Morise. *Mini-invasive Surg* 2024;8:34
DOI: 10.20517/2574-1225.2024.67

Mini-invasive Surgery

Opinion

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Current status and future perspectives of minimally-invasive redo liver surgery - what can we add with technologies of simulation/navigation and robot?

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How to cite this article: Morise Z. Current status and future perspectives of minimally-invasive redo liver surgery - what can we add with technologies of simulation/navigation and robot? *Mini-invasive Surg* 2024;8:34. https://dx.doi.org/10.20517/2574-1225.2024.67

Received: 13 Aug 2024 **First Decision:** 12 Oct 2024 **Revised:** 22 Oct 2024 **Accepted:** 21 Nov 2024 **Published:** 10 Dec 2024

Academic Editors: Ho Seong Han, Giulio Belli **Copy Editor:** Pei-Yun Wang **Production Editor:** Pei-Yun Wang

Abstract

Minimally invasive liver resection (MILR) has been developed and disseminated widely. Almost all styles of liver resection can currently be performed in the way at many high-volume centers. Decreases in blood loss and morbidity and shorter hospital stays have been reported without deteriorating long-term outcomes. The "Caudal approach", our presented concept, is responsible for these benefits. Its minimal manipulation (damage) on the residual liver and surrounding structures can lead to less operative morbidity and postoperative deterioration of liver function. Also, total adhesiolysis of the whole area is not required in redo liver surgeries under the approach. Preoperative computed tomography simulation and intraoperative ultrasound/indocyanine green (ICG) navigation are working well in conquering the specific disadvantages of MILR, including intraoperative disorientation. In redo surgery, adhesions, scar-formation and deformity of the liver from previous operations could exacerbate this issue, highlighting the increased importance of simulation/navigation. Robot-assisted applications are now expanding rapidly. Their articulated forceps that eliminate tremors make them promising for precise operation. In redo surgery, dissection of major vessels among the scars and procedures in the limited area between adhesions may be facilitated by hands. However, a wider access route into the surgical space should be needed for current bulky robotic systems, and some of the advantages of conventional laparoscopic procedures may be difficult to apply. Current robotic systems are still less equipped and require substantial support from patient-side surgeons. However, advancements such as single-port robot systems and other technological developments could address these challenges in the future.

Keywords: Minimally invasive redo liver surgery, simulation, navigation, robotic surgery

INTRODUCTION

Advantages and disadvantages of minimally invasive liver resection

Minimally invasive liver resection (MILR), which was reported first in 1991 as laparoscopic liver resection (LLR) in anterolateral segments, has been developed and disseminated widely during the following decades[1,2]. Its specific disadvantages, such as the lack of 3D view, movement restriction, less tactile sensation, and difficulty in obtaining a good overview of the whole operative field, have been conquered with many attempts to date. Currently, most styles of liver resection without vessel reconstruction can be performed minimally invasively in many high-volume centers. There have also been discussions for the specific advantages of the procedure. Decreases in blood loss, complication rate, and days of hospital stay have been generally reported without deteriorating long-term outcomes[3-5]. The "Caudal approach to LLR" [Figure 1], our presented novel concept in 2013[6], was defined as a main conceptual change of LLR in the Second International Consensus Conference on LLR[2]. This specific approach of minimally-invasive procedure can offer benefits especially for hepatocellular carcinoma (HCC) patients with chronic liver diseases (CLD), who sometimes develop liver failure postoperatively and, in many cases, need repeated treatments for multifocal and metachronous HCCs[3,7-8]. Liver resection handles the liver, which is protected inside the subphrenic space of "rib cage". Since MILR can be performed with the direct intrusion of instruments into the space without the manipulation/destruction of structures, its minimal damage on the residual liver and surrounding structures (collateral vessels of CLD patients, *etc.*) can lead to lower morbidity/mortality and less postoperative liver functional deterioration. Also, total adhesiolysis of the whole area around the liver is not required in redo liver surgeries under the approach. When enough space for surgery is obtained, the laparoscope and forceps can re-enter the space and perform the procedure[9] [Figure 1].

