

2016 Laparoscopic Surgery: Global view

Laparoscopic and robot-assisted laparoscopic digestive surgery: Present and future directions

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Abstract

Laparoscopic surgery is applied today worldwide to most digestive procedures. In some of them, such as cholecystectomy, Nissen's fundoplication or obesity surgery, laparoscopy has become the standard in practice. In others, such as colon or gastric resection, the laparoscopic approach is frequently used and its usefulness is unquestionable. More complex procedures, such as esophageal, liver or pancreatic resections are, however, more infrequently performed, due to the high grade of skill necessary. As a result, there is less clinical evidence to support its implementation. In the recent years, robot-assisted laparoscopic surgery has been increasingly applied, again with little evidence for comparison with the conventional laparoscopic approach. This review will focus on the complex digestive procedures as well as those whose use in standard practice could be more controversial. Also novel robot-assisted procedures will be updated.

Key words: Laparoscopy; Robotic surgery; Colectomy; Esophagectomy; Gastrectomy; Obesity surgery; Liver resection; Pancreatectomy; Laparoscopic training

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Core tip: Laparoscopic surgery is increasingly used in the treatment of digestive diseases. New procedures are performed and novel technologies are applied. In addition, robot-assisted laparoscopic surgery has appeared as a useful tool for the digestive surgeon. The aim of this paper is to up-date the recent advances and scientific evidence supporting clinical practice.

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INTRODUCTION

Laparoscopic surgery has spread worldwide these days and many digestive procedures have become the standard practice. The rapid development in technology and improvement in surgeon skills have allowed that virtually every complex surgical technique, usually performed through open approaches, has been accomplished laparoscopically. Numerous reports favoring this approach have been published recently.

Caution interpreting literature is, however, necessary. There is a risk for selection and publication bias. Selection bias is possible because most favorable (in terms of location, number and tumor size) cases could have been operated on through a laparoscopic approach. Publication bias could also happen, since it is generally recognized a trend to report studies only with good outcomes and those exhibiting significant differences, which can lead to an overestimation of the laparoscopic approach. This publication bias can also be induced by some journal editors, who could prefer to publish papers with positive and spectacular outcomes more than negative and poor results. In addition, most published studies have been performed at large academic institutions by experienced surgeons, which could not reflect the current general practice.

Although feasibility of most laparoscopic procedures in general surgery has been shown, some have concerns about reproducibility, at least for the most complex techniques.

There are also concerns about costs of minimally invasive techniques in the era of cost containment. The advantage could come from shortening hospital stays and possibly diminishing some complications, but the disadvantage is more expensive surgical material and longer operating room times.

All of these considerations can be applied with robotic-assisted surgery, a novel approach applied today in most surgical procedures, and this approach is becoming used more and more.

The scope of this review tries to update most digestive surgical procedures, which precludes a systematic review. Outstanding papers were reviewed, but we especially focused on most of the recent work.

MINIMALLY INVASIVE COLORECTAL SURGERY

Laparoscopic procedures started in 1902 when George

Kelling, a German surgeon, used a laparoscope to assess the peritoneal cavity in a dog^[1]. This procedure was followed by different studies until 1987 when Mouret in France performed the first video assisted laparoscopic cholecystectomy. In 1993 this technique was established by consensus as the gold standard for the treatment of cholelithiasis^[2]. Since then, laparoscopy has been successfully used to perform funduplications, appendectomies, splenectomies, nephrectomies and a long etcetera.

Colorectal cancer is the second cause of death in western countries^[3]. Despite the progress in the different medical treatments and radiotherapy, surgery remains as the only potentially curative approach for this disease. The implementation of laparoscopic surgery in the field of colorectal surgery faced bigger difficulties because of the need of working in a broader surgical field that involved several quadrants, moving apart the small bowel, dissecting the retroperitoneal planes and removing a big sized specimen^[4]. Despite all these difficulties, Jacobs *et al*^[5] in 1991 reported the first laparoscopic sigmoidectomy for colon cancer starting a new era for colorectal surgery.

The enthusiasm for laparoscopic colorectal resections for cancer suffered a setback when in 1993 Alexander *et al*^[6] reported the first case of wound recurrence three months after a right colectomy for colon cancer. Tomita *et al*^[4] published their experience in laparoscopic colorectal resections in 1999 reporting a 1% wound recurrence similar to the one reported in open surgery. We have needed more than 20 years in order to have clinical evidence to demonstrate the benefits of laparoscopic surgery over open surgery in the treatment of rectal tumors.

A prospective comparative study performed at the Barcelona Clinic Hospital comparing laparoscopic and open colonic resections with 219 patients with a 98 mo mean follow-up, demonstrated that the laparoscopic surgery group had a faster recovery after surgery and less morbidity with a longer survival and a lower local recurrence rate^[7,8].

Several multicentric prospective randomized studies have shown the advantages of laparoscopic colonic surgery in terms of complications, postoperative recovery and oncological safety (COST, COLOR and CLASSIC)^[9-11].

There is not yet enough evidence in the case of rectal surgery. The conclusions of many retrospective studies make us think that this approach will have several advantages but solid data is still lacking.

Some studies such as the prospectively performed by Ströhlein *et al*^[12] comparing laparoscopic and open surgery, conclude that the laparoscopic surgery group has the same oncological results, with faster recovery and a shorter hospital stay, finding statistically significant differences in mid and lower rectal tumors. This study presents a high conversion rate of 22%.

Braga *et al*^[13] published a prospective and randomized study with 168 patients comparing open

and laparoscopic surgery for rectal cancer with a 5-year follow-up. This study concludes that postoperative morbidity and postoperative stay were significantly lower in the laparoscopic group. Survival and local recurrence were similar in both groups with better scores in the quality of life tests in the laparoscopic group after the first year. Long term costs were similar in both groups. Conversion rate in the laparoscopic group was 7.5%.

In a review of the literature presented by Indar and Efron^[14], the results of several prospective randomized trials were analyzed. From this review we can say that laparoscopic rectal surgery is safe, with good results in terms of morbidity, leaks and hospital stay. The conversion rate ranged from 3% to 29%. A higher conversion rate could be due to a lack of experience of the surgeons even though in some studies this rate was not reduced with a progression in the learning curve^[15]. The factors associated with conversion in the CLASSIC trial^[16] were a high body mass index (BMI), inaccessibility of the tumor, fixation of the tumor, and loss of definition of the surgical planes. Pugliese *et al.*^[17] have shown a significant increase in the anastomotic leak rate in the converted cases. Other alarming data is the increase of local recurrence rate up to 16% in those cases converted during laparoscopic surgery for rectal cancer, as shown by Ströhlein *et al.*^[12]. Scheidbach *et al.*^[18] presented a prospective study with 1409 patients with a 10-year follow-up about the impact of conversion in colorectal laparoscopic surgery. They observed statistically significant differences in terms of a higher blood loss, more postoperative complications, more anastomotic leaks and a decrease of the survival rate in the cases converted to open surgery.

The COREAN Trial was a randomized and prospective study performed by three Korean centers with a wide experience, recruiting 170 patients in the laparoscopic arm and 170 patients in the open group, with a 3-year follow-up. There was a very low conversion rate of 2% maybe because of the huge laparoscopic experience of these centers. There were no statistical difference in the oncological results in both groups and in the surgical specimen quality. The laparoscopic group showed a faster recovery with less need of postoperative pain-killers, a faster recovery of oral intake and a better quality of life 3 years after surgery^[19].

In a meta-analysis published by Anderson *et al.*^[20] including 1403 cases of laparoscopic rectal surgery and 1577 cases of open rectal surgery, there was no difference in terms of survival or oncological results.

The Finnish trial published by Kellokumpu *et al.*^[21] comparing open surgery vs laparoscopic surgery for rectal cancer concluded that the laparoscopic approach offered a faster recovery after surgery, lower blood loss and a shorter in hospital stay with less complications in the long term. Survival and local recurrence

were similar in both groups. Conversion rate in the laparoscopic group was up to 22%.

In the cohort retrospective study from Brazil, Melani *et al.*^[22] analyzed 84 rectal cancer patients that had undertaken surgery between 2000 and 2003, 50% with a laparoscopic approach and 50% with an open procedure. Follow-up was longer than 5 years in both groups and they found no difference in terms of complications, survival and oncological results. No conversion rate data was provided and the authors admitted a selection bias since the study was not randomized.

Park *et al.*^[23] published a comparative study of two groups with mid-low rectal tumors in which they performed ultralow intersphincteric dissection with an open approach vs a laparoscopic approach. Oncological and survival results were similar in both groups after a 3-year follow-up, but the authors concluded that the laparoscopic surgery group had less postoperative morbidity, a shorter hospital stay and a faster functional recovery.

In 2013, the COLOR II trial results after a 3-year follow-up were published. 1103 patients from 30 centers were recruited and randomized either to laparoscopic or open surgery^[24]. The authors conclude that the laparoscopic group patients had less blood loss, a shorter time to start bowel movements and a shorter hospital stay, with statistically significant differences. No difference in specimen quality was observed. Postoperative morbidity and mortality were also similar. Conversion rate was 17% even though the surgical teams were selected among centers with experience in laparoscopic colorectal surgery.

In a recently published study^[25], the authors analyze data from 3 randomized and controlled trials that compare laparoscopic vs open surgery for rectal cancer. The mean follow up was of 124.5 mo in the laparoscopic group and 136.6 mo in the open group. Disease free survival after a 10-year follow-up were similar in both groups. There was a tendency towards a lower local recurrence in the stage III tumors treated with laparoscopic surgery.

In summary, we can say that laparoscopic colonic surgery is feasible and completely comparable to open surgery, with advantages in postoperative complications and hospital stay. Rectal laparoscopic resection is also feasible and the studies performed to date suggest that short and long-term outcomes are comparable to open surgery.

Robotic colorectal surgery

Despite the advantages of the laparoscopic approach for colorectal surgery, this approach has some limitations such as loss of the 3D vision, limitations in the freedom degrees of the surgical instruments, the amplification of the physiological tremor and the "fulcrum" effect.

