Chapter

Robotic Liver Surgery

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Abstract

Minimally invasive surgery has experienced a significant expansion in the last decades. Robotic surgery has evolved in parallel to traditional laparoscopic surgery offering additional technical advantages. Some specific aspect of Hepatobiliary Surgery led to a limited implementation of minimally invasive liver surgery in the early years of laparoscopic surgery whilst we are experiencing an exponential increase in the use of minimally invasive approaches to this type of intervention. In this chapter we describe the key aspect of robotic liver surgery with a meticulous description of the supporting evidence, its limitation and future perspectives.

Keywords: robotic surgery, robotic liver resection, hepatectomy, minimally invasive surgery, laparoscopic liver surgery

1. Introduction

Hepatic resection is the gold standard treatment for some of the most common malignant tumours of the liver, including primary tumours (hepatocellular carcinoma and cholangiocarcinoma) and colorectal liver metastasis and it can be sometimes the treatment option for some benign tumours [1]. Hepatobiliary surgery also includes complex biliary interventions for benign and malignant pathologies that, in addition to the liver resection, may require biliary reconstructions and bilioenteric anastomosis [2].

Open surgery remains the predominant approach for most of these hepatobiliary procedures. However, there is an exponential increase of minimally invasive surgery (MIS) within this field, supported by large cases series and randomised control trials (RCTs) recently published in the literature [3].

Outcomes from the available literature suggests that MIS for liver resections improves patients' outcomes in terms of length of stay, blood loss and postoperative complications. Although some series suggest longer operative time and higher initial costs, the overall cost-efficiency seems to favour laparoscopic surgery [4, 5]. Despite this data, laparoscopic liver surgery is not routinely performed in all Hepatobiliary Centres and there is a large proportion of patients being treated via open approach. The delayed implementation of this type of intervention is commonly related to the technical challenges of these operations, the long tradition of open surgery associated to liver transplantation and the specific technological requirements attached to this type of resections.

From the original era of the pioneers in laparoscopic surgery, the consensus meetings in Louisville and Morikawa highlighted the challenges of this new approach. Recommendations from these meetings were very cautious about suggesting laparoscopic liver surgery for every patient and limited its clear indication to minor resections. From them, MIS for minor liver resections (less than 3 segments) such as left lateral secitonectomy and segmentectomies from the anterior Couinaud segments (II to VI) became well established [6]. On the contrary, there has been limited diffusion of minimally invasive major hepatectomies and it is commonly confined to high volume specialised centres [7]. This is in part due to the more complex anatomical and technical challenges of major hepatic resections, and the inherent limitations of laparoscopic surgery.

Traditional laparoscopic surgery is the most commonly used MIS technique for liver resections whilst there is also an increment in the number of series of robotic liver surgery [8]. Advantages of robotic surgery when compared to traditional laparoscopic surgery are well described and include: a magnified three dimensional (3D) view, tremor filtration and improved dexterity with articulated instruments providing seven degrees of freedom [9]. It also adds some surgeon's specific advantages in terms of ergonomics with the suggested, but not proven, potential reduction of fatigue, increase precision and longer work expectancy. However controversies around robotic surgery remain when compared with laparoscopic surgery. Main limitation was always the higher cost without any evidence suggesting clinical superiority when compared to laparoscopic surgery. There is, in fact to date, lack of agreement whether they should be compared against each other, or directly compared to open surgery. We are of the opinion that both should be grouped as MIS and promoted equally for the benefit of the patient.

In this chapter we describe the key aspects of robotic hepatobiliary surgery, with a focus on technical descriptions, the current evidence base, limitations, and possible future developments.

2. Technique

Robotic liver surgery has probably evolved from laparoscopic liver surgery and therefore it is easy to find some similarities. It is however a very different intervention, specially around the economy of movements, and it will vary significantly between centres and surgeons. Local expertise, surgeon's preferences and patient's specific conditions may modify the standard approach but there are some common principles. It is important to mention that currently all reported series have performed this type of intervention with the platform Da Vinci Robot from INTUITIVE® and some of the described technical aspect may apply only to this robotic system. New development of alternative robotic system may bring different technical concepts but the principles will prevail.