Preoperative simulation, intraoperative navigation and limited anatomical resection

Preoperative simulation [such as one using the reconstruction 3D-images from preoperative computed tomography (CT) scan] and intraoperative navigation [such as those using traditional intraoperative ultrasonography and indocyanine green (ICG)-fluorescence guidance] had been working well in conquering the specific disadvantages of MILR, including lack of 3-D view, less tactile sensation, and difficulty in obtaining good overview of the whole operative field, which often lead to disorientations of the tumors and/or the major structures (such as Glissonian pedicles and hepatic veins) during surgery[10]. In redo surgery, adhesion, scar formation and deformity of the liver and surrounding structures from previous operations could accelerate this disorientation during surgery. It often causes intra/postoperative complications and insufficient tumor margin status of resection. The importance of preoperative simulation and intraoperative navigation increases especially in these situations.

The concept of anatomical resection of portal territory has been recommended as a surgical procedure handling the disseminated progression of HCC through the portal vein. Repurposing the concept to the resection of the tumor-bearing Glissonian territory (which is identified by preoperative imaging simulation and often of smaller territory such as segment or less) was advocated[11-13]. Using this approach, surgeons can remove small tumors inside the territory, even if they cannot acquire a definite fine localization of the tumor itself. The importance of preoperative image simulation and intraoperative navigation technologies is also increasing from this point of view. According to the simulation, liver parenchymal transection is performed using landmarks on the liver surface and/or vessels exposed on the transection plane in order to remove the tumor-bearing territory defined in preoperative simulation with intraoperative navigation. Also, in renal surgery, several papers highlighted the value of 3D models to improve surgical and functional outcomes[14]. For these parenchymal organs which we cannot see through their inside and need to preserve enough residual function after resection, the aid of 3D reconstruction simulation can make the implication of tailored surgeries of the parenchymal sparing combined resections of small territories (combined

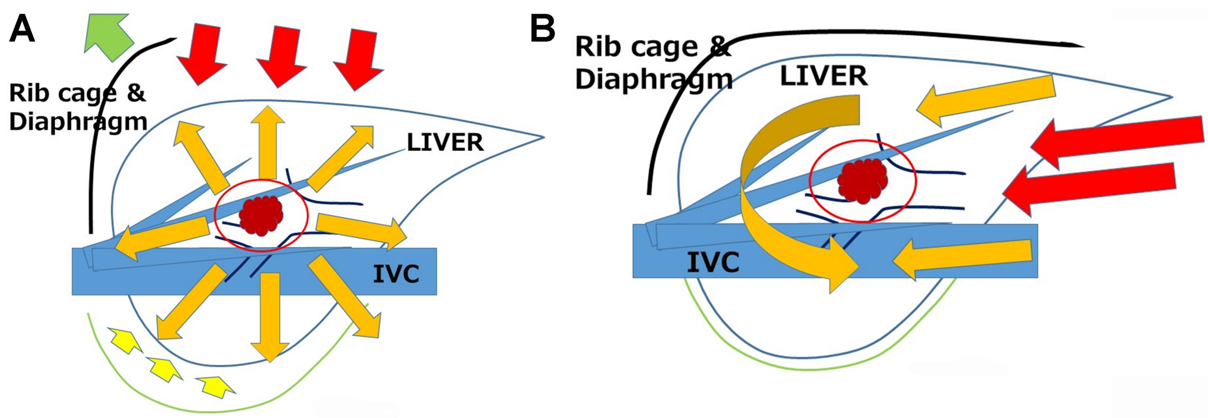

Figure 1. (A) Open approach and (B) laparoscopic "caudal approach" of redo liver surgery (Red arrows: Directions of view and manipulation in each approach). Liver resection handles the liver, which is protected inside subphrenic space of "rib cage". (A) Open procedure: The cage is opened with the big subcostal incision followed and the costal arch was lifted up (green arrow), and the liver after mobilization is picked up (yellow arrows); (B) Laparoscopic procedure: The instruments intrude into the cage from the caudal direction. Minimal damage to the surrounding structures can be achieved. Gold arrows indicate the areas of adhesiolysis. Source: Cancers 2023; 15: 421[9]. IVC: Inferior vena cava.

