Minimally invasive liver surgery: a field is maturing

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Minimally invasive liver surgery is undergoing exponential growth (1). Since its first application (2), laparoscopic surgery has been increasingly used to address benign and malignant liver lesions ranging from minor resections to major hepatectomies. First randomized controlled trials clearly demonstrate medical and economic advantages over conventional open surgical techniques, in selected groups of patients (3).

By providing enhanced vision, superior intraoperative manoeuvrability and improved surgeon comfort in enduring operative procedures, robotic surgical platforms have been introduced to overcome the intrinsic limitations of laparoscopic instruments and visualization. In this spirit, robotic assisted surgery has the potential to further propel evolution of minimally invasive liver surgery (4).

In their work: "Robotic-assisted versus laparoscopic major liver resection: analysis of outcomes from a single center", Fruscione *et al*. exclusively demonstrate that the robotic assisted approach for major hepatectomy for resection of malignant and benign liver lesions is an effective alternative to the laparoscopic resection (5). From 2011 to 2016 the team of the Division of HPB Surgery at Carolinas Medical Center, (Charlotte, NC, USA) performed a grand number of n=473 major hepatectomies out of which n=173 (37%) were completed by minimally invasive techniques (n=57 robot assisted and n=116 laparoscopic). Comparing patients who received laparoscopic and robotic assisted surgery for benign and malign liver lesions, authors conclude that patients treated with the robotic platform displayed ameliorated outcomes such as reduced postoperative ICU admission and decreased 90-day readmission.

In their study major hepatectomy (MH) was "classically" defined as the resection of three or more liver segments which are connected to each other (6). As the name implies, MHs are generally associated with a higher level of intraoperative surgical difficulty when compared to minor resections. After the first international consensus conference on laparoscopic liver surgery which generated the "Louisville Statement" (7), the definition of laparoscopic major hepatectomy, (until then generally no differences in the definition of the extent of liver resection were made between open and minimally invasive hepatectomies) was expanded to include even individual resections of posterosuperior segments 7, 8 and 4a. From a laparoscopic perspective these segments were technically difficult to visualize and resect with the conventional laparoscopic armamentarium. As a consequence, posterosuperior liver resections were hence commonly classified as "technically major" by some European groups (8).

In parallel a difficulty scoring system (DSS) reflecting on the extent of liver resection, liver function, tumor-size, -location and -proximity to major vessels was developed, to furthermore assess the difficulty of various laparoscopic liver resection procedures, based on preoperative patient characteristics (8). In search for a difficulty score valid for both, laparoscopic and robotic assisted liver surgeries, several attempts have been made to give justice to both techniques. The difficulty scoring system (DSS) propagated for laparoscopic liver resections in the second international consensus conference (9) has recently been shown to significantly correlate with surgical outcomes in patients who underwent laparoscopic and robotic hepatectomy for cases of low and intermediate difficulty. As expected, the robotic approach furthermore allowed for significant more minimally invasive approaches in liver resection cases with a higher difficulty level (10). It is important to highlight, that due to a wide heterogeneity in the definition of major and minor hepatectomies and lack of standardized difficulty scoring systems, comparison of several retrospective studies on minimally invasive major liver resections must be carried out carefully.

Anatomic liver resection by nature is based on the description of functional segments, which rely on the organs arterial and portal venous blood supply. Fruscione *et al*. report that for both laparoscopic and robot assisted liver resections surgeons aimed for vascular inflow control, prior to parenchymal transection (5). This frequently applied technique has been shown to decrease bleeding during transection and depending on the quality of the parenchyma, provides the surgeon with a demarcation line between ischemic and normally perfused liver segments. In hemi-hepatectomy, the anatomic line indicating the margin between the left and right hemi-liver is called Cantlie's line (11). As described previously, the combination of the conventional demarcation technique following inflow control together with intraoperative ultrasound examinations represents the gold standard of intraoperative visualization in minimally invasive liver surgery.

