Critical review

Robotics in general surgery: current status and critical review

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Abstract

Introduction
In the last three decades, laparoscopic surgery has gained a worldwide interest in many specialties. However, several technical drawbacks have limited its diffusion in complex procedures. Robot-assisted surgery was introduced in the late 90’s, as an advanced platform studied to overcome the technical limits of conventional laparoscopy. Today, it is a reality applied in many surgical specialties. The aim of this critical review was to assess the current status of the main applications of robotics in General Surgery, relying on our experience and scientific published literature.

Discussion

Robot-assisted gastrectomy is a valid alternative to conventional open or laparoscopic resection for the treatment of early stages of gastric carcinoma, with excellent results in terms of perioperative outcomes and oncological adequacy.

Pancreatic and liver surgery represents the most interesting fields of application for robot-assisted abdominal surgery. The preliminary results appear satisfactory in terms of feasibility, safety and preservation of oncological adequacy. The technical advantages of robotics could contribute to extend the reproducibility and diffusion of this complex surgery.

In colorectal surgery, robotics technology could play an important role in rectal resection, with total mesorectal excision, especially in male or obese patients, and in low and ultra-low cancers. A local control of disease associated to a good preservation of sexual and urinary functions is expected from robot-assisted surgery.

Conclusion
Robot-assisted surgery is growing interest in surgical community, and it has been able to achieve satisfactory results in terms of perioperative outcomes and oncological adequacy, even in high technical complexity surgical procedures.

The technical advantages of robotic platform could have an important role to enlarge indications, feasibility, reproducibility and diffusion of complex minimally invasive surgery.

However, more studies will be necessary to evaluate oncological long-term results, and to define the better indications for advanced robot-assisted surgery.

Introduction

Robot-assisted surgery (RAS) was introduced by Cadière in March 1997, when the first telesurgical laparoscopic cholecystectomy was performed. Today, RAS is a reality applied in many surgical specialties.

Conventional laparoscopy (CL) presents several limitations and drawbacks, as limited movements, few degrees of freedom of the tools, inability in performing high-precision dissection and sutures, unnatural positions for surgeon and flat vision. For these reasons, the diffusion of laparoscopy in advanced surgery remains limited to very skilled and experienced surgeons.

Robotic platform (RP) may overcome these technical limits, extending the indications for minimally invasive surgery even in complex procedures, and providing more surgeons able to perform the same ones. However, many issues are still not resolved about RAS, such as effective indications, clinical benefits and long-term oncological results.

The RAS program started at our Institution (Misericordia Hospital, Grosseto, Italy) in October 2000 with Dr. Pier Cristoforo Giulianotti, using the da Vinci Surgical System (Intuitive Surgical Inc., Sunnyvale, CA). From the beginning, RAS offered significant improvements in vision and manipulation inside the corporeal cavities, that is, the idea was that this technological evolution could assist surgeons in complex procedures requiring precise dissection and reconstruction, as in gastric, hepato-pancreato-biliary (HPB) and colorectal oncological surgeries.

We report the current status and a critical review of the applications of RAS in these three specialties, relying on our experience and scientific published literature (Table 1).

Discussion

In this critical review, the authors have referenced some of their own studies. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees associated to the institution in which they were performed. All human subjects, in these referenced studies, gave informed consent to participate in these studies.

Robot-assisted gastric surgery

The first experiences of robot-assisted gastrectomy (RAG) were published by Giulianotti and Hashizume in 20031-5. Afterwards, other reports appeared in published literature, although most included small series and were limited to perioperative outcomes, without data about long-term oncological results.
In the last years, Song and Marano published more consistent series of RAG, including 100 and 236 patients, respectively. Both these studies evaluated perioperative outcomes and oncological adequacy, confirming feasibility and safety of RAG, with radical lymphadenectomy. However, no data were reported about long-term oncological results.

More recently, two reviews and a meta-analysis were published to assess the current status of RAG. Even these papers reported short-term results, without significant data on long-term survival. Because of this shortfall of studies, the real long-term oncological benefits of RAG remain unclear.

Currently, the accepted indications for RAG are similar to those of CL, that is, RAG should be reserved at T1-T2 tumours, while the robotic approach for advanced gastric cancer (AGC) should be performed only in experienced centres, and in the context of controlled studies. However, most Western authors have reported a variable amount of AGC cases in their series of RAG, and we had a similar experience, that is, about 24% of patients presented an AGC in our unpublished series.

These data induce two important considerations. First, the proportion of AGC cancer in Western countries is higher than in Eastern countries. Second, regardless of the new diagnostic methods, preoperative staging of gastric cancer remains partially ineffective. In our experience, a consistent number of cases were staged as ‘advanced’ only at post-operative pathological examination. Several authors have reported the risk of under-staging, which can occur in up to 25% of patients diagnosed preoperatively, with early gastric cancer (EGC). For this reason, some authors have suggested to perform D2-lymphadenectomy as routine practice, even in cases preoperatively staged as EGC. This is also our opinion and part of policy followed in our clinical practice, as well as in many Western institutions.

