparoscopy-assisted and open donor right hepatectomy: a prospective case-matched study from china. *J Gastrointest Surg*. 2014 Apr; 18 (4): 744–750. https://doi.org/10.1007/s11605-013-2425-9.
70. *Lei HJ, Lin NC, Chen CY, Chou SC, Chung MH, Shyr BU et al*. Safe Strategy to Initiate Total Laparoscopic Donor Right Hepatectomy: A Stepwise Approach From a Laparoscopy-Assisted Method. *World J Surg*. 2020 Sep; 44 (9): 3108–3118. https://doi.org/10.1007/s00268-020-05572-5.
71. *Takahara T, Wakabayashi G, Nitta H, Hasegawa Y, Katagiri H, Umemura A et al*. The First Comparative Study of the Perioperative Outcomes Between Pure Laparoscopic Donor Hepatectomy and Laparoscopy-Assisted Donor Hepatectomy in a Single Institution. *Transplantation*. 2017 Jul; 101 (7): 1628–1636. https://doi.org/10.1097/TP.0000000000001675.
72. *Makki K, Chorasiya VK, Sood G, Srivastava PK, Dargan P, Vij V.* Laparoscopy-assisted hepatectomy versus conventional (open) hepatectomy for living donors: when you know better, you do better. *Liver Transpl*. 2014 Oct; 20 (10): 1229–1236. https://doi.org/10.1002/lt.23940.
73. *Troppmann C, Ormond DB, Perez RV.* Laparoscopic (vs open) live donor nephrectomy: a UNOS database analysis of early graft function and survival. *Am J Transplant*. 2003 Oct; 3 (10): 1295–1301. https://doi.org/10.1046/j.1600-6143.2003.00216.x.
74. *Fancellu A, Rosman AS, Sanna V, Nigri GR, Zorcolo L, Pisano M, Melis M.* Meta-analysis of trials comparing minimally-invasive and open liver resections for hepatocellular carcinoma. *J Surg Res*. 2011 Nov; 171 (1): e33–e45. https://doi.org/10.1016/j.jss.2011.07.008.
75. *Xiong JJ, Altaf K, Javed MA, Huang W, Mukherjee R, Mai G et al*. Meta-analysis of laparoscopic vs open liver resection for hepatocellular carcinoma. *World J Gastroenterol*. 2012 Dec 7; 18 (45): 6657–6668. https://doi.org/10.3748/wjg.v18.i45.6657.
76. *Kitajima T, Kaido T, Iida T, Seo S, Taura K, Fujimoto Y et al*. Short-term outcomes of laparoscopy-assisted hybrid living donor hepatectomy: a comparison with the conventional open procedure. *Surg Endosc*. 2017 Dec; 31 (12): 5101–5110. https://doi.org/10.1007/s00464-017-5575-0.
77. *Rhu J, Choi GS, Kwon CHD, Kim JM, Joh JW.* Learning curve of laparoscopic living donor right hepatectomy. *Br J Surg*. 2020 Feb; 107 (3): 278–288. https://doi.org/10.1002/bjs.11350. Epub 2019 Oct 25.
78. *Kurosaki I, Yamamoto S, Kitami C, Yokoyama N, Nakatsuka H, Kobayashi T et al*. Video-assisted living donor hemihepatectomy through a 12-cm incision for adult-to-adult liver transplantation. *Surgery*. 2006 May; 139 (5): 695–703. https://doi.org/10.1016/j.surg.2005.12.002.
79. *Song JL, Yang J, Wu H, Yan LN, Wen TF, Wei YG, Yang JY.* Pure laparoscopic right hepatectomy of living donor is feasible and safe: a preliminary comparative study in China. *Surg Endosc*. 2018 Nov; 32 (11): 4614–4623. https://doi.org/10.1007/s00464-018-6214-0.
80. *Rotellar F, Pardo F, Martí-Cruchaga P, Zozaya G, Valentí V, Bellver M et al*. Liver mobilization and liver hanging for totally laparoscopic right hepatectomy: an easy way to do it. *Langenbecks Arch Surg*. 2017 Feb; 402 (1): 181–185. https://doi.org/10.1007/s00423-016-1473-5.
81. *Giulianotti PC, Tzvetanov I, Jeon H, Bianco F, Spaggiari M, Oberholzer J, Benedetti E.* Robot-assisted right lobe donor hepatectomy. *Transpl Int*. 2012 Jan; 25 (1): e5–e9. https://doi.org/10.1111/j.1432-2277.2011.01373.x.
82. *Salloum C, Lim C, Lahat E, Gavara CG, Levesque E, Compagnon P, Azoulay D.* Robotic-Assisted Versus Laparoscopic Left Lateral Sectionectomy: Analysis of Surgical Outcomes and Costs by a Propensity Score Matched Cohort Study. *World J Surg*. 2017 Feb; 41 (2): 516–524. https://doi.org/10.1007/s00268-016-3736-2.
