

Early Experience of Pure Robotic Right Hepatectomy for Liver Donors in a Small-Volume Center

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ABSTRACT

Background and Objectives: Living donor right hepatectomy has become the most common method of liver transplantation. With minimally invasive surgery, laparoscopic donor hepatectomy became possible, but with some limitations. Advancements in robotic technology made it possible to overcome these shortcomings and maximize the advantages of minimally invasive surgery in transplantation. For this reason, some centers have started robotic donor hepatectomy. Our study aimed to introduce our early experience of robotic donor right hepatectomy and investigate the feasibility of this surgery.

Methods: This study included 10 (30%) living donors who underwent pure robotic donor right hepatectomy at Dong-A University Hospital from January 1, 2020 to December 31, 2021. The medical records were analyzed to determine the short-term outcomes of these patients.

Results: The total operation time and warm ischemic time were $396.6 \text{ min} \pm 62.7 \text{ min}$ and $19.7 \text{ min} \pm 5.6 \text{ min}$, respectively. Moreover, there was no transfusion during the operation and no other port use and open conversion. The average real graft volume was $590 \text{ mL} \pm 73.5 \text{ mL}$, and the mean hospital stay was $8.7 \text{ d} \pm 2.6 \text{ d}$. There have been no specific complications noted in the donor group.

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Conclusions: Based on our positive experience with pure robotic right hepatectomy for a liver donor, the robotic technique may be a new option for achieving minimally invasive surgery for a liver donor.

Key Words: Hepatectomy, Liver transplantation, Robotic surgery.

INTRODUCTION

Minimally invasive hepatectomy for liver diseases has advantages such as reduced pain, improved cosmesis, shorter hospital stays, faster recovery, and lower morbidity.¹⁻³ Recently, robotic hepatectomy has become popular because robotic surgery has some advantages over laparoscopic surgery, including improved dexterity, three-dimensional vision, magnified view, and a stable platform.^{4,5} The robotic platform may facilitate hepatectomy at a more advanced level.⁶ Also, the meta-analysis by Hu et al.⁷ revealed that the robotic donor cohort has a lower open conversion rate and is suitable for larger tumor sizes than the laparoscopic approach.

With this minimally invasive surgical development, minimally invasive donor hepatectomy (MIDH) has been performed. According to the recently released expert consensus guidelines,⁸ MIDH is not inferior in donor safety and recipient outcomes to open donor hepatectomy. Moreover, the long-term quality of life of the donor is better. In addition, in Asia, where living donors, especially the young, are the predominant modality in LDLT, the demand for MIDH is increasing. However, the barriers to MIDH entry were high for surgeons due to the prerequisites for acquiring advanced skills capable of conducting minimally invasive surgery (MIS) and sufficient experience in living transplantation.⁹ In the case of pure laparoscopic donor hepatectomy, inherent limitations, including decreased range of motion and dexterity, poor ergonomics, and unstable visualization, made it more difficult to attempt.^{2,10} Overcoming these shortcomings, the robotic platform has a shorter learning curve and provides equivalent outcomes while maintaining the benefits of MIS.^{10,11} Therefore, this paper aims to introduce our early

experiences and investigate the feasibility and surgical outcomes of pure robotic right hepatectomy for the donor.

MATERIALS AND METHODS

From January 1, 2020 to December 31, 2021, 30 living donor liver transplants were performed at Dong-A University Hospital. Among them, 10 (30%) living donors underwent pure robotic right hepatectomy. The remaining 20 cases were open donor hepatectomy, and there were no laparoscopic cases. To date, our center does not have experience with laparoscopic donor hepatectomy.

All the robotic donor hepatectomy were conducted by a single surgeon, who has had experiences with laparoscopic hepato-biliary-pancreatic surgery but not with laparoscopic pancreatoduodenectomy and donor hepatectomy. In particular, the surgeon had about 45 cases of laparoscopic liver resection, of which 25 were major laparoscopic liver resection from January 1, 2015 to December 31, 2018.