The implementation of robotic technology avoids

this disadvantages and improves the ergonomics of the surgeon^[26]. Uhrich *et al*^[27] proved that the uncomfortable positions during laparoscopic surgery increase surgeons fatigue and iatrogenic injuries.

The development of robotic surgery started in the mid-80s of the 20th century mainly focused in the development of tele-surgery. The FDA approved the use of Da Vinci system (Intuitive Surgical, Sunnyvale, CA, United States) in 2000, and nowadays is the only robotic system available for minimally invasive surgery.

The first article published about robotic colonic surgery using Da Vinci Surgical System was from Weber *et al*^[28] reporting a right colectomy and a sigmoidectomy for benign diseases. At the same time, other authors published their first robotic colonic surgery case reports^[29-31].

In 2004, D'Annibale *et al*^[32] reported 53 patients that had undertaken robotic colonic resections. In this group, 22 were resections for oncological reasons. They concluded that the operative and postoperative results were similar to those obtained with conventional laparoscopic instruments. Braumann *et al*^[33] published the first 5 robotic colonic resections performed in Germany in 2005.

Pigazzi *et al*^[34] and Hellan *et al*^[35] published the first article reporting robotic rectal resections in 2006. These authors reported the first series of 39 consecutive resections for rectal cancer, concluding that this technique is safe and feasible.

In Asia, the first robotic rectal surgery with total mesorectal excision was performed by Baik in June 2006^[36]. The same author published the first extended resection with hysterectomy^[37]. Ng *et al*^[38] reported the first robotic abdominoperineal resection in Hong Kong.

Few data are available regarding the value of robotic colonic resections but the results seem to be similar to those reported by conventional laparoscopic approaches^[39]. No final conclusions can be made at this moment.

Robotic rectal resections for rectal cancer

There are not many articles regarding robotic rectal resections in the scientific literature. Hopefully, the ROLARR (Robotic vs Laparoscopic Resection for Rectal cancer) trial results will be available in a few months and will give some valuable information.

Baek *et al*^[40] analyzed the results of 64 rectal resections for cancer with no operative mortality, a mean blood loss of 200 mL, a conversion rate of 9.4% and a leak rate of 7.7%. The mean of harvested lymph nodes was 14.5, the distal margin was 3.4 cm and the circumferential margin was negative in all cases. They found a local recurrence in 6 patients after an interval of 23 mo. The disease free survival rate was 73.7%.

Luca *et al*^[41], performed a study analyzing sexual and urinary function in 74 patients after robotic rectal resections concluding that robotic instrumentation

helped to preserve sexual and urinary function after total mesorectal excision.

Biffi *et al*^[42], studied the blood loss during robotic rectal resections and reported that only one case of their series of 49 patients required blood transfusion, by contrast with patients with open surgery who required blood transfusion in 12 cases of 105.

Shiomi *et al*^[43], in a study with 113 consecutive robotic rectal resections, 12 of them having T4 tumors, observed no conversion and no hospital mortality. The frequency of Clavien III/IV complications was 2.7%. They concluded that robotic instrumentation was helpful in performing advanced dissections with a very low morbidity and conversion rates.

Robotic vs laparoscopic surgery for rectal cancer comparative studies

deSouza *et al*^[44] compared the results obtained with robotic surgery in 36 consecutive cases against those obtained in 46 cases with laparoscopic assisted surgery using a hand port for the splenic flexure. The authors conclude that robotic total mesorectal excision is feasible and safe, and comparable with open surgery in terms of perioperative and anatomopathological results. There was a statistically significant difference in the tumor location, with more mid and low rectal tumor in the robotic group.

Kwak *et al*^[45] in another retrospective study concluded that the results of robotic surgery were comparable to those obtained with a laparoscopic group. This study was performed by a single surgeon with a huge experience in minimally invasive surgery for the treatment of rectal cancer. He recognizes a selection bias in this study and concludes that prospective, multicentric and randomized studies are necessary.

A very interesting study from Kang *et al*^[46], compared three groups of patients with mid and low rectal tumors treated with either open, laparoscopic or robotic approach. They observed that the robotic group had a faster postoperative recovery with a lower hospital stay, less pain and better specimen quality. The disease free survival rate was similar in all groups three years after surgery.

Fernandez *et al*^[47], retrospectively compared a group of patients treated with a robotic approach vs a group treated with a laparoscopic approach. They performed a low anterior resection in all cases with low anastomosis. They observed no difference in blood loss, postoperative morbidity or surgical specimen quality but, nevertheless, they recognized that the robotic group had lower tumors with a more advanced disease and more chemo radiation. The conversion rate was 17% in the laparoscopic group and 8% in the robotic group.

Patriti *et al*^[48] performed a study comparing 29 patients with robotic rectal resections against 37 treated with a laparoscopic approach with a one-year

follow-up. They obtained similar results in both groups with a higher conversion rate in the laparoscopic group: 7% vs 0%.

Lin *et al*^[49], performed a meta-analysis concluding that robotic surgery is clearly superior in terms of conversion rate. Another meta-analysis of studies comparing robotic vs laparoscopic surgery for rectal cancer performed by Trastulli *et al*^[50] suggested that the robotic surgery group had a statistically significant difference in conversion rate without significant differences in operation time, hospital stay, postoperative morbimortality or surgical specimen quality. The meta-analysis performed by Ortiz-Oshiro *et al*^[51] had similar conclusions.

In the systematic review of the literature performed by Scarpinata and Aly^[52] excluding the studies that referred to colonic resections, they suggested that there is evidence that robotic surgery may offer a better short term results, mainly in obese or male patients. It also may be better in those cases with previous radiotherapy and lower tumors. There was no evidence of any difference in terms of leakages, circumferential margins or preservation of the autonomous function.

A study performed by a Taiwanese group^[53], compared the postoperative results of 64 patients with ultralow anterior resection and intersphincteric dissection. Twenty-eight patients had undertaken a conventional laparoscopic approach and 36 a robotic approach. They found statistically significant differences in terms of surgical time - longer in the case of robotic surgery - and in the number of definitive stomas, which was 46.4% in the laparoscopic group vs 19.4% in the robotic surgery group. The authors conclude that this kind of procedure is feasible and safe with robotic instrumentation, with better functional outcomes and that surgical time will diminish as the experience of the surgeons increases.

Casillas *et al*^[54], analyzed the results of robotic colorectal surgery performed in a single institution by a single surgeon. They compared 200 laparoscopic cases vs 144 robotic cases. They observed a shorter hospital stay and a lower complication rate in the case of robotic surgery.

Park *et al*^[55], performed a prospective study with 217 patients that undertook minimally invasive surgery for rectal cancer. 133 patients had robotic surgery while 84 had a conventional laparoscopic approach. There were statistically significant differences in favor of the robotic approach in terms of hospital stay and conversion rates (0% vs 7.1%). Overall survival rate and disease free survival rate were similar in both groups with a 5-year follow-up. Saklani *et al*^[56] have reported similar results in a 3-year follow up study.

In a recently published meta-analysis, Xiong *et al*^[57] made a comparative analysis between laparoscopic and robotic rectal surgery in terms of safety and efficacy. They identified 8 studies with an overall number of

1229 patients, 554 robotic cases vs 675 laparoscopic cases. The authors concluded that the robotic approach is safe and feasible, but they did not find statistically significant differences in circumferential margins or in sexual function after surgery.

In summary, rectal robotic excision is feasible and safe, is comparable to laparoscopic surgery in terms of short and long-term outcomes, with some advantages such as shorter hospital stay, lower conversion rates and better functional results. Some particular conditions such as lower rectal tumors, male and/or obese patients or locally advanced rectal tumors may be indications that could benefit the most from the robotic approach.

Robotic colorectal surgery learning curve

The use of robotic instrumentation in rectal surgery requires not only training in surgical technique but also training in the use of the robotic system. This training has the specific handicap of the loss of the tactile feedback. The procedure is performed from a console far from the patient. This requires an excellent coordination between the surgeon and the surgical assistant.

The advantages that robotic technology provides make, for an expert surgeon in open surgery, less necessary the previous training in conventional laparoscopic surgery. The surgeon expert in conventional laparoscopic procedures has to make a specific training in robotic surgery. No differences have been observed in the learning curve for robotic surgery in surgeons with previous training in laparoscopic surgery vs those without that training.

Giulianotti *et al*^[58] observed that the robotic surgery learning curve was short for easy procedures as suture knotting or instrument use. They also observed that the training for advanced surgical procedures required previous experience in open and laparoscopic surgery.

Very few studies analyze the learning curve in robotic surgery. Bokhari *et al*^[59] estimated following the Cumulative Summation (CUSUM) technique that 50 robotic rectal procedures are necessary for a surgeon to be proficient in this procedure. Sng *et al*^[60] have recently published an article reporting a multiphasic learning curve. In the first phase (around 35 initial cases) the surgeon performs selected easy cases. In the second phase, with a worse CUSUM, the surgeon performs more complex cases (to 100 cases). Finally the surgeon enters in a consolidation phase.

Buchs *et al*^[61] have reported that the learning curve can be reduced using simulation in an animal/cadaver model or through the visualization of video clips or attending to courses.

In a recent study, Byrn *et al*^[62] compared their initial 43 robotic rectal surgery cases with the following 42 cases observing a significant reduction of surgical time and costs.

Other considerations concerning training are made

at the end of the paper.

Cost-effectiveness studies

One of the most criticized aspects of robotic colorectal surgery is the increase of cost per procedure. Cost analysis may vary depending on the criteria we use and the items we analyze. Rectal cancer process is very long and the analysis of costs of this process may vary a lot if we analyze just the perioperative period or a 5-year period including stoma cost, quality of life or local recurrence. The cost analysis also varies a lot depending on the health care system characteristics. There are not yet high quality articles that are conclusive about the cost issue.