resection of portal "cone units" territories in liver, instead of hemi-hepatectomy or sectionectomy) possible. This is one of the most important benefits from this technology. This style of liver resection is facilitated by the navigation of ICG fluorescence for the target area [Figure 2]. Detecting small tumors by fluorescence imaging can also be used for tumors in shallow areas[15].

Robotic assistance for minimally invasive redo liver surgery

Although robot-assisted LLR has been reported in small case series since the early 2000s[16], its applications are now expanding rapidly[17]. Its articulated forceps with several degrees of freedom eliminating tremors make the surgical robot promising for precise operation. The advantages may allow surgeons to access complex procedures around major vessels, vascular/biliary reconstructions and lymph-node dissection more easily. In redo surgery, dissection of major vessels among the scars and procedures in the limited area between adhesions may be facilitated with articulated hands of surgical robots. A recent report comparing the short-term results of robotic and conventional laparoscopic procedures mentioned that robotic procedures are safe and feasible and that avoiding dissection of adhesions is beneficial in the approach[18].

Additionally, the current robot systems are bulky and need more access space than conventional laparoscopic surgery, such as increased distances between the target and the ports and between the ports themselves. Although we often use position changes during conventional laparoscopic procedures by the operative table rotation in order to move and handle the liver and tumors with gravity[19], this is often difficult to apply during robot-assisted surgery. Accessing small target spaces with minimal adhesiolysis and performing the surgery is one of the benefits in laparoscopic redo surgery[9], and robotic articulated hands can facilitate the manipulation within these spaces. However, a wider access route is required for robotic arms to enter the surgical space [Figure 3]. Certain advantages of conventional laparoscopic procedures may be difficult to apply presently in current robot-assisted techniques. Current robotic systems are still less equipped due to a shortage of bendable devices on the robotic arms, and substantial support is required from patient-side surgeons and engineers. However, with the development of technologies such as single port robot systems, which require minimal access space, there is potential to solve some of these challenges.