After recognizing the merits of the robotic platform in 2019, Our center focused more on robotic than laparoscopic surgery. Prior to performing robotic donor hepatectomy, the surgeon performed 47 robotic single site cholecystectomies and eight robotic hepato-biliary-pancreatic surgeries including choledochal cyst excision, distal pancreatectomy, left lateral sectionectomy of liver, wedge resection of liver, and extended cholecystectomy.

This was our initial experience of pure robotic donor hepatectomy; thus, absolute criteria did not exist. Instead, we selected donors that met the conditions of normal anatomy, low body mass index (BMI), and an estimated graft volume of the right liver < 700 g to perform pure robotic right hepatectomy.

The medical records that included demographic and pre- and postoperative data were collected and analyzed retrospectively to compare short-term outcomes in these patients. Postoperative complications were assessed using the Clavien–Dindo classification.

All data analyses were performed with statistical software (IBM SPSS for Windows, Version 260.0, Chicago, IL, USA). Quantitative variables were expressed as the mean \pm standard deviation.

This study was approved by the ethics committee of Dong-A University Hospital. The requirement for informed consent from patients was waived due to the

retrospective nature of this study. This study was conducted according to the principles of the Declaration of Helsinki.

Surgical Procedure

Pure Robotic Donor Hepatectomy

Each donor was placed in a lithotomy position, with the head raised at 30° and the right side up at 15°. Four 8-mm trocars and one 12-mm trocar (Ethicon, Somerville, NJ) were inserted into the abdomen. The assistant port (12 mm trocar) was located about 1 cm to the right of the navel, with the remaining four trocars on the same line at a supraumbilical level (**Figure 1**). When pneumoperitoneum was established, the DaVinci® system (Intuitive Surgical, Sunnyvale, CA) was set in the upper section. After Falciform transection, right triangular ligament mobilization was done using the robotic monopolar hook. Next, the gallbladder was dissected routinely, and the cystic duct stump was sutured with Vicryl 3/0 (Ethicon, Somerville, NJ) and a rubber band (**Figure 2**) to expose the posterior part of the hilum. During hilar dissection, the right portal vein and the hepatic artery were dissected and encircled with a vessel loop (Scalan, Minnesota, USA). After that, a short hepatic vein was dissected and clipped. Before right lobe mobilization, the caudate lobe was transected for retro hepatic vena cava exposure. Then the right liver rotated toward the patient's left, and a retro hepatic vena cava dissection was performed. After the right liver mobilization, the right portal vein and the hepatic artery were clamped temporally, and the transection line was checked.

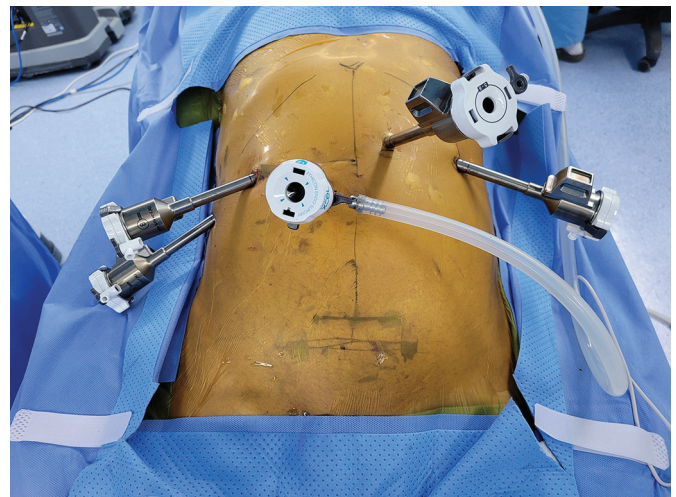


Figure 1. Trocar placement.