Complex liver surgery not only requires delicate surgical skills but also a thorough intraoperative understanding of anatomy. Novel imaging techniques in conjunction with minimally invasive surgical techniques have the potential to transform the way liver surgery is performed today. In this context, Indocyanine green Fluorescence Imaging has recently found broader application in the sector of laparoscopic and robotic assisted liver surgery. Indocyanine green (ICG) is a fluorescent dye developed for near infrared photography by Kodak in 1954 (12). Administered intravenously ICG undergoes neither intrahepatic conjugation nor enterohepatic circulation and is removed from the bloodstream exclusively by the liver. In this context, ICG clearance has initially been used preoperatively for the estimation of the functional reserve of the human liver undergoing future resection, in patients with known liver or biliary tract disease (13).

Used peri- and intra-operatively and applying near infrared (NIR) light for fluorescent visualization, ICG has been shown to either "directly stain" hepatocytes around malignant intrahepatic lesions or be able to "indirectly counterstain" liver segments which are addressed by vascular inflow control (14). Since 2-D laparoscopy lacks depth perception, and conventional inflow demarcation techniques, at best only provide superficial visualization of ischemic liver segments, ICG fluorescence imaging can also be used for precise intraparenchymal navigation, since ICG staining or counterstaining provides the surgeon with a resection plane based on tumor entity or vascular anatomy, depending on the staining technique used (15). Since the introduction of Firefly® to the robotic surgical world, intraoperative ICG visualization is not only limited to specially equipped laparoscopy units, but also available in latest generation medical robots (daVinci.org).

The surgical robot is a machine devised to overcome many of the limitations of conventional laparoscopy. This is especially true for urologic and gynecologic operations, which account for more than 90% of all robotic operations worldwide (16). However, when it comes to parenchymal liver transection, which to a great extent is performed with ultrasonic devices (e.g., laparoscopic cavitron ultrasonic surgical aspirator, or laparoscopic ultrasonic sheers), minimally invasive instruments by technical nature, are straight and have currently no capacity to flex intracorporeally, which impede delicate intraparenchymal CUSA preparation in regions which are difficult to access and make minimally invasive parenchymal transection only feasible when adhering to conventional rules of laparoscopic triangulation. Furthermore, explicit robotic assisted CUSA devices are currently not available for clinical use. Regardless, when laparoscopic devices are even so used for robotic assisted surgery, they cannot be instrumented by the console surgeon but rather have to be handled by the scrub-assistant. This is why current robotic console surgeons may rather favour stapler parenchymal transection for deeper layers of the parenchyma. However, Fruscione *et al*. state that robotic assisted liver resections even so required less staple reload cartridges than laparoscopic right hepatectomies (5).

In contrast to Fruscione *et al*. who reported no significant differences in blood loss and operative time, a recent meta-analysis by Montalti *et al*. revealed that laparoscopy was superior to robotic assisted liver surgery with regard to these two parameters. However, more importantly, there were no significant differences in conversion rate, R1 resection rate, morbidity and length of postoperative stay between laparoscopic and robotic assisted surgical procedures in both studies (5,17).

It is anticipated that robotic assisted liver resections, due to the ability of advanced intracorporal sewing, could be of significant advantage in cases with vascular and extrahepatic bile-duct resections, where complex reconstructions are necessary. However, to date only small numbers of these type of surgical cases are reported in the literature (18). This once more highlights the fact, that a case selection bias is eminent in most studies on minimally invasive liver surgery. Furthermore, randomized controlled trials shedding light on laparoscopic and robotic assisted major liver surgeries are strongly required for the establishment of well-grounded evidence in this emerging field of surgery. For now it is more than fair to say that minimally invasive liver surgery is an exponentially growing field of surgery, which demonstrated feasibility and safety in selected groups of patients while significantly improving patient morbidity and patient's life quality.

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