Delaney *et al*^[63] reported a significant increase of in-hospital costs with robotic colorectal surgery: 2946 dollars per laparoscopic procedure vs 3721.5 dollars per robotic resection. This increase was mainly attributed to the increase in intraoperative costs.

However Rawlings *et al*^[64] did not find any statistically significant difference when they analyzed intraoperative, staff and surgical time costs.

Park *et al*^[55] compared robotic with laparoscopic rectal cases with 150 laparoscopic rectal cases and concluded that the robotic approach increased the perioperative costs. These authors recommended cost effectiveness studies including long-term results, oncological results and functional outcomes. Bodner *et al*^[65] have reported similar results.

MINIMALLY INVASIVE ESOPHAGECTOMY

The esophageal cancer frequency - mainly adenocarcinoma - is increasing worldwide, presently being the 8th in the incidence ranking and 6th in mortality^[66].

For patients with advanced loco-regional disease (T2-T4a and N +, stages II and III), controlled randomized trials and a large meta-analysis have shown a clear benefit in disease-free survival in patients treated with chemo-radiotherapy and surgery^[67]. However, esophagectomy is one of the most complex procedures of the gastro-intestinal surgery, with a high postoperative morbidity and mortality, mainly of respiratory origin^[68]. The potential advantages of minimally invasive procedures, especially regarding a decrease in pulmonary complications, have been studied for the last 4 decades^[69]. Minimally invasive esophagectomy (MIE) includes conventional pure laparoscopy/thoracoscopy, hybrid procedures (celiotomy/thoracotomy; celiotomy/thoracoscopy), hand-assisted surgery and, more recently, robot-assisted esophagectomy.

The first thoracoscopic esophagectomy was performed in 1992 by Cuschieri^[70]. Later, other experiences have been published: some reporting less than 5 cases of MIE Ivor Lewis each^[71], larger series of three-field esophagectomy -McKeown technique such as that of Luketich *et al*^[72] in 2003 with 222 patients, that of

Palanivelu *et al*^[73] in 2006 with 130 cases or others including hybrid procedures^[74]. Three meta-analysis have compared MIE with open esophagectomy and find a benefit of MIE in a hospital stay, respiratory complications and overall morbidity^[75-77]. Current evidences suggest that MIE is a feasible and safe technique with benefits in the short term. As a result, indications have been expanded from the Barrett's esophagus with high grade dysplasia to locally advanced tumors after neoadjuvant therapy, which are also the indications of open esophagectomy^[74]. Some aspects such as oncological outcomes, anastomosis location or patient positioning are, however, controversial. There are to date only a few works reporting long-term oncological outcomes and they have a short follow-up and a small number of patients, but they have failed, up to now, to show benefits by comparison with open esophagectomy^[78,79]. Probably, because of this, and despite the MIE procedures increasing, today only 30% of esophagectomies are performed worldwide through minimally invasive approaches, with 20% in 2009 in Japan or 19% in the United Kingdom in the last 8 years^[80-82].

Patient positioning influences the MIE technique. In the MIE as well as in the open technique, the left lateral decubitus has been more frequently used, although the prone decubitus is now being increasingly used. In 2012, the first controlled randomized trial analyzing this position was published^[83]. Fifty-nine MIE patients who were operated on in prone decubitus were compared with 56 patients treated by esophagectomy through a thoracotomy in semi lateral left decubitus. A significant decrease in respiratory complications in the MIE group was found by comparison with the open group (9% vs 29%). It is not clear whether the benefits are due to the position or the minimally invasive approach or, more probably, a combination of both. However, recent studies comparing both positions^[84,85] show that the prone decubitus provides some advantages such as better oxygenation and exposition of the surgical field, which lead to improved postoperative outcomes. As a result, the prone decubitus is being increasingly used.

Regarding the anastomosis location, the McKeown technique with cervical anastomosis, using thoracoscopy only for the esophageal mobilization, has been the most used procedure to date since a lower skill is needed by comparison with the intrathoracic anastomosis. However, the McKeown technique is associated with high complication rates such as recurrent laryngeal nerve injury, and anastomosis leak. As a result, there is a tendency to perform more intrathoracic anastomoses. In 2012 a large series of 1000 MIE patients compared 481 cases treated by the McKeown technique with 530 with the Ivor Lewis procedure^[86]. The outcomes in both groups were similar with low mortality rate and a similar number of retrieved lymph nodes, but the authors

concluded that Ivor Lewis MIE is preferable because a lower frequency of recurrent laryngeal nerve injury and a mortality rate of 0.9%, not higher than that of McKeown. Similar outcomes were found in another study from 2014 comparing 103 Ivor Lewis MIE with 185 McKeown MIE^[87], with significantly better results found in the first group: overall morbidity (16.5% vs 31.4%), respiratory complications (8.7% vs 25.9%), anastomosis leak (1.9% vs 13%), anastomosis stenosis (0% vs 4.9%), and recurrent laryngeal nerve injury (1% vs 7.0%).

Nevertheless, intrathoracic anastomosis is difficult to do through a minimally invasive approach, so there is a limited number of papers reporting more than 50 cases each in the last 2 years^[88-92].

Robot-assisted esophagectomy

Some limitations of the MIE can be overcome by the aid of the robotic systems, which provide some advantages such as a tridimensional view of a field selected for the surgeon instead of the assistant-, the 7 degrees of freedom allowing movements similar to open surgery, the tremor suppression resulting in a better precision, and a better ergonomics which leads to less surgeon fatigue. All of these advantages are even greater in small surgical fields, with few instrument exchanges as the thoracic phase of an esophagectomy is.

The first robot-assisted MIE using the Da Vinci system was published by Kernstine *et al.*^[93] in 2004. A few short series, between 6 and 47 cases, have been reported since then, always with cervical anastomosis^[94-99]. The first robot-assisted Ivor Lewis series were published from 2013 to now, reporting 22^[100], 17^[101], and 50^[102] cases, respectively, all with the patient in lateral decubitus. In 2014 our group published the first series of robot-assisted Ivor Lewis in prone decubitus with intrathoracic manual anastomosis^[103]. We feel that the prone position makes the dissection and lymphadenectomy easier, in an optimal field. We had no respiratory complication in 39 cases, although a stapled anastomosis, either transthoracic or transoral, is more difficult. The robotic assistance makes a manual intrathoracic anastomosis easier and allowed us to use the prone position and its potential advantages without flawing short and long-term oncological outcomes, as we recently reported in a series of 21 cases^[104].

Despite these potential advantages, the evidence to show any possible superiority of the robot-assisted MIE over either open esophagectomy or conventional thoracoscopic esophagectomy is still very limited. Since 2012 a single center controlled randomized trial has been ongoing in the Netherlands to compare the robot-assisted and open esophagectomy^[105], with a recruitment prevision of 112 patients - 56 per arm and a follow-up of 5 years. However, for stronger evidence, multicentric trials with a large number of patients is

needed.

MINIMALLY INVASIVE GASTRECTOMY

Gastric cancer incidence is decreasing but is still fourth in the world ranking and accounts for 10% of the overall cancer deaths. There are wide geographic variations, not only in incidence but in their clinical features also. Fifty percent of world cases are diagnosed in Asia and it is the most common cancer in South Korea^[106]. In the western world there is a trend for tumors to be advanced at diagnosis, to locate more proximally, to be histologically diffuse, and the patients tend to be older - 10 years more on average, to have an increased body mass index and more comorbidities^[107]. Because of these differences, two classification systems have been developed - the Japanese Gastric Cancer Association (JGCA) and the Union for International Cancer Control (UICC/TNM)^[108,109]. Also, different concepts concerning the optimal surgery, the reconstruction type and the minimally invasive surgery implementation have arisen between the West and the East. Fortunately, unification of the classification systems and approximation of the lymphadenectomy extent have been achieved in the last decade. As a result, the D2 lymphadenectomy has been implemented in the West^[110,111] and in the East now is accepted that no more than a D2 lymphadenectomy is mandatory^[112].

The same as in other procedures, minimally invasive gastrectomy (MIG) in case of cancer could show some advantages. These techniques were pioneered by Kitano *et al.*^[113] in 1992 with a laparoscopic -assisted gastrectomy. Since then, the development has been determined, not only by the tumor features - location and stage, but also by the above mentioned differences between the West and the East. In general, the high incidence or early tumors in the East led to 7341 distal and 1103 total laparoscopic gastrectomies in 2009 in Japan, and 3783 laparoscopic procedures in South Korea, in contrast with 245 in Spain between 2005 and 2008 and 133 in the United Kingdom between 2011 and 2012^[114].

Laparoscopic distal gastrectomy

For tumors in early stage and distal location, literature is profuse in retrospective studies, case series and comparative studies but there are seldom randomized controlled trials (RCTs) comparing Laparoscopic distal gastrectomy (LDG) with open gastrectomy and they have a limited case number^[115-122]. Despite the limitations, LDG appears to have advantages over open gastrectomy in terms of postoperative pain, recovery of gastrointestinal and pulmonary function, hospital stay and return to normal activity. The complexity of a proper lymphadenectomy - especially if a D2 is mandatory, and the concerns about oncological safety has slowed down its generalization^[123].

Additional evidence has been provided by several

meta-analysis^[124-127], some of them with more than 3000 patients including advanced stages^[128-131] and the most recent with 2144 cases^[132]. All coincide in the LDG perioperative advantages - blood losses, overall morbidity, hospital stay - and that oncological results are not inferior to those of open surgery, although more operative time is spent.

Currently two multicentric phase III RCTs are ongoing, one from the Japan Clinical Oncology Group^[133] and another from the Korean Laparoendoscopic Gastrointestinal Surgery^[134]. The joined recruitment prevision is more than 2300 patients and the results are expected for 2015.

At the moment, and after the international expert group meeting, the LDG is accepted for distal tumors cT1-2 cN0 and the laparoscopic total gastrectomy (LTG) for proximal tumors cT1 cN0, although no consensus was achieved for other stages^[135].