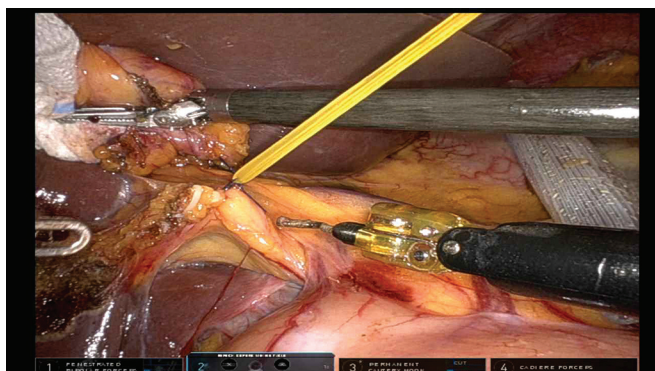


Figure 2. Using a rubber band for exposure of the posterior part of the hilum.

Intravenous injection of indocyanine green (ICG) (Verdye; Diagnostic Green, Germany) and Firefly (Intuitive Surgical, Sunnyvale, CA) was used to clarify the transection line (**Figure 3**). For stable and meticulous dissection, the rubber band technique was performed¹² (**Figures 4A and B**), and parenchymal transection was done with the robotic harmonic scalpel (Ethicon, Somerville, NJ), monopolar hook for coagulation, and fenestrated bipolar forceps for traction. Intervening vessels were ligated by metal clips (Challenger clips; Aesculap, Tuttlingen, Germany), and the V5 and V8 veins were ligated by Weck Hem-o-lok clips (Teleflex, Morrisville, NC). A pringle maneuver was used during the liver transection (on for 15 minutes, off for 5 minutes), and the right hilar plate was divided under the guidance of real-time ICG. After most of the liver parenchyma was transected, the right hepatic vein was encircled with a loop. A Pfannenstiel incision was made before harvesting. When the recipient was ready, the graft was put in a plastic bag in advance, the right portal vein and the hepatic artery were double ligated by Hem-o-lok clips, and the right hepatic vein was transected by a vascular stapler (Covidien Endo



Figure 3. Demarcation line using indocyanine green and firefly.

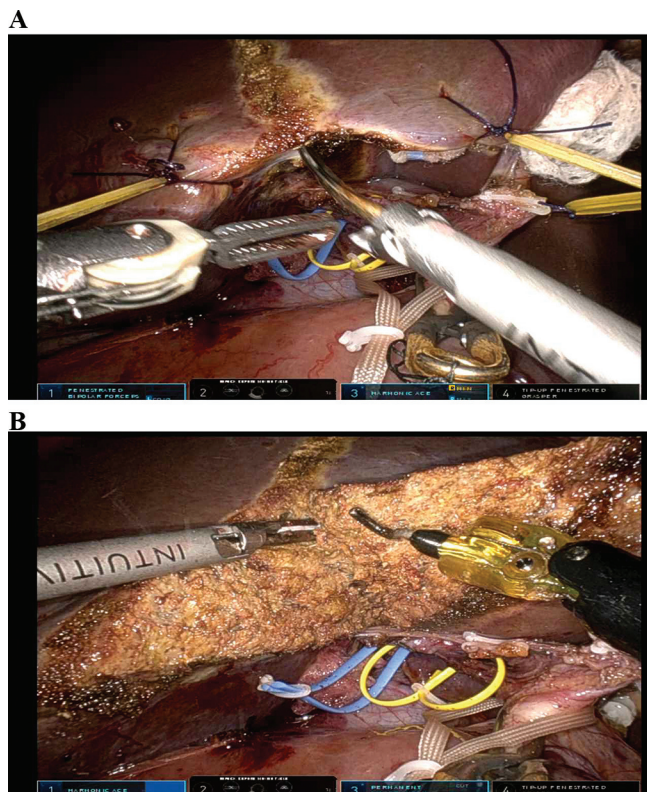


Figure 4. A and B. Rubber band technique during liver transection.

GIA 30 mm; Medtronic, Minneapolis, MN). The right liver graft in the plastic bag was retrieved through a Pfannenstiel incision. After meticulous hemostasis in the hilum and liver parenchyma, one Jackson–Pratt drain was inserted in the subhepatic space. The fascia was closed by an interrupted suture, and the skin was closed by a subcuticular suture (**Figure 5**).



