Editorial Commentary

Robotic liver surgery: should improving the safety and expanding the indication over laparoscopic liver surgery

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Minimal invasive surgery represents the forefront of surgical techniques and is increasingly being adopted in liver surgery. Since its introduction by Giulianotti *et al.* in 2003 (1), robotic liver surgery (RLS) experienced rapid growth. Initially, the robotic system was limited to simpler procedures, but as the technology advanced and surgical experience accumulated, it has expanded to accommodate more complex operations, such as caudate lobe resection and other challenging procedures (2,3). Today, RLS is indicated for a wide range of both benign and malignant liver diseases. Despite the clear technical advantages offered by robotic systems, the clear benefits of RLS over traditional laparoscopic liver surgery (LLS) have rarely been demonstrated.

Herein, Sijberden and colleagues (4) conducted an international multicenter retrospective cohort study to compare the perioperative outcomes of RLS and LLS. The study enrolled a substantial number of patients, with 1,507 undergoing RLS and 8,568 undergoing LLS, across various clinical settings. This large sample size allowed the researchers to assess and highlight potential advantages of RLS on a broader scale, providing valuable insights into its performance compared to traditional laparoscopic approaches.

In the overall cohort, the authors found that RLS was associated with more favorable intraoperative outcomes compared to LLS. Specifically, RLS presented with shorter operative times (P=0.015), less Pringle usage (P<0.001), shorter Pringle duration (P<0.001), less blood loss (P<0.001), fewer transfusions (P=0.003), fewer grade 2 intraoperative incidents (P=0.003), and fewer conversions (P<0.001). The reduction in blood loss with RLS may be attributed to the magnified three-dimensional vision provided by robotic platform, which allows for more precise identification of vessel structures. Furthermore, the articulating instruments used in robotic surgery offer greater stability and enhanced degrees of freedom, which facilitate more precise vessel handling. The flexibility and accuracy of these instruments also contribute to quicker hemostasis. These advantages also contribute to a reduction in intraoperative incidents. In recent years, Pringle maneuver is often applied to reduce blood loss during parenchymal transection. The reduced blood loss observed in RLS helps explain the explains the decrease in the demand for Pringle maneuver during liver resection. In addition, precise vascular recognition and management, coupled with the stability of the robotic system, enhance intraoperative performance and contribute to shorter operation times. As a result of these benefits, patients in the RLS group experienced lower rates of overall morbidity (P<0.001), R1 resections (P=0.015), and a higher rate of achieving "textbook outcome" in liver surgery (P<0.001). Although previous studies have also highlighted the advantages of RLS in terms of short-term outcomes, most of these studies have been limited to specific disease types, such as hepatocellular carcinoma (HCC) or hepatolithiasis (5,6). This study, however, incorporated a diverse range of liver diseases and performed a comparative analysis of LLS and RLS across a broader spectrum of cases to explore the potential advantages of RLS.

Meanwhile, an interesting subgroup analysis was carried out in this study. In the subgroup of patients who underwent a minor resection in the anterolateral segments (segments 2, 3, 4b, 5, and 6), RLS offered several benefits over LLS. These included reduced Pringle usage (P<0.001), shorter Pringle duration when applied (P=0.023), less blood loss (P<0.001), fewer transfusions (P=0.010), and lower conversions (P<0.001).

These results are similar with previous data (7). However, while RLS offers notable advantages in terms of enhanced visualization, precision, and dexterity, these benefits need to be balanced against the financial implications, especially when performing procedures in the anterolateral segments, where traditional laparoscopic techniques may already be highly effective and cost-efficient.

RLR in posterosuperior segments (segments 1, 4a, 7 and 8) is considered a technically demanding procedure according to the IWATE criteria and the Institut Mutualiste Montsouris (IMM) classification system (8,9). These segments are located in the right subphrenic space, surrounded by the ribs and diaphragm, resulting in increased surgical complexity. In the subgroup of patients who underwent minor resections in the posterosuperior segments, RLS was associated with a shorter Pringle duration (P=0.011), less blood loss (P<0.001), and a lower conversion rate (P<0.001). A previous meta-analysis conducted by Bin *et al.* (10), which included six comparative studies on laparoscopic and robotic approaches for posterosuperior segment liver resection, identified several advantages of RLS. Similar perioperative outcomes were observed in this meta-analysis: patients underwent RLS presented with shorter operative time (P<0.00001), reduced blood loss (P<0.0001), and lower blood transfusion requirement (P=0.001). The benefits of RLS in the posterosuperior segments can be attributed to several key features of the robotic platform, which enhance both the precision and accessibility of the procedure. Firstly, unlike conventional LLS, which typically offers a two-dimensional view, the robotic platform provides a three-dimensional view of the surgical field. This three-dimensional visualization allows for better depth perception and a more comprehensive view of the liver and surrounding structures, improving the ability to identify critical blood vessels, bile ducts, and other important anatomical features. This enhanced visualization reduces the difficulty of identifying and protecting vital structures during surgery. Secondly, the wristed instruments used in RLS offer superior dexterity compared to LLS. This allows for nonlinear manipulation, making it easier to access the challenging posterosuperior segments (11). Thirdly, one of the inherent limitations of LLS is the potential for tremors in the surgeon's hand, which can negatively impact precision. The robotic system filters out these tremors, ensuring smooth, stable movements. This contributes to more accurate dissection, particularly when separating delicate structures.

Of the patients who underwent a major resection, RLS was associated with less Pringle usage (P<0.001), reduced blood loss (P<0.001), and lower conversion rates (P=0.027), and lower overall morbidity rate (P<0.001). This finding was similar with a previous international multicenter study (12). In addition, a previous single center analysis suggested that the RLS was associated with improved outcomes including reduced postoperative intensive care unit (ICU) admission and 90-day readmission (13). Major liver resection demands a broader surgical range and a longer operation time, which typically implies that surgeons will consume more energy and physical strength. This "surgical fatigue syndrome" could be avoided by the optimal working ergonomics of robotic major hepatectomy (14). Coupled with above advantages including improved optic visualization, operative dexterity, and ease of dissection, RLS showed more favorable outcomes over LLS in major hepatectomy.

The advent of new technologies is aimed at enhancing the perioperative outcomes and addressing the intractable problems of current technologies. In recent years, improved perioperative outcomes of RLS over LLS have been verified by a lot of studies. And Sijberden *et al.*'s research enrolled patients with different settings to provide a support of evidence-based medicine. Moreover, robot-assisted techniques are developed to overcome the challenges inherent in laparoscopic procedures. For liver resections in challenging locations or those requiring extended operation times, robotic-assisted systems may offer distinct advantages (15).

To sum up, RLS has enhanced the safety of liver surgeries. However, future studies should pay more attention to explore its efficacy in highly difficult operations, such as anatomical resection of posterior superior segment, major liver resection, donor hepatectomy, and liver resection in patients with cirrhosis or portal hypertension.

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