2.1 Set up and docking

There is significant overlap in the patient positioning, set up and operative technique between laparoscopic and robotic liver resections. This is commonly decided by the operating surgeon and based on his/her preferences. The main difference for a robotic approach is around port placement and the position of the "bed-side"/ assisting surgeon. It is essential to consider instrument clashing when deciding port placement. Alternatives to patient's position include supine (with or without split legs) or left prone position. The latter is the preferred position in some centres to intervene in right posterior segments. Ports position in laparoscopic surgery is more versatile whilst robotic surgery demands wider space between trocars without any port caudal or cephalic to another one (commonly smooth curved line or zig-zag) (**Figures 1**–**3**).

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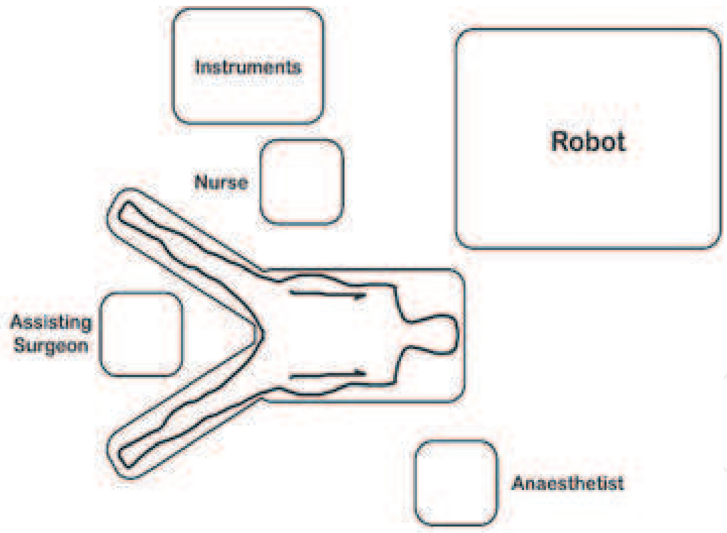

Figure 1.
*Patient (supine with split legs in a 15-0 degree reverse Trendelenburg) & assistant (between legs) positioning commonly utilised for major robotic hepatectomy. Subsequent camera and port placement depends on type of resection (**Figures** 2 and 3).*

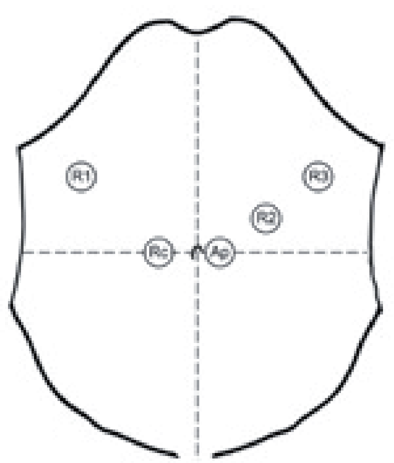

Figure 2.
Port placement for robotic major hepatectomy.

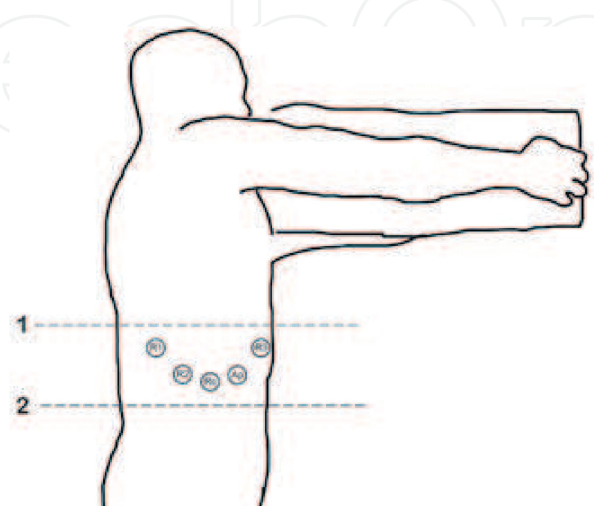

Figure 3.
Patient positioning (left lateral decubitus) & port placement for robotic partial hepatectomy of postero-superior segments. Rc, Robotic Camera Port; Ap, Assistant port (12mm); R1-3, Robotic ports (8-10 mm); 1, transpyloric plane; 2, intertubercular plane.

