EJT European Journal of Transplantation

2024;2:17-21
DOI: 10.57603/EJT-418

REVIEW

THE ROBOTIC LIVING DONOR LIVER DONATION: TECHNICAL ASPECTS AND RESULTS

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Received: December 19, 2023
Accepted: January 22, 2024

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How to cite this article: Cassese G, Giglio MC, Campanile S, et al. The robotic living donor liver donation: technical aspects and results. EJT 2024;2:17-21. https://doi.org/10.57603/EJT-418

Summary

Liver transplantation (LT) is the only effective treatment for end stage liver disease. Both medical and surgical improvements allowed to reach excellent survival results for such frail patients. Nonetheless, LT is still challenged by the organ shortage, with two subsequent issues that cannot be avoided: the long waiting period, and the growing risk of dropout. Living donor liver transplantation (LDLT) has been widely accepted to overcome the shortage of deceased donors and has greatly improved thanks to tremendous technological advances. Furthermore, LDLT in many countries is the main resource of organs due to cultural and social reasons.

The evolution in the last three decades of minimally invasive liver surgery (MILS) has generated heated debate regarding the appropriateness of MILS in living-related donor graft hepatectomy, where the priority is represented by donor safety. Technical innovations have allowed a growing recruitment of potential donors, thanks to smaller incisions and fast recovery after graft procurement. However, the technical difficulties related to MILS for major hepatectomies and the concerns about donor safety still represent a barrier for its wide adoption. The introduction of robotic system may ease such process, potentially leading to an improved safety for the donor, thanks to the overcoming of the technical difficulties of the laparoscopic approach, related to challenging ergonomics and long learning curve.

The aim of this review is to summarize the technical aspects of robotic-assisted living donor hepatectomy (RLDH), with its pros and cons, showing the latest available results.

Key words: liver transplantation, living donor nephrectomy, organ donation, kidney transplantation, mini-invasive surgery, laparoscopic, robotic

INTRODUCTION

Since the first reported case in 1963 by Thomas Starzl, liver transplantation (LT) is considered the cornerstone treatment of end-stage liver disease [1,2]. Subsequently deceased donor liver transplantation (DDLT) became soon a standard clinical practice, causing a growing disparity between the constantly growing number of LT candidates and the available grafts. Such challenge paved the way to the era of living donor liver transplantation (LDLT).

The evolution of LDLT has not been easy, starting from the first theorization of the possibility to split a whole liver in 1968 from the Verona group led by

Dagradi [3]. The first attempt was performed by Raia et al. 20 years later, unfortunately not successful. Then Strong et al. published the first successful case, followed by a large series of adult-to-child LDLT in USA and Europe [4,5]. However, it is in Asia that this procedure has tremendously developed, since here DDLT is not common, mainly due to social and cultural reasons.

Similarly, in the last three decades minimally invasive liver surgery (MILS) has slowly but continuously improved. After Reich reported the first laparoscopic liver resection in 1991 [7], MILS has become a standard of care in high volume referral hepatobiliary centers thanks to less postoperative pain, reduced morbidity, and faster post-operative recovery. Nonetheless, its spreading has been slower than other surgical specialties, owing to different reasons, such as the technical complexity of parenchymal transection and hilar dissection, the risk for massive bleeding, the oncological concerns about resection margins (limited by the initial unavailability of intraoperative ultrasounds), and the consideration of cirrhotic patients as too fragile and complex for a minimally invasive approach [8]. However, more and more papers showed clear advantages of MILS. Some situations still represent a challenge for the liver surgeon, such as a difficult tumor location, tumor size, the proximity of the tumor to large vessels, and underlying liver disease. All these aspects are not considered contraindications, but have limited the wide adoption of MILS for major liver resection, with a percentage reported in literature as low as 22% in last five years in most major series [9].

The concerns about safety in minimally invasive major hepatectomies involved also LDLT, since the donor safety is probably the most important aspect of LDLT, representing the priority of the liver transplant surgeon for such cases. Minimally invasive donor hepatectomy (MIDH) is a very challenging surgical procedure, also considering that the donor is a healthy person with no underlying diseases, subjected to non-negligible intra-operative and post-operative risks. Indeed, this has always been the main reason for the initial caution and skepticism accompanying MIDH. However, MIDH slowly spread again from Europe, where in 2002 Cherqui et al. reported the first pure laparoscopic adult-to-child left lateral sectionectomy [10]. From this experience, LDLT for pediatric recipients developed and spread very easily, thanks to an immediate standardization of the technique, a great reproducibility, as well as a less complex intervention with acceptable risks. The first pure laparoscopic donor right hepatectomy (PLDRH) was performed in South Korea by Han et al. in 2010 (but reported later) [11], while Troisi et al. reported the first pure laparoscopic full left donor hepatectomies (PLDLH) [12].