Literature data concerning LDG in locally advanced tumors (stage II and III) are even scantier. Only two RCTs have compared MIG and open gastrectomy^[136,137]. Two meta-analysis, have been published: the first included 7 studies with 174 laparoscopic and 278 open gastrectomies^[138], and the second analyzed 10 studies with 495 laparoscopic and 544 open gastrectomies, both with D2 lymphadenectomy^[139]. Both coincide in that the minimally invasive approach in advanced gastric cancer is associated with a longer operative time, but less blood losses, pain, postoperative complications and hospital stay. Similar lymph node number and overall survival were found in the two approaches.

A recently published phase II prospective clinical trial with 157 patients concluded that laparoscopic gastrectomy with D2 lymphadenectomy for advanced gastric cancer is technically feasible and safe, with acceptable morbidity and mortality rates^[140].

More high quality RCTs comparing open and laparoscopic gastrectomy are needed, as well as multicentric studies. Even so, some aspects will probably not be able to be applied to the West due to the above mentioned clinical and histological differences.

Laparoscopic total gastrectomy

The Laparoscopic total gastrectomy (LTG) spreading has been slower worldwide, even in Korea and Japan, due to the need of an esophagogastric anastomosis, which is technically demanding, and because of the low incidence of the proximal gastric cancer in the East. The first relatively large series appeared in 2009, such as that of Shinohara *et al.*^[141] with 57 patients or the multicentric study from South Korea by Jeong *et al.*^[142] of 131 laparoscopic-assisted total gastrectomies. Both conclude that LTG is feasible and safe - morbidity of 31% and 19%, respectively with no mortality, it is possible to retrieve sufficient lymph nodes - 46 and 35, respectively - although with long operative times - 4.5 h on average.

In the West, the European pioneer groups in this field, such as Dulucq *et al.*^[143] or Huscher *et al.*^[144] published a series of only 8 and 11 LTG, respectively. In 2013, a specialized center, the MSKCC published a series of 17 cases^[145].

Three recent meta-analysis^[146-148] also suggest that, in skilled hands, LTG has better perioperative outcomes than the open procedure in terms of blood losses, pain, resumption of oral intake, hospital stay, with no inferiority concerning lymph node retrieved and survival. However, the operative times are longer.

A phase II multicentric prospective trial (KLASS-03) in patients with stage I gastric cancer is currently ongoing, with the aim of assessing perioperative morbidity and mortality of LTG by comparison with the open procedure^[149].

Robot-assisted gastrectomy

The main advantages of the robotic systems have already been discussed. In the case of gastric cancer, these potential advantages lie in a better precision for the lymphadenectomy and an improved skill for intracorporeal anastomosis^[150]. Hashizume *et al.*^[151] published the first Robot-assisted gastrectomy (RAG) in 2002, but because the procedure is technically complex and the equipment is expensive, the spreading has been slow. Several groups have compared the RAG with the laparoscopic and open techniques. The Yonsei University group published in 2009 the initial experience with 100 patients, extended to 236 cases more (73% subtotal and 27% total) in 2011 of RAG compared with 591 laparoscopic (81% subtotal and 19% total). They concluded that RAG seems to have better short-term results with comparable oncological outcomes^[152,153]. Other published series until 2012 support these conclusions, although the largest one reports less than 40 cases^[154,155]. The first meta-analysis, also from 2012, compared 268 RAG with 650 laparoscopic gastrectomies^[156]. Significant differences were not found in overall morbidity, hospital stay, or number of lymph nodes retrieved.

Interesting, to make the most of the benefits of the robotic assistance, the morbidity due to anastomotic leak must be minimal. A study analyzing postoperative complications in 5839 patients (4542 open, 861 laparoscopic and 436 robotic gastrectomies) concluded that, even in expert hands, minimally invasive techniques are associated with an increased risk of anastomotic leak by comparison with open gastrectomy, although the overall morbidity and mortality rates were similar^[157].

Since 2012, seven new meta-analysis have been published, analyzing between 404 and 762 RAG patients^[158-164]. All concluded that RAG was associated with lower blood loss and shorter hospital stay, with an adequate lymphadenectomy, by comparison with the laparoscopic and open gastrectomy, although with longer operative times.

More high quality studies are needed to clearly define the role of RAG.

MINIMALLY INVASIVE BARIATRIC SURGERY

Obesity is a world health problem of epidemic dimension in western countries^[165,166]. A WHO report estimates that more than 1600 million people are overweight and 400 million people have frank obesity^[167]. The increase in obesity prevalence is associated with a rise in the associated disease prevalence such as diabetes mellitus, hypertension, hyperlipidemia, obstructive sleep apnea, cardiovascular and pulmonary disorders, some tumors, osteoarticular disorders, and depression^[167,168]. Life expectancy of obese patient is approximately reduced by 12 years^[167]. Bariatric surgery has been shown to be the most effective treatment to achieve significant and sustained weight loss^[169-173] and also improves every cardiovascular risk factor, with the exception of the hypercholesterolemia^[174]. These comorbidities lead to an increased consumption of health resources, and as a result, to increased costs of obesity treatment.

The therapy of this disorder includes both medical and surgical treatment. The former is based on a multidisciplinary approach with the participation of endocrinologists, dieticians and psychologists. The aim is to achieve a change in the life style, promoting physical exercise and healthy nutritional habits with the support of multiple drugs of limited efficacy^[175,176]. The current surgical techniques can be divided into restrictive (adjustable gastric banding and sleeve gastrectomy), malabsorptive (biliopancreatic diversion) and mixed (gastric bypass)^[177,178]. Since 1993, these techniques are being increasingly performed laparoscopically with preference over the open approach^[179]. Laparoscopy in obesity surgery offers several advantages: less pain, lower frequency of wound infection and incisional hernia, less postoperative complications, shorter hospital stay, faster recovery and better cosmetic results^[180]. Several early studies on vertical banding gastroplasty^[181], adjusted gastric banding^[182], and Roux-en-Y gastric bypass^[183-186], support some of these advantages, although the mortality rate did not decrease, probably because of the limited number of cases in each series. Later, several reviews^[187,188], including the 2009 Cochrane study, compared laparoscopic and open surgery, but no statistically significant difference was found regarding mortality, morbidity, reoperations or weight loss.

Two reviews of observational studies conclude that the frequency of incisional hernia and wound infection are lower in laparoscopic surgery, although lacking a direct comparison with open procedures. The systematic review by Reoch *et al.*^[180] analyzed 6 randomized studies including 510 patients with a minimum follow-up of 12 mo. The risks of reoperation,

wound infection, incisional hernia, anastomotic leak and cause of death were studied. They found that in the laparoscopically treated patients a 75% and 89% decrease of wound infection and incisional hernia risk, respectively. The risk of reoperation, anastomotic leak, and death cause were, nevertheless, similar in the laparoscopic and open surgery groups. Another review of 361 studies including 85048 patients^[189] analyzed the 30 d mortality and found a 0.28% rate for biliopancreatic diversion and duodenal switch and 1% for revisional surgery.

The restrictive procedures are associated with lower mortality rates than the mixed techniques, and the malabsorptive procedures have the highest mortality. In the meta-analysis by Buchwald *et al.*^[189] a higher mortality is found in open surgery by comparison with the laparoscopic procedures, with the exception of BPD/DS. Higher complication rate has, however, been reported in laparoscopic cases^[190]. Flum *et al.*^[191] published a population-based study of Medicare beneficiaries and found a laparoscopic surgery mortality at 30 d, 90 d and 1 year of 2%, 2.8% and 4.6%, respectively as well as higher mortality for individuals older than 65 years.

Morino *et al.*^[192] studied the mortality risk factors of several bariatric procedures, such as gastric bypass, banding gastroplasty, adjusted gastric banding, biliopancreatic diversion, biliointestinal diversion and other procedures in a 13871 patient retrospective analysis. They concluded that the laparoscopic approach significantly reduces the mortality risk, and the surgical technique, the open approach, a prolonged operative time, associated comorbidities and the surgeon experience increased the risk.

Mortality associated to laparoscopic bariatric procedures has been shown to be lower in centres with more than 100 cases per year (0.3%) than in those with less than 100 (1.2%)^[193].

In summary, the laparoscopic approach significantly reduces the overall mortality risk, since the hazard of thromboembolism as well as other complications decreases by comparison with open surgery. However the evidence level of long term outcomes of most review studies are low since many patients are lost to follow-up in many series.

Robot-assisted bariatric surgery

Robot-assisted bariatric surgery (RABS) has been used since 1998, when a gastric band was put from the distance^[194], and shows some advantages over the laparoscopic techniques, which have some limitations related with a poor ergonomics due to a limited instrument mobility due to the abdominal wall width, and hepatomegaly. RABS suppresses the position port limitation as well as the physiological tremor and confers a better ergonomics^[195]. The three dimensional view allows a more precise dissection^[196] and a decrease in blood loss. A shorter learning curve

by comparison with conventional laparoscopy has been claimed^[197].

Several studies report that RABS is safe with lower complications than the laparoscopic techniques. Edelson *et al.*^[198] compared 287 robotic and 120 laparoscopic gastric banding cases, and they did not find any significant difference in intraoperative or postoperative complications, hospital stay or operative time; the time was, however, significantly lower in patients with a BMI > 50 kg/m² operated on through a robotic approach (91 min vs 103 min). Fourman *et al.*^[199] reported similar findings in a literature review of RABS which included gastric banding.

The gastric bypass has been used since 2000, with satisfactory outcomes^[200]. Lower complication rates than those of the laparoscopic approach, without mortality or anastomotic leaks have been published^[199,201-205]. Others also report significantly less anastomotic failures with RABS^[206]. Skilled teams have achieved similar operative times and even shorter^[199,206,207], with comparable long-term results concerning weight loss and comorbidity improvement.