Figure 5. Wound after the operation.

RESULTS

From January 1, 2020 to December 31, 2021, 10 (30%) living donors underwent pure robotic right hepatectomy. Only one donor was male, and the mean age of donors was 33 ± 9.5 years. Most of the donors' American Society of Anesthesiology score was 1 (80%), the others were 2 (20%), and their average BMI was 23.4 ± 3.2 kg/m². Nine out of the 10 patients had less than 5% fatty liver, and only one showed 10% fatty liver from a biopsy. Anatomically, two donors showed abnormalities; one had a right hepatic artery from the superior mesenteric artery, and the other had two right hepatic veins. (Table 1)

The total operation time and warm ischemic time (WIT) were 396.6 min \pm 62.7 min and 19.7 min \pm 5.6 min, respectively. Our study defined operation time as follows:

Table 1.	
Patient Characteristics	
	(n = 10)
Age, mean \pm SD	33 ± 9.5
Sex, Male/Female, n (%)	1/ 9 (10/90)
ASA status, n (%)	
I	8 (80)
II	2 (20)
II	0 (0)
Body mass index, mean \pm SD, kg/m ²	23.4 ± 3.2
Estimated Graft volume, mean \pm SD, mL	634 ± 74.6
Remnant liver volume, mean \pm SD, %	35 ± 3.2
Fatty change, n (%)	
< 5%	9 (90)
5% – 10%	1 (10)
$\geq 10\%$	0 (0)
Anatomical abnormality, n (%)	
Hepatic artery	1 (10)
Portal vein	0 (0)
Hepatic vein	1 (10)
Bile duct	0 (0)
Right Inferior hepatic vein	4 (40)
Graft type, n (%)	
Right graft	8 (80)
Extended right graft	2 (20)

Abbreviations: ASA, American Society of Anesthesiologists; SD, standard deviation.

1) total operation time: the time from skin incision to skin closure; 2) WIT: the time from ligation of the right hepatic artery to retrieval of the liver graft. There was no transfusion, additional port use, or open conversion during the surgery. The average real graft volume was 590 mL \pm 73.5 mL. The mean hospital stay was 8.7 d \pm 2.6 d. There have been no specific complications noted in the donor group. (Table 2)

As shown in Figure 6, operation sequence and operation time had a strong negative correlation with $r^2 = 0.638$ and $P < .01$.

DISCUSSION

Several studies have demonstrated that MIDH is safe and has comparable surgical outcomes;^{8,13–16} and it has gradually evolved to become the main method of donor

Table 2.	
Perioperative and Postoperative Outcomes	
	(n = 10)
Total operative time, mean \pm SD, min	396.6 ± 62.7
Warm ischemic time, mean \pm SD, min	19.7 ± 5.6
Perioperative transfusion, n (%)	0 (0)
Real Graft volume, mean \pm SD, ml	590 ± 73.5
Hospital stays, mean \pm SD, days	8.7 ± 2.6
Open conversion, n (%)	0 (0)
POD #5 LFT	
AST (U/L)	54.5 ± 25.1
ALT (U/L)	125.5 ± 69.9
Total bilirubin (mg/dL)	1.7 ± 0.55
Peak LFT in hospital stay	
AST (U/L)	481.8 ± 283
ALT (U/L)	449.9 ± 283.4
Total bilirubin (mg/dL)	2.8 ± 0.9
Complication, n (%)	
I	0 (0)
IIa	0 (0)
IIb	0 (0)
IIIa	0 (0)
IIIb	0 (0)
IV	0 (0)

Abbreviations: POD, Postoperative day; LFT, Liver function test; AST, Aspartate aminotransferase; ALT, Alanine aminotransferase; SD, standard deviation.