In the setting of LDLT, the transplant surgeon is expected to minimize the complication rates offering at the same time a fast and complete recovery for the donors, also to make donation attractive and to maintain an adequate pool of donor candidates. Traditional laparotomy resulted in high rates of post-operative pain and complication, with incisional hernia, bowel obstruction, and chronic abdominal discomfort accounting for 30-50% of the complications in donor hepatectomy [13]. Thus, MIDH showed some advantages, such as small incisions, improving post-operative pain and reducing the incision-related post-operative complications, improving the post-operative recovery, and eventually reducing the guilty feelings of the recipients.

Finally, the Chicago group led by Giulianotti et colleagues reported the first robot-assisted living donor hepatectomy (RALDH) in 2012, harvesting a right lobe with no post-operative complications [14]. More and more studies were published showing robust evidence about the safety of MIDH, confirming the advantages over open technique when performed in expert centers, such as lower blood loss, shorter length of hospital stay, and lower morbidity [15]. Similarly, a recent wide meta-analysis confirmed the better results in terms of post-operative length of stay and estimated blood loss after both robotic and laparoscopic donor hepatectomies when compared to open, without affecting post-operative complications [16].

The path of robotic surgery in MIDH had finally been opened, and in the following years this approach literally revolutionized minimally invasive surgery in light of excellent results and a strong attraction towards both the surgeon and the patient. This review summarizes the advantageous aspects both in terms of technique and results of RALDH, without neglecting any problems still open and to be resolved.

TECHNICAL ASPECTS

Herein, the authors present some technical solution according to their experience and current literature.

For RALDH, the patient is placed in supine position, and an open technique is used to set a pneumoperitoneum up to 12 mmHg, through an infra-umbilical port that will be then used by the assistant surgeon on the bedside. After a careful exploration of the abdominal cavity, four robotic trocars are placed as per other robotic liver resection, at 8-10 cm one from each other: one on the right anterior axillary line, one on the right midclavicular line, one on the left midclavicular line, one on the left anterior axillary line. When using a Da Vinci Xi Robot, the ports are placed on a linear shape slightly oblique toward the right hypochondrium.

A Pfannenstiel incision can be performed at this phase, to avoid later difficulties due to the robotic positioning.

The surgery starts with the opening of the falciform ligament down to the level of the hepatic veins, using an

ultrasonic dissector. The gallbladder or the stump of the round ligament can be grasped to retract or lift the liver.
According to the type of resection, the right or the left lobe are mobilized, and a careful dissection of the retro hepatic Inferior Vena Cava is performed using two robotic bipolar Maryland dissectors. Retro hepatic veins are clipped or sutured depending on the caliber. The caval ligament is divided by using an energy device, and the hepatic vein is isolated to facilitate the hanging maneuver, that is always very helpful to safely perform the hemi-hepatectomy according to our experience.
Dissection of the hilum can be performed with the help of the monopolare hook and Maryland bipolar dissector, while lifting up the liver. The cystic duct is followed to isolate the common bile duct, and the portal vein can be found behind it by gently lifting it up. The hepatic artery is usually isolated close to the common bile duct. The hilar structures are encircled with a vessel loop. The ipsilateral portal branch is clamped with a bulldog clamp the obtain a demarcation line, that can be even more highlighted using the ICG-fluorescence through the Firefly system after an intravenous injection of 0.5 mg/kg of indocyanine green (ICG). Also, intraoperative ultrasounds can be used to confirm the position of major vascular structures. A Silicone Foley catheter is placed along the IVC emerging between the hepatic veins to perform a hanging maneuver.
The bulldog clamps are removed, and the parenchymal transection is performed with the aid of an ultrasonic device with open and closed jaw techniques, as well as with bipolar device using the crush-clamp technique. Another alternative in case of experienced bedside assistant surgeons can be the so called "robo-lap approach", with the CUSA handled by the assistant surgeon [14]. Small crossing hepatic veins are secured with titanium clips, paying great attention to spare the median hepatic vein.
After completion of the biggest part of parenchymal transection, the attention moves to the hilar plate: thanks to the previous injection of ICG, the Firefly mode allows to identify bile duct anatomy [18]. After a small opening of the right bile duct under real-time ICG-cholangiogram, a probing of the bile duct is performed.
Finally, the donor bile duct stump is closed with a monofilament suture. Parenchymal transection is completed, then the silicon catheter is looped and held with a pro grasp the fourth robotic arm to dissect the remaining part of liver parenchyma. The hepatic vein is also encircled, and everything is settled to remove the graft.
The hepatic artery is closed by using hem-o-locks, while portal and hepatic veins are secured with vascular staplers. The graft is extracted in a vinyl bag.