In a review of 1686 patients comparing laparoscopic and robotic bypass, similar results were found regarding anastomotic leaks, postoperative complications, operative time and hospital stay^[208]. However, an advantage was found in a decrease of the anastomosis stenosis rate at 6 mo. Most groups coincide in that anastomosis leak is lower with RABS, although without reaching statistical significance.

The vertical gastrectomy or sleeve gastrectomy (SG) has become in one of the most popular bariatric procedures due to its effectiveness in reducing weight. Overweight losses as high as 61% after 24 mo have been reported^[209], as well as comorbidity improvement such as diabetes resolution in 47%-66%^[210,211]. Other advantage are the lower operative time needed, the shorter hospital stay and the lower frequency of complications, by comparison with the laparoscopic GB. Since the use of robotic surgery has been limited to the most complex procedures - revisional surgery and gastric bypass, there are only a few studies on SG^[199,211-217] which do not show any significant difference concerning complication frequency - stenosis, bleeding-, mortality or hospital stay. One study reports a lower fistula frequency and a shorter stay in the robotic cases, but without statistical significance^[218]. This technique, when performed with robot assistance, is associated with longer operative times and is more expensive, and thus is controversial its generalized use. However, it is proposed as a way to learn robotic skills before performing the gastric bypass.

The Scopinaro biliopancreatic diversion (BPD) and the biliopancreatic bypass with duodenal switch (DS) are more effective than the gastric bypass in achieving weight loss and improvement of obesity associated comorbidities^[219,220] but due to their complexity, higher complication rates and the need of nutritional control,

are the least used. The first results of these procedures performed through a laparoscopic approach were published by Ren *et al.*^[221] in 2000, with a 2.5% mortality. In a systematic review, a 30-d mortality of 0.1% for restrictive procedures, 0.5% for gastric bypass and 1.1% for BPB/DS were reported. Sudan *et al.*^[222] reported a series of 59 robotic BPB/DS without mortality, anastomotic leaks, bleeding, sepsis or pulmonary thromboembolism.

The main criticism to RABS is its high cost, as well as the longer operative time, especially because of the preoperative docking time needed. This however, can be minimized with increasing experience of the surgical team.

LIVER SURGERY

Nowadays, laparoscopic resection is increasingly being performed for both benign and malignant liver lesions. This review will focus on the latter.

There are several options to perform a laparoscopic liver resection (LLR): totally laparoscopic, hand-assisted and hybrid resection. In the latter, the liver is mobilized laparoscopically, with the hilar dissection and parenchymal division performed through an abdominal incision, usually epigastric as described by Koffron *et al.*^[223]. Hand-assisted laparoscopy and the hybrid technique have been recommended as a bridge to the totally laparoscopic technique as the first steps of surgeons not familiar with complex laparoscopic procedures^[224]. There is not sufficient data supporting the superiority of any technique over the other in terms of operative time, blood losses or complication rates^[225].

Every type of liver resection has been performed: from non-anatomic resection to segmentectomy or right lobectomy, removing from one tumor node to multiple nodes^[226]. Pedicle control can be done, the same as in open surgery, in order to minimize bleeding.

Laparoscopic liver surgery is associated with some potential benefits by comparison with the open technique. There is a better view due to magnification and favorable vision angles. This is the case of the adrenal glands and the area around the inferior vena cava, since these structures are located on the dorsal side of the liver and are best seen by a laparoscope inserted through the umbilicus^[227]. There is also less bleeding with less transfusion needs, as most papers show^[226], explained in part by the laparoscopic magnification, and decreased venous oozing from the cut surface under pneumoperitoneum^[227]. Another explanation is a longer portal clamping time by comparison with open surgery, as reported in some works^[228], although this is not seen in others^[226]. The lower analgesia requirements are due to less postoperative pain^[228]. A lower frequency of postoperative complications has been claimed; several papers have reported a trend to decreased complications

rates, although without significant differences^[229-232]. Particularly, a lower overall incidence of pulmonary complications has been reported^[233]. A recent published metaanalysis reports a significant decrease in the complication rate of laparoscopic cases^[226], but other studies find similar complications in laparoscopic and open groups^[228]. Other advantages are shorter in-hospital stays - due to less pain and less complications-, better cosmetic results. Lower frequency of incisional hernia. Further resections, if necessary, or even salvage transplantation in the case of hepatocellular carcinoma (HCC) are probably easier and this could increase the re-resection rates. All of this without compromising the oncologic aims as free borders (R0 resection)^[228]. Increased liver regeneration has been reported in living donor patients operated by laparoscopy by comparison with open procedures^[234]. Although the reason is unclear and these findings have to be confirmed, the diminished acute-phase stress response and improved immune system function reported after laparoscopic surgery could explain this in part.

There are however some concerns regarding the laparoscopic technique. The first is the problem of venous gas embolism^[230]. Since the pneumoperitoneum rises intrabdominal pressure, an increased risk of CO₂ embolism is possible, although because of its greater solubility than nitrogen, it is much safer. Also, the use of argon beam coagulation could increase the risk of argon gas embolism. As a result, some authors recommend its avoidance or extremely cautious use^[224], only over minor bleeding points and opening one port to allow venting excessive gas pressure. Concerns also remain regarding the oncologic adequacy of LLR compared with open liver resection as well as failure to detect occult lesions, which is especially important in the case of metastases. This will be discussed later. There is a potential risk of tumor dissemination (port metastasis, peritoneal carcinomatosis). In case of major bleeding, the restriction on movements make the suture difficult^[227], leading to important risks. On the other hand, laparoscopic procedures might result in additional hospital costs due to the need for laparoscopic instrumentation, and possibly longer operative times. However, these costs can be offset by shorter lengths of stay. Estimates of costs in some centers find that the laparoscopic approach is not associated with higher costs^[230].

The advent of minimally invasive liver surgery could result in overuse of these procedures. Some authors have stated with caution that laparoscopic procedures could lead to their use in cases where surgery is not indicated and therefore that laparoscopic procedures should only be used when an open procedure is clearly indicated. However, some authors argue that in some cases, especially when faced with diagnostic and therapeutic dilemmas, laparoscopic procedures might be considered instead of conservative nonsurgical

management^[231].

Most published papers report case series of laparoscopic resections, usually comprising a small number of patients. To date there are no published randomized clinical trials. In addition, few works have reported comparisons with open resection. This is probably due to the difficulty of putting together a team skilled in both advanced laparoscopic and open hepatic surgery.

Conversion rates are variable. The reasons are oncological, bleeding, strong adhesions due to previous surgery and no progression for anatomical reasons.

Transection methods are variable but any energy device or staplers can be used. For deeper transection, an ultrasonic aspirator (CUSA or equivalent) or the clamp-crushing technique can be used^[224].

Indications for LLR are the same as those of open surgery: large and symptomatic benign lesions, diagnostic concerns and, especially malignant tumors. The latter comprise any type of malignancy, but most frequently, colo-rectal metastases, HCC and cholangiocarcinoma. Our discussion will be focused on the malignant lesions.

Recently, the Second International Consensus Conference published their recommendations for LLR. They found these were not inferior to open resection in mortality, postoperative complications, margin negativity, overall survival, and costs. Laparoscopy was superior in length of stay. Also, technical recommendations were provided. They state that minor LLR (less than 3 segments) is "confirmed to be a standard practice in surgery but is still in an assessment phase". They also state that "major LLR is an innovative procedure and is still in an exploration or learning phase and has incompletely defined risks"^[224].

LIVER METASTASES

When several years ago laparoscopic LLR began, some concerns regarding liver metastasis resections arose: will free margins can be achieved? Will small metastases be found^[235]? No trials comparing open and laparoscopic metastasis resection were available in 2009 when the few available studies reported an 80%-87% 3-year overall survival^[235]. Nowadays we have some studies which allow comparing several aspects of open and laparoscopic surgery.

As mentioned above for liver resections in general, most published papers concerning metastasis reports a negligible or nihil mortality with a trend to a lower complication rate in laparoscopic series^[226,232], although this is not seen in other works^[229,236]. Also, the bleeding and transfusion needs are significantly lower than in open surgery^[226,229,237-239].

The mean operation time ranges from 180 to 377 min - depending on the resection extent - which is similar to the time spent in open resections^[226,229,237-239].

The length of stay ranges from 3.7 to 7.3 d^[226,229,237-239]

and 18.3 in a study from Japan^[230] but is significantly shorter in laparoscopic resections in all of them.

Concerning oncologic outcomes, the papers report R0 resection rates ranging 82.7%-100%, not different from those obtained in open resections^[226,229,232]. The long-term outcomes - overall and disease-free survival - are also similar. The 5-year overall survival rate found in the metaanalysis by Schiffman *et al*^[226] is 51.4%, although rates as high as 76% have been reported^[226]. In addition, non-significant differences have been found when compared with survival after open procedures^[226,229,232,237]. Importantly, no significant difference between laparoscopic and open resections disease-free survival has been found^[226,237], reflecting that no missed metastasis was left behind after laparoscopic procedures.

HCC

Resection is the usual therapy for HCC in non-cirrhotic patients. However, most cases in the western world arise in cirrhotic patients. This implies to deal with a liver with some functional impairment as well as more fibrotic tissues. Current guidelines recommend resection only in solitary tumors when portal hypertension has been excluded and serum bilirubin is normal^[240]. Although the best candidates are those patients with tumors up to 5 cm of diameter, resection in bigger tumors is also acceptable^[240]. Anatomic resections are recommended because of its better survival rate than wedge resections^[230,240].

In 2007 some benefits - reduced blood losses and morbidity in cirrhotic patients as compared with open resections, especially with lower frequency of postoperative ascites - were already recognized for the laparoscopic approach^[241]. The possible benefits of laparoscopy in cirrhotic patients can be due to preservation of the abdominal wall and round ligament, which avoids interruption of collateral circulation and, therefore, preventing a rise in portal pressure; less mobilization and manipulation of the liver which reduces liver trauma; avoidance of exposure of the abdominal viscera, which allows to restrict fluid requirements and decreases electrolytic and protein losses; and by reduction of intraoperative blood losses.