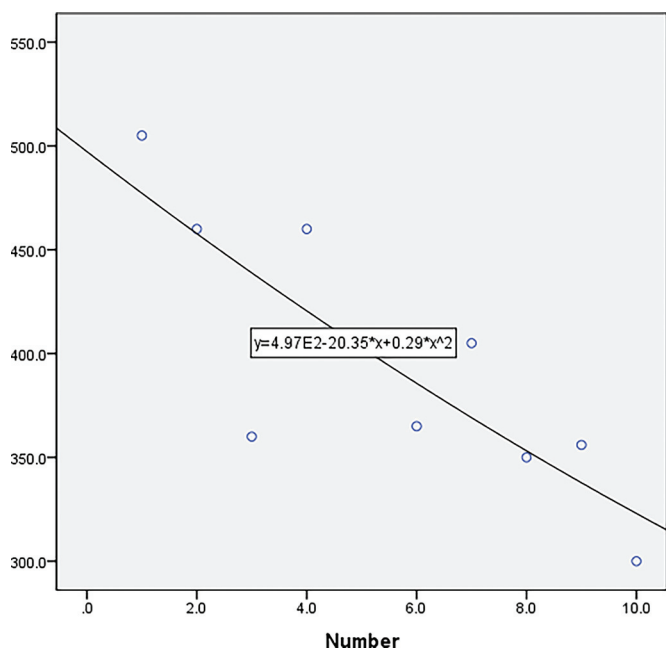


Figure 6. Correlation between operation sequence and operation time.

hepatectomy. However, because of inherent laparoscopic limitations, laparoscopic donor hepatectomy is somewhat difficult to perform. Nevertheless, the advancements in robot platform technology not only overcomes the laparoscopy’s drawbacks but also offer the advantage of Firefly, real-time ICG cholangiography that can be performed more accurately with bile duct division,^{1,11} better hand dexterity; and articulated instruments that enable precise suture and more meticulous dissection, even in difficult to reach locations.^{10,17,18} With these advantages, surgeons are less mentally and physically burdened and can perform more stable surgeries, thus, establishing this procedure as a standard for donor liver transplantation. Several recent studies have been published about robotic donor hepatectomy and have shown comparable outcomes to open and laparoscopic donor hepatectomy.^{1,11,17,19}

In our center, regarding the donor selection for robotic hepatectomy, although we had no previous experience with laparoscopic donor hepatectomies, we selected donors according to the initial selection criteria for laparoscopic donor hepatectomy for the donor’s safety and stable outcomes of the recipient.^{19,20} Among the donors suitable for right hepatectomy who met the conditions of normal anatomy, those with low BMI and estimated graft volume of the right liver < 700 g were selected.

The two biggest barriers to the uptake of robotic surgery may be the high cost and instrument limitations,²¹ of which how to transect the liver parenchyma is the main issue in the robotic donor hepatectomy. Moreover, a cavitron ultrasonic surgical aspirator (CUSA), mainly used in open and laparoscopic hepatectomy, cannot be used in the robot console. This may be why liver transplant surgeons hesitate to operate with robots. A CUSA was used by a bedside surgeon in the first case; however, it was very difficult to transect the liver by CUSA properly. This is because it is necessary to exchange opinions between two surgeons who are experts in liver resection in the console and operative field; a collision occurred between the CUSA and robot equipment. Therefore, the port for CUSA needed to be away from other robotic trocar ports to avoid injury or collision.

Moreover, to use CUSA, mutual understanding and cooperation are crucial. In addition, two expert liver surgeons are not always available in a small volume center like ours. For this reason, only the energy device, the robotic harmonic scalpel, was used to perform parenchymal transection to get good surgical outcomes. However, the transection axis must be very well-planned to use harmonics because harmonics have no endo-wrist function, and the open and close action of the harmonics jaw would be similar to that used in the clamping-crushing technique. In addition, the activation of the harmonic scalpel with the jaw opened is very similar to the vibration of CUSA. This finding is consistent with that reported by Chen et al.²² Also, from our experience, we observed that the harmonic scalpel might play an alternative role in situations where CUSA is not available.