Based on previous considerations, the importance of technical standardization of lymphadenectomy is clear. Most surgeons consider D2-lymphadenectomy as the more critical step of minimally invasive gastrectomy for gastric carcinoma. This lymphatic dissection requires a longer learning curve, and it is difficult to reproduce this on a routine basis. This is the main limit for the diffusion of laparoscopic gastrectomy, especially in the Western countries.

Technical advantages offered by RP may help to standardize minimally invasive D2-lymphadenectomy, and to enable surgeons in performing and reproducing this procedure. However, in a comparative study among open, laparoscopic and robotic gastrectomy, Kim reported no differences in terms of number of harvested lymph node. However, this result reflected the large experience of this surgical team in open and minimally invasive gastrectomy.

Kim reported an estimated blood loss significantly lower in the RAG group than in open and laparoscopic groups, the same result was confirmed in a meta-analysis. These data confirmed the ability of surgeons in reducing and controlling bleeding with RP.

Finally, other reports suggested that RAS could make easier D2-lymphadenectomy in obese patients, compared with CL.

Intracorporeal techniques for digestive restoration seem to be the preferred solution for RAS, suitable in every type of patient, the technical precision of suturing is comparable to that of open surgery. Several Eastern authors have reported a technical shift from extracorporeal to intracorporeal anastomoses. Probably, increased experience and confidence with RP has enabled surgeons to perform high-precision intracorporeal sutures and digestive anastomoses, especially after total gastrectomy.

Technical advantages of RAG (routine reproduction of D2-lymphadenectomy, possibility of enlarged resections and complex reconstructions) could get an important role for RAG, even in therapeutic strategy of AGC, integrating minimally invasive resection with neoadjuvant and adjuvant therapies.

Robot-assisted hepato-pancreato-biliary surgery

Liver

Minimally invasive liver resections (LR) are growing worldwide. To date, more than 3000 cases have been published. Knowledge of surgical anatomy, improvements in perioperative care, enhanced imaging modalities, advancement in laparoscopic skills and development of new devices...
Critical review

A curious report cited a case of laparoscopic LR of segments 7 and 8 that was ‘converted’ to RAS, because of a stapler malfunction in transecting the right hepatic vein. In this case, Boggi demonstrated the usefulness of RP in controlling major bleeding.

Idrees claimed that several features of the da Vinci robot (three robotic operating arms, articulating tools lockable in place as vascular clamps, and the ability of suturing in difficult situations) were extremely useful in controlling and definitively, managing bleeding without conversion at open surgery. The possibility to lock an articulating tool in place as a vascular clamp could be invaluable, because it gives time for the anaesthesia team to resuscitate the patient, and for the surgical team to formulate a management plan when bleeding complications occur.

Although robot-assisted LR appears safe and feasible in experienced hands, long-term oncologic outcomes remain unclear. However, the preliminary short-term results show that RAS is comparable to CL for the treatment of selected liver malignancies.

Pancreas

The current diffusion of laparoscopic pancreatic surgery is limited to easy procedures, as distal pancreatectomy or enucleation. Conversely, laparoscopic pancreateoduodenectomy (LPD) has gained a limited consensus during the years, because of its technical complexity, high rate of conversion and questionable benefits.

In 2003, Giulianotti first reported the robot-assisted pancreateoduodenectomy (RAPD), and in 2010, he published the larger series of pancreatic LR performed by a single surgeon. This study included 134 patients (60 RAPD), focusing on technical details and perioperative outcomes. Conversion rate, morbidity and mortality were 10.4%, 26% and 2.23%, respectively. Pancreatic fistula (PF) rate was found to be 31.3% for RAPD and 20.9% for distal pancreatectomy. A redo surgery was performed in four patients (2.9%).

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### Table 1. Suggestions for using robot-assisted surgery.