A recent metaanalysis of studies dealing with HCC in both cirrhotic and non-cirrhotic patients found lower rates of bleeding and transfusion requirements in laparoscopic resections, by comparison with open procedures^[242]. There were no significant differences in operation time. Concerning complications, lower rates of postoperative ascites and liver insufficiency were found. However, the frequency of other complications such as bile leakage, postoperative bleeding, intra-abdominal abscess, and mortality was similar^[242,243]. These results ought to be interpreted cautiously since not all the analyzed patients were cirrhotic. The length of hospital stay appeared to be similar after both approaches^[242].

Concerning oncologic results, significant differences in free margin rates have not been found^[242], although in a non-randomized study it was significantly higher in LLR than in open surgery^[244]. Both overall and disease-free survival have been shown to be similar in cirrhotic patients^[242-244]. Also, tumor recurrence seemed similar^[242-244].

As a result, LLR for hepatocellular carcinoma appears feasible and safe both in cirrhotic and non-cirrhotic patients, provided the functional status of the latter is acceptable. Also, oncologic long-term results are not inferior to those of open surgery.

CHOLANGIOMYOCARCINOMA

Laparoscopy can be used in cholangiocarcinoma both for staging work-up and for therapy.

Cholangiocarcinoma (CC) has considerable rates of unresectability due to the common invasion of vessels, secondary and tertiary biliary duct divisions, presence of distant lymph node metastases and peritoneal metastases. Staging laparoscopy (SL), often combined with ultrasound, detects many of this settings, therefore avoiding unnecessary laparotomies and has been used with staging purposes for many years. The usefulness appears to have decreased considering reports from 2002 and from 2011, showing a drop both in efficacy (41.8% to 14%) and accuracy (72% to 32%)^[245]. This decrease can be explained by the continuous improvement in imaging techniques which detect today minimal disease. As a result, today the most extended opinion is that SL only is indicated in case of concerns of unresectable disease on imaging techniques or in patients with high risk of holding it, as T2/T3 cases of the Jamagin-Blumgart staging system are^[246].

On the other hand, experience with laparoscopic treatment of CC is short, with most papers reporting only a few cases of laparoscopic^[247,248] or robot-assisted laparoscopic treatment^[249]. Two case series report 14 cases each. Yu *et al*^[250] treated 8 Bismuth I tumors by local excision and 6 Bismuth II cases by partial hepatectomy. The R0 resection rate was 100% in the former but only 60% in the latter. Importantly, they do not perform caudate lobe excision. Overall, there was no mortality and there was 35.7% of biliary fistula. They report two tumor recurrences. Gumbs *et al*^[251] report a multicenter experience of 9 intrahepatic and 5 perihilar CC. The former were treated by partial hepatectomy as well as 3 of the perihilar tumors, with a conversion rates of 11% and 20%, respectively. No caudate lobe resection was carried out. The R0 resection rate was 77.7% in the intrahepatic and 80% in the perihilar CC. In the intrahepatic CC the mortality and morbidity rates were 11% and 33%, respectively, whereas in the perihilar CC there was no mortality or complications. The survival rates were 66.6% at 22 mo in the intrahepatic and 100% at 10 mo in the perihilar CC.

Concerning robot-assisted surgery, there is an anecdotal published case of hilar CC treated by extended right hepatectomy and bile duct excision^[249]. They had free margins with no complications.

This scanty experience allow us to conclude that laparoscopic treatment of CC is feasible and that the rates of mortality, morbidity and survival are comparable to the open surgical procedures.

In the absence or randomized control trials is difficult to reach any conclusion concerning superiority of laparoscopic over open resection. For the moment, only clinical data mainly coming from case series performed in highly specialized centers show comparable oncological results and some advantages in hospital stay.

LIVING-DONOR LIVER TRANSPLANT

Right lobe living donor liver transplantation is the usual way of adult-to-adult live liver transplantation. Laparoscopic approach for liver procurement has been used in a few reports. The procedure has been performed as totally laparoscopic right or left hepatectomy^[252-257] and laparoscopically assisted using a hand port system^[256,257]. Also, the hybrid technique has been performed^[256] because some authors claim a shortening in the prolonged operative times of the procedure with this technique^[256]. The reported donor outcomes were satisfactory with low complication rates -most of them minor- and without mortality^[252-257].

Some studies have compared the laparoscopic and open techniques. Baker *et al.*^[234] studied donor right hepatectomies and found in the donor similar rates of complications, estimated blood losses, and hospital stays, as well as shorter operative times and higher liver regeneration volumes in the laparoscopic group. Kim *et al.*^[258] studied left lateral sectionectomies and found a significantly shorter hospital stay and time to oral diet in the laparoscopic group. Duration of operation, blood loss, warm ischemia time and complications were comparable, with no deaths in any group.

In summary, every liver resection procedure seems safely feasible through a laparoscopic approach provided the surgeon has proper training in both complex laparoscopic and liver procedures. The learning curve for this training has been estimated in 60 cases^[259]. Short and long-term results for metastases and hepatocellular carcinoma are as good as in open procedures, with shorter in-hospital stay and a trend for less complications and intraoperative bleeding. The Second International Consensus Conference considers that there are insufficient evidence from few centers to give any recommendation^[224].

ROBOTIC HEPATECTOMY

Theoretical advantages of robotic over laparoscopic hepatectomy are increased freedom degrees of the

instrument movements, abolition of the physiologic hand tremor and 3-dimensional view. Also easier suture ligation for vessel control rather than stapling has been claimed as well as easier retrohepatic dissection thus facilitating access to the hepatic veins^[260,261]. Intracorporeal suturing and tying in difficult locations can also be facilitated by the robotic technology.

Among the disadvantages of robotic hepatectomy are the longer times required to dock the robot, to exchange instruments, and to reposition or redock the instruments if the viewing field has to be changed. Also, the lack of tactile sensation when suturing and knot tying might lead to injury due to uncontrolled tissue overstretching or suture disruption^[262].

Although the published experience on robotic hepatectomy is scanty, Ho *et al.*^[262] published a systematic review in 2013 comprising data of more than 200 patients. The procedures performed included wedge resection, segmentectomy, right and left hepatectomy and left lateral segmentectomy for both benign and malignant diseases. A right live donor hepatectomy was also done. The conversion rate was 4.6%. Mean operation time was variable, ranging 200 to 507 min. The morbidity rate was 20.3%, with bile collections and abdominal abscess being the most frequent complications. No mortality has been reported. It can be concluded that robotic liver resection is safe and feasible when performed by experienced surgeons.

Because of the relatively short follow-up, results concerning cancer-specific survival are scanty and most papers only report some recurrence cases. As a result it is too early to draw any conclusion concerning oncological results.

Some studies comparing robotic vs laparoscopic hepatectomy in both benign and malignant lesions have been published.

Ji *et al.*^[261] showed that robotic hepatectomy is safe and feasible, with slightly lower complication and conversion rates than traditional laparoscopic and open resections. However, longer operative times and hospital stays were found by comparison with laparoscopic procedures, as well as increased costs. On the other hand, Berber *et al.*^[263] did not find significant differences in operative time in a comparison between a small series of robotic and laparoscopic resections.

Tsung *et al.*^[260] recently reported 51 robotic resections. Importantly, liver mobilization and adhesiolysis were carried out by conventional laparoscopy prior to robotic docking for transection. When compared with matched laparoscopic resections, no significant differences in blood losses, postoperative complication rates, mortality rates, postoperative intensive care unit admission rate, length of stay or margin involvement were found. Robotic resections used up more operation room time, although leading to less conversions than laparoscopic resections did.

In summary, although robotic liver resection is feasible in skilled hands, experience is very short. Indeed, the Second International Consensus Conference considers that there is insufficient data for evaluation^[224].

PANCREATIC SURGERY

Different types of laparoscopic pancreatic resection are performed: tumor enucleation, distal pancreatectomy, central pancreatectomy, pancreatico-duodenectomy and total pancreatectomy, although the latter is anecdotal. These techniques have been used for both benign (chronic pancreatitis, cystic tumors) and malignant diseases.

Tumor enucleation

Although in general formal pancreatic resection is recommended for most tumors, enucleation can be performed for neuroendocrine neoplasms if tumor size does not exceed 2 cm and if no findings of malignancy are detected on preoperative staging^[264]. Pancreatic tumor enucleation can be easily performed by laparoscopy with excellent morbidity and mortality outcomes^[265].

Distal pancreatectomy (pancreatic left resection)

This is the most frequently performed type of laparoscopic pancreatectomy for both benign and malignant diseases^[266,267].

Distal pancreatectomy can be accomplished with or without splenic preservation. Splenectomy could adversely influence oncologic long-term outcomes, in addition to predispose to infectious complications. As a result, efforts to preserve the spleen should be done in case of benign or low grade malignancies, provided that splenic vessels are not involved with the tumor. More controversial is splenic preservation in case of adenocarcinoma. Whatever the case, if the spleen is to be preserved, two techniques are used^[264,268]: in the first, section of the splenic vessels both at the level of transection of the pancreas and at the splenic hilum is performed, leaving the short gastric vessels as the only blood flow supply. In the second technique, the splenic vessels are preserved by meticulous ligation of all the branches reaching the pancreas. However, patency of splenic vein - although not that of the artery - can be compromised after a laparoscopic DP in as high as 35%^[269]. The frequency of splenic infarction and appearance of gastric varices is higher in case of splenic vessel section^[268].

Blood losses have been reported to be significantly lower in case of a laparoscopic approach by comparison with open procedures^[270-273]. Localizing small tumors by laparoscopy or laparoscopic ultrasonography can be difficult and this leads to conversion in many cases. Other causes of conversion can be bleeding or difficult structure identification which lead to conversion in

17%-30% of cases^[270-272]. Obesity is significantly associated to conversion^[271].