Following patient positioning and port insertion, the robotic cart is positioned within the surgical field and the arms docked. Traditional bed-side units are placed cephalic to the surgical field for most hepatobiliary and upper gastro-intestinal procedures. Newer versions allow the cart to be docked sideways to the patient. This adds the benefit of better access to the patient's airway for the anaesthetic team. Irrespective of the system, close collaboration with the anaesthetist is essential at the time of docking.

2.2 Liver mobilisation

Following successful docking, the procedural steps are the same as for any hepatic resection and depend on the nature of the required procedure. Liver mobilisation is typically the first step and can be performed utilising a combination of a diathermy or an alternative energy device. For full mobilisation, all liver ligaments (Round/Falciform, Coronary and Triangular) need to be transected. Limited resections however, would not require full mobilisation. Traction and counter traction through lifting of the required liver lobes is provided with the combination of retractors and changes in the patient's position. This requires special attention if the operating table's movement are not linked to the robotic cart. New docking might be required. Lack of tactic feedback can lead to underestimation of the pressure applied to the liver with the consequent capsular tear. Alternatives will include a laparoscopic liver retractor manipulated by the bed side surgeon. Similarly, intraoperative ultrasound can be performed at this point with the close collaboration of the console and bed side surgeons.

2.3 Hilar dissection and hepatoduodenal clamping

Robotic surgery can overcome the limitations of laparoscopic surgery during complex hilar dissections, with the combination of 360 degrees angulation, 3D view and scaled movements providing significant advantages to the operator. The exact technicality of hilar dissection will again depend on the surgeon's experience and preferences. Some centres will routinely establish a window in the lesser omentum and pass a sloop or tape to facilitate a Pringle manoeuvre. Similarly to traditional LLS, this can be performed purely intracorporeally or extracorporeally (exteriorization of the clamp/tourniquet via an accessory port). However the high volume specialist centres have suggested this is not routinely required during robotic hepatectomy [10–12].

2.4 Parenchymal transection

There are multiple techniques for parenchymal transection and they are widely modified to the personal preferences of the operating surgeon. Kellyclasia technique (clamp-crushing) is held as the current gold standard, although recent advances have focused on the introduction of open and laparoscopic energy devices aimed at reducing blood loss during parenchymal division [13]. This crucial part of the operation is viewed as one of the limiting factors in the diffusion of MIS for the liver across hepatobiliary centres. Whilst robotic surgery improves the suturing capacity and bleeding control in difficult circumstances, the lack of an equivalent robotic energy device may require a hybrid approach with the assisting surgeon performing laparoscopic parenchymal transection at the operating table using an appropriate energy device [14]. Based on this principle, traditional laparoscopic instruments and stapling devices can be used similarly to the traditional laparoscopic approach (i.e. stapling hepatic veins or hilar structures).

2.5 Specimen extraction

There is no difference between robotic and laparoscopic surgery at this point, with removal of the specimen via a retrieval bag is achieved following undocking of the robotic arms. Options for specimen extraction include extension of an existing port site or a new incision. There is little evidence comparing all available options but there seems to be a preference towards the Pfannestiel incision [15].

3. Current evidence

3.1 Major resections

Major hepatectomies (resection of 3 or more contiguous segments) and extended hepatectomies with bile duct resections are complex, challenging procedures. High volume specialist centres have shown a minimally invasive approach to be feasible but the results from the only prospective randomised trial (ORANGE-II plus) are yet to be published [8, 10, 16]. At present, less than 10% of major liver resections are performed laparoscopically, largely due to the challenges posed by the location of the liver, its proximity to major vasculature and the difficulty in appreciating the complex biliary and hepatic vascular anatomy during a laparoscopic procedure [17]. Utilising a robotic approach may negate these disadvantages, with improved views and dexterity facilitating a precise hilar and hepatocaval dissection, advanced suturing and easier biliary-enteric anastomosis.