ADVANTAGES AND DISADVANTAGES OF ROBOTIC-ASSISTED LIVING DONOR HEPATECTOMY

Following the first successful right lobe donor hepatectomy in 2012, more and more RALDH have been reported worldwide, from countries including Korea, Taiwan, and Saudi Arabia [19-21].
The robotic platform seemed to overcome some drawbacks of laparoscopic surgery, thanks to a magnified 3-dimensional view with better depth perception, a steadier visualization, unlimited degrees of freedom when using tremor-free surgical instruments, which is reflected in a major ease in dissection maneuvers and suturing [22]. Therefore, the ability to perform suturing more easily and more efficiently may enable a longer vascular stump and proper bile duct opening of the graft [23]. Moreover, surgical navigation with Firefly indocyanine green imaging could facilitate precise parenchymal anatomic dissection, thanks to the deeper surgical field, as well as exact division of the bile ducts [24,25].
Another reported advantage of the robotic approach is a shorter learning curve, that could play an important role when implementing a MIDH program. Indeed, the learning curve for PLDRH has been reported between 45 and 60 cases for an experienced transplant-laparoscopic surgeon [26,27]. However, the learning curve for robotic donor hepatectomy was reported to be as low as 15-30 cases [28-30]. More importantly, a prior knowledge of laparoscopic surgery is not an absolute prerequisite for initiating a robot donor hepatectomy program [31]. According to a prospective multicenter study, robotic major liver resection can be safely performed by robotic beginners who are expert open and laparoscopic liver surgeons [32]. Finally, the robotic platform offers the advantage of using a double console, with the possibility of having a proctor surgeon who helps and guides the first operator in the initial stages of his learning curve [33].
When focusing on the outcomes of robotic major hepatectomies in general, several studies highlighted how the postoperative results are not inferior overall, when compared with both open or laparoscopic approaches, with the only shortcomings being the operative time and associated cost [34,35]. According to a meta-analysis of 2,728 cases of robotic liver surgery, the operative complication rate was lower after robotic liver resections than after open hepatectomies (I^2 = 46.49%; P = .021; risk difference = 0.093 [0.036-0.15]) [22]. When comparing the robotic and the laparoscopic approach, the robotics had a positive effect specifically in major liver resections (I^2 = 0%; P = 0.499; risk difference = 0.114 [−0.000-0.228]) [22]. The post-operative hospital stay was shorter after robotic liver resection than after open liver resection. However,

the operative time and cost of robotic liver resection were higher than both laparoscopic and open liver resection.
In the specific setting of liver transplantation, a recent meta-analysis including four studies with a total of 517 patients also showed excellent outcomes of RALDH. The mean difference (MD) in the length of hospital stay (MD: -0.8 95% CI -1.4, -0.3), Clavien– Dindo complications I–II (RR: 0.5 95% CI 0.2, 0.9), and pain score at day > 3 (MD: -0.6 95% CI -1.6, 0.4), as well as postoperative total bilirubin level (MD: -0.7 95% CI -1.0, -0.4), were reduced after RALDH when compared to laparotomic procedures [36]. When comparing to laparoscopic approach, the pain score at day > 3 was lower after RALDH (MD: -0.4 95% CI -0.8, -0.09). Furthermore, this meta-analysis showed some advantages even in the recipients, with lower post-operative AST level (MD: -0.5 95% CI -0.9, -0.1) and post-operative length of stay after RALDH. No postoperative deaths were reported.
When dealing with open issues, it must be underlined that most of the published data on robotic living donor hepatectomy come from centers with huge experience, unique skillsets, and high volumes of robotic cases that do not facilitate the generalizability of the results.
Furthermore, most available studies had set strict initial selection criteria for both donors and recipients to combine the goals of non-inferior transplant-related outcomes and advantages of minimally invasive surgery (cosmetics, less pain, shorter LOS). For instance, some Asian experts recommend that the initial indications for PLDH for a right graft should be a graft-to-recipient weight ratio > 1.0, remnant liver volume > 35%, normal vascular and biliary anatomy, and a nonemergent setting [37]. Still, very few donors outside these criteria were included in the published studies.

CONCLUSIONS AND FUTURE DIRECTIONS

The robotic approach to the recipient surgery seems to be the next step in this robotic revolution in surgery. Thanks to its efficient suturing movements under the magnified steady visualization, robotic surgery has been incredibly applied to recipient surgery in LDLT.
Despite many difficulties and skepticism, in 2021 the Seoul National University transplant team used the robotic platform to implant a liver graft that had been previously laparoscopically harvested in a living donor [38,39]. Then, the same team then explanted the recipient's liver and reconstructed the hepatic and portal veins using the laparoscopic approach, to shorten the ischemic time, then using the robotic platform to perform more challenging anastomosis of the hepatic artery and bile duct [40]. However, the operative time and ischemic time were more than doubled compared to open procedures. Subsequently, the longer ischemic time and operative time may have a potential negative impact on graft survival and on the post-operative recovery of the recipient, who is in a medically very vulnerable condition. Therefore, the surgical indications of minimally invasive recipient surgery should be carefully considered.
Nonetheless, the journey in the use of the robotic approach for LDLT is far from being over.

Conflict of interest statement

The authors declare no conflict of interest.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

GC, RM, MCG: conceived and designed the manuscript; GF, LR: gave administrative support; RM, GC: wrote the manuscript; GR, MCG, SC: critically revised the manuscript.

Ethical consideration

Not applicable.

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