<table>
<thead>
<tr>
<th>Field of application</th>
<th>Surgical procedures</th>
<th>Indications</th>
<th>Technical advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stomach</td>
<td>Subtotal distal gastrrectomy</td>
<td>EGC AGC (only in experienced centers) Other malignancies (evaluating single cases) Benign diseases</td>
<td>Lymphadenectomy (D2 or more) Bleeding control Obese patients Shorter learning curve vs. CL Shorter post-operative stay vs open</td>
<td>Need of experienced team Longer operative time vs open High costs</td>
</tr>
<tr>
<td></td>
<td>Total gastrectomy</td>
<td>EGC AGC (only in experienced centers) Other malignancies (evaluating single cases) Benign diseases</td>
<td>Lymphadenectomy (D2 or more) Bleeding control Esophageal anastomosis Obese patients Shorter learning curve vs. CL</td>
<td>Need of experienced team Longer operative time vs. open High costs</td>
</tr>
<tr>
<td>Liver</td>
<td>Major hepatectomies Other hepatectomies Resection of posterior segments</td>
<td>HCC Colorectal metastases Cholangiocarcinoma (select cases) Endocrine tumors or metastases Benign diseases</td>
<td>Dissection of hepatic hilum Preliminary and selective control of vascular pedicles Bleeding control Exposure and access to posterior segments Biliary suturing and reconstruction Cirrothic patients Obese patients</td>
<td>Lack of specific robotic tools for parenchymal transection Need of experienced team in liver and minimally invasive surgery Longer operative time vs. open High costs</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Pancreatoduodenectomy</td>
<td>Peri-ampullary tumours Non-advanced ductal carcinoma Endocrine tumors Cystic lesions</td>
<td>Dissection and lymphadenectomy Uncinate process detachment Anastomoses (pancreatic, biliary) Bleeding control Standardization and reproducibility</td>
<td>Very difficult and complex procedure Need of experienced team in pancreatic and minimally invasive surgery Longer operative time vs. open High costs</td>
</tr>
<tr>
<td></td>
<td>Distal pancreatectomy</td>
<td>Non-advanced ductal carcinoma Endocrine tumors Cystic lesions</td>
<td>Preserving of spleen Lymphadenectomy Bleeding control Model for advanced training (before pancreatoduodenectomy)</td>
<td>High costs</td>
</tr>
<tr>
<td>Colon and Rectum</td>
<td>Rectal anterior resection</td>
<td>Rectal carcinoma</td>
<td>Pelvic dissection for TME Nerves sparing Ultra-low resections Obese patients Standardization and reproducibility Shorter learning curve vs. CL</td>
<td>Need of experienced team High costs</td>
</tr>
</tbody>
</table>
A systematic review was published recently by Zhang, in order to compare robot-assisted pancreatectomies (RAP) and open pancreatectomies (OP). Seven non-randomised studies, for a total of 340 resections (137 RAP and 203 OP) were analysed, in both robotic and open groups, which included pancreaticoduodenectomies and distal pancreatectomies. The meta-analysis showed significant advantages in favour of RAP in terms of morbidity, redo surgery, negative margins, blood losses and length of hospital stay. The operating time was significantly lower in OP. No differences were observed about PF rate and mortality.

Currently, pancreaticoduodenectomy represents more interesting application of robotics in pancreatic surgery, because of its high complexity and technical difficulty. In personal experience, the major advantages offered by RP in this procedure were appreciable in hepatic hilum dissection, lymphadenectomy, uncinate process detachment and reconstruction (biliary and pancreatic anastomoses) (Figure 3).

In the last three years, more of 180 RAPDs were reported in the published literature against a more limited number of LPDs reported in the published literature during a larger period of time, to confirm the increasing interest of surgical community in applying robotics in more complex pancreatic surgery.

The open conversion rate of RAPD ranges between 0%-18.3% versus 0%-46% of LPDs. This favourable trend of RAPD is probably because of a better technical standardisation and reproducibility of complex procedures, and to an easier management of difficult steps or intra-operative incidents (as major bleeding), using robotic assistance. Unfavourable data were reported about the post-operative PF rate, which resulted an apparently upper value for RAPD as compared to the one reported usually for open pancreaticoduodenectomy. This may be explained first by the initial learning curve of robotic pancreatic surgeons. Another explanation could be a bias in patients’ selection, because in most series, the more frequent indication for RAPD was not the pancreatic ductal carcinoma (tough pancreas, dilated duct), but other pathologies, such as peri-ampullary tumours or benign lesions (usually associated with soft pancreas and small duct). Zeh observed a PF rate of 22% in a series of 50 RAPDs, which included 72% of soft pancreas and 60% of pancreatic duct <3 mm. The incidence of PF was significantly higher in the group of patients with a <3 mm pancreatic duct; furthermore, grade B and grade C fistulas occurred only in this group. These results confirmed that incidence and severity of PF are firstly associated to the anatomical features of pancreas, that is, this is a common problem with open surgery, rather than a specific issue of RAPD. Other robot-assisted pancreatic procedures were demonstrated to be feasible and safe, as compared to distal and central pancreatectomies, enucleations and decompression of pseudocysts; the interest for these ones is lower than RAPD, because of their feasibility and reproducibility even in CL. However, a particular advantage of RAS seems appreciable in spleen-preserving distal pancreatectomy, a high percentage of success (95%-100%), with preservation and patency of splenic vessels, was reported in a small preliminary series.

Robot-assisted colorectal surgery

In recent years, RAS is assuming greater significance and interest in the treatment of colorectal cancer.