Specialised centres have published favourable outcomes (**Table 1**) and a limited number of multi centre comparative studies have demonstrated positive results [18–21]. A recent review of outcomes from 584 major robotic liver resections demonstrated acceptable blood loss, operation time, R0 resection rate, length of hospital stay and post op morbidity. When directly compared to laparoscopy, robotic major hepatectomies demonstrated significantly improved rates of post-operative

Author	Year	Total Cases	Specific procedures	Conversion Rate	Length of stay	Morbidity Rate	Mortality Rate
Giulianotti et al.	2011	27	RH (74%), LH (19%), RTS (7%)	3.7%	7 days	30%	0%
Choi et al.	2012	20	RH (30%), LH (70%)	10%	15 days	40%	0%
Spampinato et al.	2014	25	RH (64%), LH (28%), ERH (4%), LLS + SgVI (4%)	4%	8 days	16%	0%
Fruscione et al.	2019	57	RH (35%), LH (35%), other (30%)	NA – excluded from analysis	4 days	28%	0%
Wang et al.	2019	92	RH (48%), LH (52%)	1%	7 days	13%	0%

RH, right hemi-hepatectomy; LH, left hemi-hepatectomy; RTS, right tri-sectionectomy; ERH, extended right hemi-hepatectomy; LLS, left lateral secitonectomy; SgVII, segment 6. Morbidity rate, includes post op complications from Clavien Dindo grades I-V. Mortality rate, 30 day post-operative mortality.

Table 1.
Published series focused on outcomes following robotic major hepatectomies in the literature.

critical care admission, 90 day re-admission rate and a similar length of stay and complication rate [22].

The robotic approach has also been shown to be feasible for simultaneous resection of a colorectal primary malignancy and the associated liver metastasis. Analysis of a small number of major hepatic resection with synchronous colorectal resection, demonstrated robotic resection to have acceptable morbidity and oncological outcomes [23].

The robotic approach has also been considered as an alternative to open surgery for hepatectomies requiring more extended resections and or biliary reconstructions. Outcomes published by 2 specialist centres demonstrated the robotic approach as a safe and feasible alternative to open surgery for hilar cholangiocarcinoma. However whilst technically feasible and safe, the results did not demonstrate equivalence to open surgery. Indeed they reported longer operative times and a higher estimated blood loss relative to open surgery. Furthermore, robotic resection was associated with poorer oncological outcomes with a lower recurrence free survival rate [24, 25].

Given the relative infancy of robotic innovation within the field of minimally invasive surgery, it is perhaps unsurprising that the literature around major robotic liver surgery is somewhat limited. The utility of a laparoscopic approach to major hepatectomy is only presently under investigation and any advantages relative to open surgery remains unestablished. Within this context, it is unclear if open or laparoscopic surgery should be the standard against which robotic surgery is held. At present, level II and III evidence suggests that robotic surgery is safe, feasible, and certainly non inferior to laparoscopic or open surgery. However it remains uncertain if this will translate to clinically significant short and long term outcomes in larger, prospective studies.

3.2 Minor resections

Minor hepatic resections, a category encompassing non-anatomical wedge resections, left lateral sectionectomies, segmentectomies and bisegmentectomies, are the most commonly performed minimally invasive hepatic operative interventions in both the laparoscopic and robotic settings [10, 17].

While the evidence discussed above suggests the multitude of technical advantages as well as non-inferiority of the robotic approach to major hepatic resections, it is pertinent to critically examine the role of robotic surgery in minor resections if aiming to confer improved operative outcomes to the greatest number of patients.

In keeping with the increasing trend for parenchymal sparing liver resection, non-anatomical and anatomical wedge resections are the mostly commonly performed robotic liver minor resection [10]. Indeed, a minimal access approach to resect only small amounts of hepatic tissue seems logical considering the morbidity associated with large abdominal incision; a position supported by international consensus in 2008 [26]. Particular difficulties exist, however, when performing laparoscopic in the postero-superior segments of the liver where a combination of the costal margin and rigidity of laparoscopic instruments conspire to make operative access difficult [12].

A number of robotic minor resection cases series from enthusiast centres report broadly equivalent operative times, operative blood loss and post-operative morbidity without significant differences to laparoscopic approaches, although the technical benefit of the robotic endo-articulated wrists were repeatedly emphasised as a partial solution to the difficulties involved with postero-superior segment resections [10, 20, 27, 28]. Furthermore, the use of robotic tremor filtration and gain reduction adjustments were reported to facilitate a greater degree of parenchymal sparing surgery and finer hilar or hepato-caval dissection, technical feats which can be challenging in the laparoscopic setting, potentially reducing requirement for conversion to open [27, 29]. These studies are retrospective, and while some include propensity score matching, prospective randomised controlled trial data is lacking. Results from the Dutch ORANGE-SEGMENTS trial investigating the role of open vs. laparoscopic postero-superior liver segmental resection and results are awaited, but to date no such trials are ongoing in regard to robotic non-anatomical and anatomical wedge resections.