83. *Broering DC, Elsheikh Y, Alnemary Y, Zidan A, Elsarawy A, Saleh Y et al*. Robotic Versus Open Right Lobe Donor Hepatectomy for Adult Living Donor Liver Transplantation: A Propensity Score-Matched Analysis. *Liver Transpl*. 2020 Nov; 26 (11): 1455–1464. https://doi.org/10.1002/lt.25820.
84. *Chen PD, Wu CY, Hu RH, Chen CN, Yuan RH, Liang JT et al*. Robotic major hepatectomy: Is there a learning curve? *Surgery*. 2017 Mar; 161 (3): 642–649. https://doi.org/ 10.1016/j.surg.2016.09.025.
85. *Troisi RI, Elsheikh Y, Alnemary Y, Zidan A, Sturdevant M, Alabbad S et al*. Safety and Feasibility Report of Robotic-assisted Left Lateral Sectionectomy for Pediatric Living Donor Liver Transplantation: A Comparative Analysis of Learning Curves and Mastery Achieved With the Laparoscopic Approach. *Transplantation*. 20211; 105 (5): 1044–1051. https://doi.org/10.1097/TP.0000000000003332.
86. *Cai X, Li Z, Zhang Y, Yu H, Liang X, Jin R, Luo F.* Laparoscopic liver resection and the learning curve: a 14-year, single-center experience. *Surg Endosc*. 2014 Apr; 28 (4): 1334–1341. https://doi.org/10.1007/s00464-013-3333-5.
87. *Lee B, Choi Y, Han HS, Yoon YS, Cho JY, Kim S et al*. Comparison of pure laparoscopic and open living donor right hepatectomy after a learning curve. *Clin Transplant*. 2019 Oct; 33 (10): e13683. https://doi.org/10.1111/ctr.13683.
88. *Yu YD, Kim KH, Jung DH, Lee SG, Kim YG, Hwang GS.* Laparoscopic live donor left lateral sectionectomy is safe and feasible for pediatric living donor liver transplantation. *Hepatogastroenterology*. 2012; 59 (120): 2445–2449. https://doi.org/10.5754/hge12134.
89. *Park J, Kwon DCH, Choi GS, Kim SJ, Lee SK, Kim JM et al*. Safety and Risk Factors of Pure Laparoscopic Living Donor Right Hepatectomy: Comparison to Open Technique in Propensity Score-matched Analysis. *Transplantation*. 2019 Oct; 103 (10): e308–e316. https://doi.org/10.1097/TP.0000000000002834.
90. *Seo J, Hong SK, Lee S, Hong SY, Choi Y, Yi NJ et al*. Pure Laparoscopic Versus Open Right Hepatectomy in Living Liver Donors: Graft Weight Discrepancy. *Ann Transplant*. 2022 Dec 2; 27: e938274. https://doi.org/10.12659/AOT.938274.

91. *Lee KW, Choi Y, Hong SK, Lee S, Hong SY, Suh S et al*. Laparoscopic donor and recipient hepatectomy followed by robot-assisted liver graft implantation in living donor liver transplantation. *Am J Transplant*. 2022 Apr; 22 (4): 1230–1235. https://doi.org/10.1111/ajt.16943.
92. *Chen PD, Wu CY, Hu RH, Ho CM, Lee PH, Lai HS et al*. Robotic liver donor right hepatectomy: A pure, minimally invasive approach. *Liver Transpl*. 2016 Nov; 22 (11): 1509–1518. https://doi.org/10.1002/lt.24522.
93. *Binoj ST, Mathew JS, Nair K, Mallick S, Chandran B, Menon R et al*. 260 Robotic Donor Right Hepatectomy: Is It Just Flaunting the Scar? *Gastroenterology.* 2020; 158: S-1263. https://doi.org/10.1016/S0016-5085(20)33815-4.
94. *Semash KO, Dzhanbekov TA, Akbarov MM*. Vascular complications after liver transplantation: contemporary approaches to detection and treatment. A literature review. *Russian Journal of Transplantology and Artificial Organs*. 2023; 25 (4): 46–72. https://doi.org/10.15825/1995-1191-2023-4-46-72.
95. *Broering DC, Zidan A*. Advancements in Robotic Living Donor Hepatectomy, Review of Literature and Single-Center Experience. *Curr Transpl Rep.* 2020; 7: 324–331. https://doi.org/10.1007/s40472-020-00311-0.
96. *Li D, Wang M.* A 3D Image Registration Method for Laparoscopic Liver Surgery Navigation. *Electronics*. 2022; 11 (11): 1670. https://doi.org/10.3390/electronics11111670.
97. *Golse N, Petit A, Lewin M, Vibert E, Cotin S*. Augmented Reality during Open Liver Surgery Using a Markerless Non-rigid Registration System. *J Gastrointest Surg*. 2021; 25 (3): 662–671. https://doi.org/10.1007/s11605-020-04519-4.
98. *Naito S, Kajiwara M, Nakashima R, Sasaki T, Hasegawa S.* Application of Extended Reality (Virtual Reality and Mixed Reality) Technology in Laparoscopic Liver Resections. *Cureus.* 2023 Sep 1; 15 (9): e44520. https://doi.org/10.7759/cureus.44520.

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