In pure robotic donor hepatectomy, another important consideration is liver injury during liver manipulation, hilar plate transection (bile duct division) without cholangiogram, and increased WIT.

In MIDH, a liver injury occurs more easily than in an open procedure during liver manipulation,²³ which causes the elevation of liver enzymes and affects the graft’s function. Moreover, without tactile feedback from the robot, surgeons are often unaware of the pressure applied to the liver during mobilization. Hence, it is important to remain gentle to avoid subcapsular hematoma and liver lacerations. Therefore, in our center, the rubber band technique and stable and gentle traction by the third robotic arm was used to obtain a similar graft condition as the open donor hepatectomy.

Regarding the bile duct division, the magnified view by the robotic platform and the real-time ICG (Firefly) mode

facilitate precise bile duct anatomy. However, this step requires donor hepatectomy experience as the Firefly mode does not always provide a good view of the duct anatomy. Fortunately, none of our donors had any specific bile leak or biliary complication.

Regarding WIT, i.e. the time from ligation of the right hepatic artery to the retrieval of the liver graft, long WIT causes biliary and hepatocellular injury, affecting biliary complications and overall graft outcomes.^{24–27} The average WIT in our center was 19.7 min ± 5.6 min, which is comparable to WIT in other studies, although it can be classified into two according to the procedure. In the first five cases, the average WIT was 23 min ± 6 min which took a long time. Afterward, to reduce the WIT, we put the graft into a plastic bag before harvesting, and the average WIT decreased to 16.4 min ± 2.4 min. Moreover, changes in the harvesting method and an increased experience could have shortened the WIT, affecting the recipient's outcome. However, it is a short period to evaluate the outcome for the recipients.

From our study results, the average operation time was 396.6 min ± 62.7 min, and the hospital stay was 8.7 d ± 2.6 d. These results are comparable to another multicenter laparoscopic donor hepatectomy performed by Hong et al.¹⁵ with the average operative time: 340.1 min ± 106.3 min, hospital stay: 9.4 d ± 3.6 d; Soubrane et al.¹⁶ average operative time: 424.4 min, hospital stay: 10.6 d, and the robotic donor hepatectomy of recent papers (Chen et al.¹⁷ average operative time: 596 min, hospital stay: 7 d; Rho et al.¹⁹ average operative time: 493.6 min ± 91.5 min, hospital stay: 9 d ± 2.1 d). Moreover, as expected, there was a strong negative correlation between operation sequence and operation time in our study ($r^2 = 0.638$, $P < .01$).

The largest worldwide laparoscopic MIDH series estimates that about 60 pure laparoscopic donor hepatectomies are required over one year to standardize the procedure.²⁸ Also, a lower volume center in Korea recommends that a center performs at least 70 – 75 cases of major laparoscopic hepatectomy before introducing laparoscopy into living donor surgeries.²⁹ However, according to the studies mentioned above, our center cannot apply MIDH because we do not have enough cases to overcome the learning curve for MIDH.

However, after recognizing the advantage of the robotic platform in 2020 with a small number of cases of laparoscopic major hepatectomy, no experience of laparoscopic donor hepatectomy, and sufficient open donor hepatectomy experience, we have rapidly gained the ability to

perform robotic donor hepatectomy and our average operating time proves this. This might imply that the learning curve can be sufficiently reduced if the advantages of the robot platform are well utilized.

This study had some limitations because of its retrospective nature and the relatively low number of cases performed. Furthermore, it did not include the donors' long-term and recipients' outcomes as the follow-up period was too short to analyze long-term results in both groups. Nevertheless, this paper was written to share the initial robotic experience without any laparoscopic experience for a liver donor in an out-center. In future studies, with increased cases and sufficient data, we intend to evaluate donors' long-term and recipients' outcomes.

CONCLUSION

Despite the small cohort included in our study, our favorable outcomes have demonstrated that robotic surgery is a promising platform for minimally invasive living donor hepatectomy.

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