Left lateral sectionectomy consists of the resection of hepatic segments II and III. The minimally invasive approach has become standard of care for this minor resection with comparative ease of access to the left lateral section, a relatively distant relationship to major vasculature and often minimal difficult mobilisation requirement leading this hepatic resection to be considered one of the more straight forward minor hepatectomies [7].

A small number of retrospective studies have aimed to compare the laparoscopic to open approach in left lateral sectionectomy [30–32]. These studies compared a small number of robotic left lateral sectionectomies with retrospective laparoscopic approaches, finding broadly similar results, with no significant differences in operative blood loss, clinical outcomes or operative time, although increased operative costs. A further study, which examined a subgroup of more complex left lateral sectionectomy, with BMI >30, larger tumours or closure operative proximity to major vasculature, reported a significant reduction in operative blood loss, although no significant difference in the overall study group [33]. These results led authors to conclude that the laparoscopic approach to left lateral sectionectomy should remain the standard of care, although it is notable that while gold standard, the only randomised controlled trial comparing laparoscopic vs. open left lateral sectionectomy, ORANGE-II, failed to show a significant difference in outcome when compared the laparoscopic to open approach to left lateral sectionectomy [34]. This result was, in part, due to premature trial cessation due to slow trial recruitment, perhaps reflecting the board uptake of minimal access approach to left lateral sectionectomy. It remains possible that with evidence of clinical non-inferiority of robotics, enthusiastic uptake may further popularise the robotic approach in a similar fashion.

4. Oncological outcomes

Given that liver resections are predominantly carried out for malignant pathology, oncological standards such as resection margins, lymph node yields, recurrence and disease free survival are the critical outcomes against which robotic hepatectomy should be evaluated. To that end, we have recently published a review of the literature and found robotic liver surgery to be equivalent with regards to the completeness of the resection margin (96% R0) [35]. Although there are a limited number of studies reporting longer term oncological outcomes such as recurrence and disease free survival, the results so far have been promising.

4.1 Hepatocellular carcinoma (HCC)

HCC is the predominant malignancy for which a robotic approach has been utilised, with 40% of the cases published in the literature indicating this as the underlying indication [22]. Three studies have examined the longer term oncological outcomes following robotic hepatectomy in this cohort and found the oncological outcomes to be comparable. Two of these studies compared robotic surgery to open resection and reported a similar 3 year disease free rate at 64% (Lim et al) and

72% (Chen et al). The overall 3 year survival rate was approximately 98% and 93% [36, 37]. The remaining study compared the oncological outcomes between robotic and laparoscopic resections and reported the 5 year disease free and overall survival rate at 42% and 65% respectively [5].

4.2 Colorectal liver metastases (CRLM)

Seven studies have examined the oncological outcomes from robotic hepatectomy for colorectal liver metastases. A 100% R0 resection rate was reported by 5 of the 7, whilst the remaining 2 studies reported a rate of 92% and 73.7% [23, 38–43]. A single study evaluated longer term oncological outcomes, and in a propensity matched comparison to laparoscopic resections, reported equivalent 5 year disease free and overall survival rates at 38% and 61% respectively [43]. Matched comparisons of long term oncological outcomes between open and robotic surgery are awaited.

4.3 Cholangiocarcinoma (CAA)

Minimally Invasive Surgery utilising a robotic approach should theoretically convey the significant advantages to hilar CCA resections given the necessity of extreme precision and micro-anastomosis formation. However CCA resections form less than 10% of robotic liver surgery in the current literature, likely due to the required tertiary level of surgical expertise and robotic technology [22]. As such, the literature exploring oncolocological outcomes is very limited. The largest case series (48 patients) of patients undergoing robotic resections for Type I, II and III CCA, reported successful lymphadenectomy from stations 7,8,9, 12 and 13 and an R0 resection rate of 72.9% [44]. A single study has reported on longer term outcomes following robotic resections and demonstrated significantly higher rates of recurrence and peritoneal disease when compared to a contemporaneous group of open resections in the same centre [45]. As such whilst technically feasible and safe in expert hands, further studies are required to fully elucidate the oncological equivalence of robotic MIS for CCA.