The complication rate has been reported significantly lower in laparoscopic cases^[271,274], although the severity grade was similar than in open procedures^[263]. Other papers showed similar rates^[272,273]. Tran Cao *et al*^[267] studied a nationwide database and compared the short-term outcomes of 382 minimally invasive distal pancreatectomy (mainly laparoscopic and some robotic) with those of open distal pancreatectomy. They found a significant reduction in overall perioperative morbidity among patients undergoing minimally invasive surgery, including a significant decrease in hemorrhagic complications and postoperative infections in laparoscopically treated patients. Results of five meta-analyses^[266] support these findings concerning overall perioperative morbidity, although clinically relevant pancreatic fistula frequency was significantly lower in laparoscopic cases only in one of the analyzed studies.

Patients converted from laparoscopic to open surgery have significantly more severe complications than those with not converted^[271] which reflects the need of proper selection for a laparoscopic approach. The reported mortality ranges 0%-1%^[267,271,273].

Some have reported operation times significantly longer in laparoscopic than in open procedures^[271], but others find similar duration^[273].

The hospital stay has also been reported to be significantly lower with a laparoscopic approach^[27,270,271,273].

A recently published meta-analyses^[275], comprising data of 3701 patients, all of them from non-randomized studies, confirmed most of the above mentioned findings: superiority of laparoscopic over open DP in terms of blood loss, time to first oral intake, and hospital stay. Mean operation time, mortality -0.4% in DP-morbidity and safety showed no difference. However, data concerning oncologic radicality and effectiveness are limited.

Distal pancreatectomy for adenocarcinoma

Most articles report a mixture of benign and malignant diseases as indication of distal pancreatectomy (DP). As a result, to reach conclusions concerning safety and oncological outcomes when dealing with adenocarcinomas is difficult. A few papers compare open and laparoscopic approaches only in case of pancreatic adenocarcinoma. Kooby *et al*^[270] performed a multicenter matched analysis of 23 laparoscopic procedures compared with 189 open procedures and found no significant differences in positive margin rates, number of nodes examined or overall survival. The median follow-up was only 10 mo and, thus, it is premature to conclude that the long-term results are as safe as in open procedures. Magge *et al*^[272] compared 28 patients with 34 operated on by an open approach. They found not significant differences in margin-negative resection (open, 88%; laparoscopic,

86%) and median lymph node clearance. Also, no significant differences were found for overall survival or risk of local recurrence.

Distal pancreatectomy for neuroendocrine tumors:

A recent paper compared laparoscopic an open DP performed for neuroendocrine tumors^[274]. The laparoscopic procedure showed no mortality, a significant lower complication rate and shorter hospital stay. No significant difference was found concerning margin involvement, long-term survival, and overall costs.

In summary, DP is feasible, safe and reproducible for most laparoscopy skilled surgeons. Concerning its use in case of adenocarcinoma, it also appears as safe as open DP but more studies analyzing long-term results are needed.

Robotic distal pancreatectomy

Theoretical advantages and disadvantages of robotic surgery have been discussed earlier. The published papers dealing with robotic DP are still scanty.

Zureikat *et al.*^[276] report 83 robotic DP with no mortality and a low rate of severe complications, although with 43% cases of pancreatic fistula. The average operative time was 256 min and 2% required conversion.

Waters *et al.*^[277] compared 17 robotic against 32 open and 28 laparoscopic DP. Cystic tumors predominated among the indications of robotic resection. In this group, longer operative times, similar blood losses, no mortality, shorter hospital stay and lower hospital costs were found. Higher rates of splenic preservation were achieved in comparison with the open and laparoscopic approaches. Daouadi *et al.*^[278] compared 30 robotic DP and 94 laparoscopic DP patients. The robotic DP group included more adenocarcinomas. Significant differences in blood loss, hospital stay, or morbidity were not found. However, there was a statistically significant 36% increase in R0 resection with robotic surgery, as well as more lymph nodes harvested. Also the conversion rate was lower.

The study by Kang *et al.*^[279] included 20 robotic and 25 laparoscopic DP for benign and borderline malignant lesions. Although the intent was to preserve the spleen, the overall rate of splenic preservation was very low. A higher splenic preservation rate was achieved with the robotic approach. This took longer operative times and had increased costs compared to laparoscopic cases.

In summary, although feasible and safe, robotic DP has not yet shown clear advantages over laparoscopic DP.

Central pancreatectomy

This technique can be applied for the treatment of benign or borderline lesions of the pancreas situated in the pancreas neck. Although uncommonly performed,

this technique is feasible by laparoscopy^[265-280].

A review from 2013^[281] collected 51 published cases operated on through total laparoscopy or robotic assistance. Pancreatic reconstruction was done with a Roux-en-Y pancreato-jejunostomy, or pancreato-gastrostomy. The procedure was long with a mean time of 356 min. Blood loss was minimal in most cases. Mortality was nil, but morbidity was high, mainly due to pancreatic fistula (46%).

When performed by a robotic approach, the procedure is associated with long operative times (mean: 394 min) and a 23% of severe complications, although without mortality^[276].

Pancreaticoduodenectomy

Three techniques are currently employed for LPD: pure laparoscopy (PL), hand-assisted (HA) laparoscopy, and laparoscopic-assisted (LA) surgery. In contrast with DP, where only resection is to be performed, the pancreaticoduodenectomy (PD) requires a complex resection as well as pancreato-jejunal, hepato-jejunal and gastro-jejunal anastomoses. As a result, although feasible, the difficulty of the procedure makes that experience with laparoscopic pancreaticoduodenectomy is limited to a few case series.

Gumbs *et al.*^[282] analyzed most reported cases until 2011 comprising 285 patients, although only 32% had pancreatic adenocarcinoma. The most important findings for the entire cohort were a 9% conversion rate, 2% mortality, 48% morbidity and a length of stay of 12 d. Margin involvement was found in 0.4% with an average of retrieved lymph nodes of 15. The mean disadvantage was a long operation time ranging from 263 to 750 min.

Direct comparison between laparoscopic and open PD has been performed by some groups. The first^[273], which included 60% of patients with malignant tumors - pancreatic, biliary, ampullary - found significantly lower blood losses, and hospital stay as well as more lymph node harvested in the laparoscopic group. However, the average operative time was significantly increased. There were no differences in overall complications, pancreatic fistula, delayed gastric emptying, and resection margin involvement. The main finding of the second study^[283] was a significant reduction in blood losses and, thus, the transfusion need in the laparoscopic patients although it did not show relevant differences in morbidity.

Asbun and Stauffer^[284] compared 53 laparoscopic and 215 open PD. They found significant differences favoring laparoscopic PD blood losses, transfusions, length of hospital stay, length of ICU stay ($P < 0.001$), and number of lymph nodes retrieved although the operative time was significantly longer. The rates of overall complications, pancreas fistula, delayed gastric emptying, margin involvement were not significantly different.

Kuroki *et al.*^[283] compared 20 laparoscopic and 31

open PD. They also report a significant reduction of blood losses and transfusion need but they did not find significant differences in morbidity.

Song *et al.*^[285] report a comparison between 137 laparoscopic and 2055 open pylorus-preserving PD for periampullary tumors. A shorter hospital stay and a lower analgesic consumption was seen in the laparoscopic cases. No other difference was found including complications, blood losses margin involvement or lymph nodes retrieved.

In a recent systematic review of several series^[286], the operative time averaged 464.3 min (338-710 min) with conversion in 9.1% of patients. The mean estimated blood loss was 575 mL. Average mortality was 1.9% and morbidity ranged between 18.1% and 64.2%, with pancreatic fistula ranging between 4.5% and 52.3% of patients. An average of 14.4 lymph nodes were retrieved and 4.4% of cases had marginal involvement.

In summary, laparoscopic PD is feasible and as safe as the open procedure in highly skilled hands and high-volume centers. Long operative times are needed. Decreased blood losses seem to be the main advantage. Concerning its use in case of adenocarcinoma, more studies are needed.

Robotic PD

Published experiences concerning robotic PD are even less common. Zureikat *et al.*^[276] report 132 cases with a 90 d mortality rate of 3.8% and a frequency of severe complications (III-IV) of 21%. The frequency of pancreatic fistula was 17%, although only 3.7% were of grade C. Conversion was needed in 8%. The procedure took long operative times (mean 527 min), and although decreased with improved experience, the last cases of the series lasted over 400 min.

In the systematic review by Boggi *et al.*^[286], the robotic PD used up more operative time and had higher pancreatic fistula rate by comparison with pure laparoscopic PD (but not laparoscopically assisted PD). However, significant differences were not found concerning overall morbidity or mortality (2.7%, 1.1%, and 2.4% for pure laparoscopic, laparoscopically assisted, and robotic PD, respectively).

Another systematic review analyzed several non-randomized studies comparing open and robotic pancreatectomies, most of them PD^[287]. It included 137 cases of robotic PD and 203 open PD. The median conversion rate was 10%. Overall complications, reoperation rate, and margin involvement were significantly lower in robotic group, with no significant difference in postoperative pancreatic fistula, and mortality. In one study included in this review^[288] involving only PD, a significant increase in the R0 resection rate, with 100 % of patients in the robotic group compared with 87% in the open group.

A recently published paper^[289] comparing robotic and open PD, report similar findings such as lower

blood losses, shorter hospital stay, longer operative times with no significant difference in morbidity, mortality, as well as R0 resection rate and number of lymph nodes retrieved in case of malignancy. Patients with pancreatic adenocarcinoma of both groups had similar overall and disease-free survival.

In summary, the same as laparoscopic PD, robotic PD is feasible in highly skilled hands and high-volume centers. Although the very short published experience makes to reach firm conclusions difficult, it suggests that robotic PD is as safe as laparoscopic PD with some advantages over open PD. However, the former is more time-consuming.

TRAINING IN LAPAROSCOPIC SURGERY

In 1889 Halsted established at the Johns Hopkins Hospital the need of a new training system in surgery. Nowadays, it is rewarding to see how surgeons can be proficient in several techniques when they repeat them in a simulator^[290].