In the last decade, several large randomised studies have shown comparable results between laparoscopic and open surgery, in terms of long-term survival. Nevertheless, technical complexity of laparoscopic total mesorectal excision (TME), long learning curve and other intrinsic drawbacks of CL are considered as the main limits for the diffusion of laparoscopic rectal resection (LRR), especially for restorative low and ultra-low resections.

Till date, LRR remains a challenging procedure with conversion rates as high as 30%. Furthermore, the excellent oncological results of classical randomised trials, comparable with those of open surgery, were obtained by experienced surgeons, in high volume centres, and in selected patients, this is not a warranty to reproduce the same results always and everywhere. Combined with the high rate of conversion, this may explain why LRR is not diffused as expected.

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Recently, RAS has been claimed in order to make the dissection easier in the narrow pelvis and in obese patients, to reduce the conversion rate and to allow an accurate intersphincteric dissection in case of ultralow resections (Figure 4).

Other technical advantages of rectal RAS seem to be interesting. First, the ability to perform a purse string on the rectal stump, even in low resections, avoiding the double stapling rectal Anastomosis, the single stapling anastomosis can theoretically reduce the rate of leakage. Second, the possibility to treat synchronous rectal cancer and liver metastases, even in difficult cases, as well as hepatic lesions are located in posterior segments or when a major hepatectomy is required.

Several meta-analyses reported comparable results between robot-assisted rectal resection (RARR) and LRR, that is, in some cases RARR has shown several advantages versus LRR in the preservation of sexual and urinary functions, especially at short-term follow-up. The learning curve or RARR was reported shorter than in LRR. For trained surgeons in colorectal laparoscopy, the robotic learning curve is reduced approximately to zero. Although robotic technology seems particularly suitable to improve the minimally invasive TME and to enlarge its diffusion, further studies are required to define its role and its real efficacy in local control of rectal cancer and disease-free survival, in reducing open conversion and postoperative morbidity, and in preserving sexual and urinary functions. These are the goals designed in the worldwide randomised study named Robotic versus Laparoscopic Anterior Rectal Resection (RO-LARR), which is still in progress.

For other colonic surgery, RAS does not seem to show significant technical advantages. However, colorectal surgeons can get major ability in helping obese patients, in extended lymphadenectomies for right or transverse colectomy, and for intra-corporeal anastomoses.

**Conclusion**

Till date, RAS appears to be a growing interest in surgical community. The reported results are satisfactory in terms of conversion rate, blood losses, morbidity and mortality, even for complex surgery as gastric, HPB and rectal procedures.

The technical features of the robotic system can make complex procedures easier and more reproducible, as compared with CL.

A steady three-dimensional view provides excellent resolution, depth perception and magnification. The vision at the console is very similar to that of a surgical microscope and the anatomical details appear to be very clear and precise. Furthermore, technological innovation offers new options, such as fluorescence camera, contemporaneous endoscopic and ultrasound images (Tile Pro), and probably in the future, the possibility of having images in augmented reality. Wristed instruments enhance the capabilities of dissecting and suturing; this is very important during major oncologic procedures, requiring difficult lymph node dissection and visceral reconstruction.

The fourth robotic arm is used frequently as a stable retractor during surgery. This achieves a prefect exposure of operating field and dissection planes. Furthermore, the surgeon can use the fourth arm like a vascular clamp in order to control major bleeding.

There are two major issues, which are still a burden on RAS. First, the high costs for purchasing the system, yearly maintenance and disposable tools. Second issue is the requirement of an experienced assistant surgeon at the operating table, to perform more complex procedures safely and in better technical conditions.

Finally, the results reported in the published literature for RAS are generally limited to technical features, perioperative outcomes and short-term results. More studies will be necessary to evaluate oncological long-term results and to define the better indications and selection of patients for advanced RAS.

**Abbreviations list**

AGC, advanced gastric cancer; CL, conventional laparoscopy; EGC, early gastric cancer; HPB, hepatopancreato-biliary; LPD, laparoscopic pancreatoduodenectomy; LR, liver resection; LRR, laparoscopic rectal resection; OP, open pancreatectomies; PF, pancreatic fistula; RAG, robot-assisted gastrectomy; RAP, robot-assisted pancreatectomies; RPD, robot-assisted pancreatoduodenectomy; RARR, robot-assisted rectal resection; RAS, robot-assisted surgery; RP, robotic platform; TME, total mesorectal excision.

**References**

4. Song I, Oh SJ, Kang WH, Hyung WJ, Choi SH, Noh SH. Robot-assisted gastrectomy with lymph node dissection and visceral reconstruction. The fourth robotic arm is used frequently as a stable retractor during surgery. This achieves a prefect exposure of operating field and dissection planes. Furthermore, the surgeon can use the fourth arm like a vascular clamp in order to control major bleeding.
Critical review