4.4 Gallbladder Cancer

When compared to open radical cholecystectomy, the robotic approach has been shown to result in analogous operative times, blood loss, and length of stay. Specialist centres have also reported equivalent lymph node yields and demonstrated the feasibility of complete robotic lymphadenectomy of stations 8,9 12 and 13 [46–48]. An 100% R0 resection rate has been reported by the only 2 studies that present oncological outcomes [47, 48]. To date, no studies have yet to report on longer term oncological data following robotic radical cholecystectomy.

5. Limitations

As with other subspecialties of surgery, while the robotic approach can confer major operative advantages, limitations also exist and it is important to consider these closely, not only for assessment of robotic feasibility, but also in order to adopt adoptions of solutions to such limitations.

The initial purchase of robotic systems poses a major financial outlay to healthcare institutions. With many health systems facing unprecedented pressures, such upfront costs may be difficult to meet. Ongoing maintenance and updates to newer robotic models, as well as requirement for further robotic systems associated with a growing surgical evidence base will add to financial expense.

Such upfront costs may make the financial case for initial investments difficult in a publicly funded health care system such at the UK National Health Service. However, as with all technology, costs of equipment have already been seen to decrease in older models, while newer designs remain at the top of the market. In the same way that laparoscopic stacks and equipment, initially considered a major investment, are now considered as standard in any theatres inventory (albeit with differing quality across healthcare institutions) robotic theatre systems are likely to become common place in the operating theatre complex.

Furthermore, while the earliest days of robotic surgery, saw one company at the forefront of robotic design and technology, maintain a virtual monopoly on the robotic equipment, market competitors have already emerged, a trend which looks set to continue. This is highly likely to bring about a reduction in costs. In this context however, it cannot be assumed that an evidence base for robotic surgery built on one robotic system is necessarily transferable to different systems, and care must be taken when applying this evidence and making financial decisions regarding newer market technology.

In a manner not dissimilar to the initial uptake of laparoscopic minimally invasive surgery in the twentieth century, the uptake of robotic surgery within hepatobiliary surgery has not been as marked as within other surgical specialties. However, this may confer an advantage in financial terms, where robots already purchased and present in theatres based on an early uptake in other specialties can be utilised for education and training in less robotically advanced surgical specialities.

Another disadvantage posed in much of the literature, in both major and minor liver resections is increased operative time, although the clinical maxim "surgical time in measured in inpatient days, not theatre minutes" may be prescient here. Whilst theatre time is a precious financial resource, particularly in an era of unprecedented surgical waiting lists, reduced critical care and overall inpatient stays could confer an overall institutional financial advantage.

Length of surgical theatre time is multifactorial. Technical learning curves of individual surgeons, which have previously shown to be flatter than that of laparoscopic surgery, show operating times inversely proportion to training and experience, as expected with any new skill set [49]. Furthermore, overall operating theatre time not only encompasses the primary surgical procedure, but also robotic system set up, patient positioning, robot docking, and additional tasks performed by the theatre team as a whole. In a similar fashion to the primary surgeon activity discussed above, the increased experience of adequately trained and well drilled theatre team can be expected to significantly reduced theatre times, allowing an increased case load for theatre lists.

While every surgical speciality performs unique technical tasks requiring specific equipment, liver surgery, to perhaps a greater extent than other forms of abdominal surgery, utilise a cornucopia of specific tools not common to other subspecialties. Ultrasonic probes, used for intra operative identification of specific lesion, hepatobiliary specific energy devices and minimally invasive articulated retractors, as well as ultrasonic surgical aspirators, which allow cavitation and aspiration of hepatocytes whilst sparing vascular and biliary structures, are not yet incorporated into standard robotic systems. This technology, however, already exists within the minimal access domain of laparoscopic surgery, so incorporation into robotic systems should not pose an insurmountable barrier.

An often described limitation of MIS is the relative lack of tactile feedback present in open surgery, making dissection of difficult but vital structures significantly more challenging, with potential for catastrophic tissue damage from excessive forces. While much comment was made on this in the advent of laparoscopic surgery, the degree of tactile feedback offered in early robotic surgery systems was even less. Hydraulic haptic feedback systems are, however, already in development with in vivo trials showing significant grip strength reduction more akin to that in open surgery [50, 51].