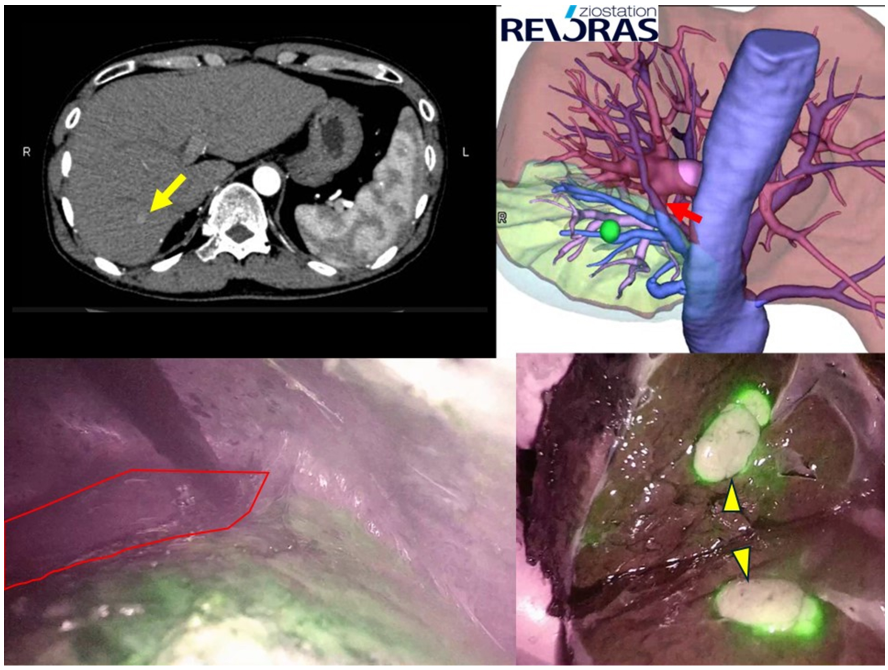

Figure 2. A tiny HCC resection planned by preoperative simulation and intraoperative navigation. Left upper: A tiny HCC in the subsegment of 8dorsal (yellow arrow) was revealed in arterial phase of contrast computed tomography. Right upper: The area of 8dorsal subsegment (pale blue area, red arrow shows the root of the portal vein) was planned to be resected in preoperative simulation. Left lower: After the transection of 8dorsal subsegment Glissonian pedicle, the planned area of resection (surrounded by red line) was revealed as ischemic area (no-fluorescent area with ICG injection). Right lower: The tumor was resected inside the planned area of resection. HCC: Hepatocellular carcinoma.

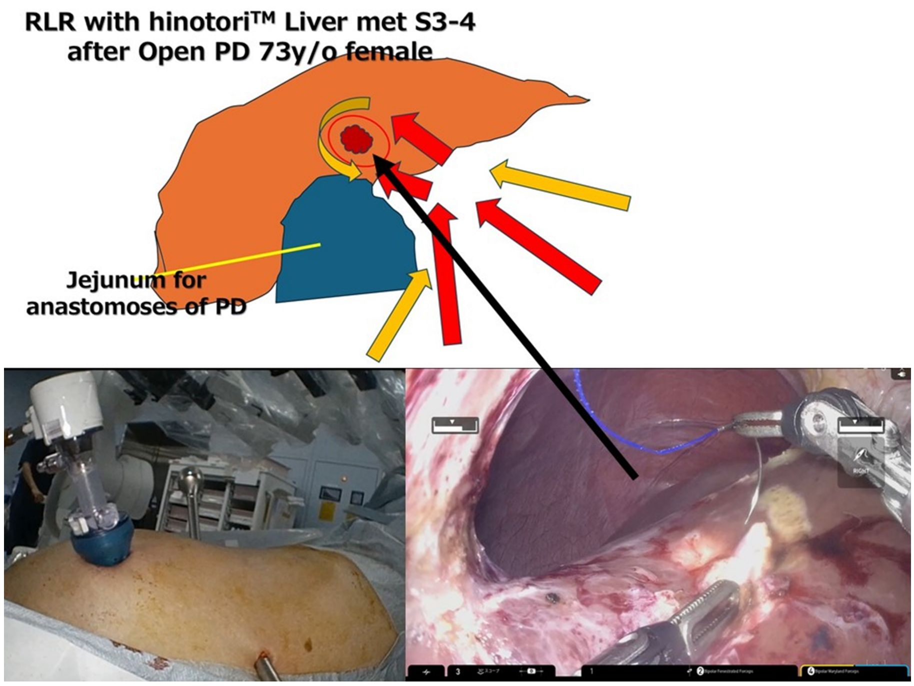

Figure 3. Robot-assisted laparoscopic partial liver resection after ope pancreatoduodenectomy. Upper (Schema of planned surgery): It was planned to be performed by the approach of going around and avoiding the area of jejunum for reconstruction and adhesion using the bendable robot hands. Lower left: Image from the roll-in of the robot arms. Lower right: Findings of target surgical area.

CONCLUSION

Realization of an ideal redo solo-liver surgery with the technologies of simulation/navigation and robot-system assistance could be expected in the near future.

DECLARATIONS

Authors' contributions

The author contributed solely to the article.

Availability of data and materials

Not applicable.

Financial support and sponsorship

None.

Conflicts of interest

Morise Z is an editorial board member of the journal *Mini-invasive Surgery*. Morise Z was not involved in any steps of edtorial processing, notably including reviewers' selection, manuscript handling and decision making.

Ethical approval and consent to participate

Informed consent was obtained from the patient for the usage of these imaging data.

Consent for publication

Not applicable.

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