As with any novel surgical technology, it is necessary to temper adoption of technology with strict clinical governance to maximise patient safety. This includes inclusion of robotics cases in morbidity and mortality discussions, a forum for discussing serious untoward events and near misses, and strategies within scientific literature to avoid publication bias.

Obesity has become an epidemic in many parts of the western world and extremes of BMI offer difficulties in many aspects of surgical practice. While a number of studies in other surgical subspecialties have shown the robotic approach not to offer significantly worsened outcomes in extremes of BMI, hepatobiliary surgery offers specific challenges with non alcoholic fatty liver disease, steatohepatitis and liver cirrhosis associated with morbid obesity [52–54].

A recently published US study examined the effects of BMI, prospectively observing outcomes in patient subgroups of BMIs <25, 25-35 and > 35, found no significant differences found in operative blood loss, operative time of length of stay [55]. With a relatively small number of patients in this study however, more work is required to accurately identify the possible difficulties or benefits posed with hepatic robotic surgery in the obese patient cohort.

Operative training is a vital part of any health service in order to provide future surgeons adequate experience and competence to take on standard as well as challenging cases with a minimal access approach. While early adopters of robotic surgery are often consultant surgeons with strong minimal access laparoscopic practice, for these enthusiasts to become robotic trainers themselves takes time for building of robotic experience. It is therefore expected that robotic training for surgeons in formal training stages will take time to diffuse down, as with the uptake of any new surgical practice. However, flatter learning curves with robotic surgery, with dual operator consoles and built-in simulation trainer modules to robotic surgical systems can offer clinical and non-clinical based training experience. These opportunities will increase with a corresponding increasing prevalence of robotic systems within healthcare institutions.

6. Future outlook

While limitations within robotic hepatic surgery exist, the future outlook for incorporation of robotics into liver surgery, with additional integration of other technology offers exciting promise.

Robotics systems, with the primary operator working from a non-sterile station with a visual screen, already offers the opportunity to consult pre-operative imaging for comparison to intra operative findings. Infrared fluorescence technology, incorporated into robotics systems, offers visualisation of vital biliary and vascular structures with near fluorescence of indocyanin green. This poses a major advantage during dissection of the liver hilar structures, where anatomical variation is commonplace and iatrogenic injury can prove catastrophic. With constantly improving imaging and artificial intelligence technology, it is not difficult to imagine intraoperative overlay of imaging to on screen anatomical structures allowing real-time surgical decision making, such as lymph node dissection or surgical resection margins. With the rise of artificial intelligence integrated into robotic systems, it is possible that pre-operative structural recognition of vital hepatobiliary structures or predefined areas within resection margins could be predefined as "no go areas" during operative intervention offering intraoperative artificial intelligence guidance to the operating surgeon. It is perhaps even conceivable that automated robots could perform hepatic resections, with the primary surgeon adopting a supervisory role.

While questions are understandably raised regarding the early stages of surgical training on robotic systems, telecommunications incorporated into robotic systems can arguably vastly improve training in the latter stages. With shared access, real time intra-operative images could be viewed on technology outside of the operating theatres allowing recommendations from experienced colleagues in the event of intraoperative uncertainty. Indeed, it is conceivable the operative control could be managed at work-stations distant to the immediate operating theatre.

Perhaps the most important aspect of the future of robotic surgery, however, will be widespread inclusion into standard surgical practice. If robotic surgery is to exist outside of a few specialist centres, a balance must be struck between using robotics for the most complex technical cases, where a clear evidence base exists within the literature, and the everyday use of the robotic system, allowing not only the operating surgeon but also whole team to become at home managing and trouble-shooting issues that arise with all technology. While major advantages of routine use of robotic technology for, for example, minimally invasive cholecystectomy will be difficult to evidence, adoption of such technology on a day-to-day basis will be essential for surgical training.

7. Conclusion

Robotic liver surgery is rapidly evolving. There is growing evidence suggesting this approach to be feasible and safe. This evidence however is limited to highly specialised centres and cannot be consider standard of care. Robotic liver surgery shares the advantages of laparoscopic liver surgery and both should be developed in parallel to promote wider access to minimally invasive surgery for patients undergoing liver resections. Certain limitations remain whilst there is a promising future of innovation and research for robotic liver surgery.

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