Today, traditional methods are not enough to teach and learn surgical skills because of the reductions in training hours during the residency programs and the lack of time of the surgeons to adequately teach these techniques. On the other hand, laparoscopic surgery learning curve and the risk of severe complications when inexperienced surgeons perform these procedures, make it more difficult for residents to learn minimally invasive techniques.

Costs per procedure have increased with minimally invasive procedures and technology is making the surgical environment more complex. A surgeon does not learn alone anymore, and they depend on a complex team that has to be trained and work together. As a result, surgical training models are evolving to serve as a complement to the standard surgical training in the theatre^[291].

Current situation of surgical residents training

With the arrival of laparoscopic surgery to the surgical departments in the 90s, the surgical resident training has suffered a huge transformation with a decrease in its autonomy. This has resulted in the need of additional training to obtain the confidence and maturity of judgment. As a result, the number of fellowships has dramatically increased during the last ten years. This change has enlarged the surgical training^[290].

Laparoscopic surgery training programs have evolved in several ways in the different countries. Sweden or The Netherlands have national programs limited to basic procedures (cholecystectomy) using training techniques as virtual reality^[292]. In the United States and Canada, the surgical training method is structured and the program of the American College of Surgeons (ACS) demands the inclusion of basic training in the Fundamentals of Laparoscopic Surgery

(FLS) in the residency programs^[293]. Spain has a limited training of two 3-d courses for the residents, one basic and another for advanced training^[294]. In Latin America, the project of Laparoscopia Avanzada Práctica (LAP), pretends to bring near a big number of countries to basic programs in laparoscopic training^[295].

How does the resident get trained in laparoscopic surgery? The curricular model

One of the most important aspects of the residency program is that training has to be based in a curricular model. Based on the premises that experts indicate^[296], these curricula have to be: (1) Endorsed by an accredited training institution (ACS) with a clear message regarding how this surgical training will be; (2) If simulation is used as a training tool, this demands a new and different approach of the instructors; (3) Training has to be integrated with clinical practice; (4) Adequate simulators have to be used in the correct timing and they should be validated for training; (5) The features and different types of surgical simulators are continuously changing. This has to be taken into account in order to plan the update of these simulators; (6) Residents must have reserved time to use simulators in their training; and (7) Financing has to be sustainable using business principles.

How do surgical simulators contribute to laparoscopic training?

Virtual reality (VR) simulators provide surgical training without supervision in a safe environment for both patient and trainees. Skills obtained in the VR simulator can be transferred to the theatre. However, evidence is only limited to basic surgical skills and laparoscopic cholecystectomy. There is no evidence yet of the effect of VR simulators on advanced laparoscopic procedures^[297]. The introduction of haptic feedback in these VR simulators has not increased the validation of laparoscopic surgical competences^[298]. In summary, all the trails that compare the training using VR simulators and standard laparoscopic training in the theatre observe a higher performance after training with VR, confirming that current training using structured simulation is more efficient than traditional training^[291]. Supported by these findings, countries such as Sweden or The Netherlands have established a structured training for laparoscopic cholecystectomy based in the use of VR simulators. This has allowed these countries validate resident competency before being trained in the theatre^[299,300].

Animal models for resident training in advanced laparoscopic techniques (Nissen, Colectomy) are the more realistic models, but they are limited in some countries because of religious beliefs or laws. All these reasons are behind the substitution of these animals by synthetic models or even by simulated models with

“*ex vivo*” viscera^[301]. Without any doubt, the animal model most frequently used is the porcine model, mainly in colorectal surgery training^[302]. Despite this, it is not possible to define nowadays when competency is reached with an animal model, if this model is the best one for laparoscopic training and if what is learned in this model is translated into clinical practice.

There are few studies about the use of cadaveric human models^[303]. These models have been used for training in laparoscopic skills, such as cholecystectomy, and have demonstrated the increase of capacitation by comparison with VR simulators. We believe that this model has to be reserved for advanced laparoscopic procedures (colorectal or bariatric surgery) that require a huge degree of realism. Leblanc *et al*^[304] assessed the use of fresh human cadavers for surgical training in laparoscopic sigmoidectomy. They observed that the use of this model improved clinical practice in terms of dissection, traction/counter traction, eye-hand coordination, suture, bleeding control and theatre time comparing with the use of a VR simulator. Palter *et al*^[305] studied the sequencing of VR simulators with human cadaver models for training in colorectal laparoscopic surgery. He added a cognitive module in order to help the participants to understand the procedure and how to plan and execute a right colectomy or a sigmoidectomy. He observed that this training approach improved the technical knowledge and the performance in the theatre in comparison with the traditional training during the residency program.

Hybrid models are those that use a complex robotized mannequin together with the abdomen/thorax of a live animal. These models allow us a high laparoscopic realism simulation while we adjust the cardiologic/respiratory parameters of the robotized mannequin. This way we are able to simulate for example a coronary event during the simulated laparoscopic procedure.

In other opportunities^[306], scenarios can be created to train the laparoscopic surgery team in a simulated theatre with a hybrid patient (SimMan 3G; Laerdal) and a laparoscopic VR simulator (Lap Mentor Express, Symbionix). These authors observed that the global assessment of the team showed a high qualification. Powers *et al*^[307] observed that these simulation models let us discriminate between the technical and non-technical abilities in residents and experienced surgeons. The target of this innovative multidisciplinary simulation is to identify the problem and to start with the adequate solution by the surgical team.

Zendejas *et al*^[308] observed in a recent review that whenever simulator is used, it has huge advantages in laparoscopic or open surgery training comparing with no simulator use. These authors also observed that adding the use of simulators to the traditional training is more effective than the use of traditional training

alone.

Our model for laparoscopic surgery training for residents

Following the experience of authors such as Haluck *et al.*^[296], we think that the University Hospital Marqués de Valdecilla resident training meets a number of requirements^[309]: (1) Our curriculum in laparoscopic procedures is developed during the full residency period. We think like Sadideen *et al.*^[310] that the first steps in surgical skill training have to be done outside the theatre and that practice is the most important thing to achieve automaticity in surgical skills. In the clinical environment, the needs of the patient prevail over the needs of the trainee; (2) The curriculum is compound by 19 laparoscopic modules; this allows the trainee to progressively gain competence as he learns. At the same time, each year modules are more technically advanced; (3) We support training in a simulated environment and advance in the learning curve during simulation. We have observed that doing gastrointestinal anastomosis and colonic resections this curve is shorter and increases patient safety^[311]; (4) Working with the most realistic models in each training phase, we observed that an important part of the initial training can be performed with low cost animal "ex vivo" models. Some examples are gastrointestinal anastomosis, cholecystectomy or gastric bypass; (5) The modular curriculum covers not only technical skills competencies but also teamwork competencies during crisis in laparoscopic surgery procedures. Teamwork competencies are trained in hybrid simulators; (6) The training process of the resident is assessed with Global Rating Scales of Operative Performance. Even though we also apply this assessment to the clinical practice, it is very difficult to move this assessment to the professional competence^[312]; and (7) The ACS accredits this training program and the center where it is developed.

We think that progress is very difficult and it may be necessary a trial/error system that let us advance. Learning from other programs that have tried, failed or succeeded may be a key point^[313].

Current challenges of resident training in laparoscopic surgery

For most of the groups around the world, the most important challenge is defining how simulation based training can be implemented and improve the training system. There are many questions to be answered, as we cannot say with scientific evidence in which degree simulated training improves results or quality in clinical practice and patient safety.

Simulators have to improve their benefits and design, and objective measures have to be developed so we can say in which degree the trainee acquires the adequate clinical competencies that can be translated in to the theatre^[314].

How can we keep and improve the acquired training during residency?

Mattar *et al.*^[315] observed that general surgery residency inadequately prepares trainees for fellowship results of a survey of fellowship program directors.

Fellowship programs are well established in countries such as the United States, Canada, United Kingdom or Australia. On the other hand, they have not had a good degree of implementation in the rest of Europe or in Eastern countries. These fellowship programs are advanced laparoscopic surgery training programs that have their own problems. Fellowships coexist with residency programs in the same institution and the continuous advance of new surgical techniques and the complexity of the surgical equipment make that some of the training is short in time or objectives. These reasons are making fellowships more and more specific as the recent fellowships in robotic colorectal surgery or rectal surgery is^[316].

The development of national training programs in advanced laparoscopic surgery, such as the one developed in the United Kingdom^[317] in laparoscopic colorectal surgery (Lapco) have shown good results in terms of short- and long-term training and have had a positive impact on the trainee learning curves^[318,319].

There are an increasing number of short length training courses in advanced laparoscopic surgery. They are usually limited to 3-5 d and they include live procedures performed by expert surgeons in most of the cases. Some theoretical knowledge is also given either during the course or on-line and, in some cases, the trainees have the opportunity to practice the technique on an animal or cadaver model. These courses have been mostly developed in colorectal, bariatric and upper gastro-intestinal surgery.

The impact of these courses on the training of the participant will depend on his previous experience in laparoscopic or open surgery. This way, we see that surgeons that come to a course with previous laparoscopic experience posteriorly implement the acquired knowledge during the course in a 60%-70%. Without this experience the degree of implementation is under 25%^[320,321]. Kinoshita *et al.*^[322] have demonstrated in Japan that after a training course in gastric laparoscopic surgery the number of laparoscopic gastrectomies increased in a 50% in the participating institutions. Participants answered to the survey saying that they felt improvement in their surgical skills in 100% of the initial procedures. On the other hand, Brunckhorst *et al.*^[323] say that there is very poor evidence concerning the training value of live operations and that very few high quality studies have been performed in this field.

Our point of view is that these 3-5 d courses provide knowledge and skills that help the trainee in starting laparoscopic surgery in an already established unit. These courses also help surgeons in sharing experience with experts.

In summary, we can say that current literature consistently proves the positive impact of simulation in theatre time and the scores in predefined performance but, however, this is not enough to ensure the transfer of these lab acquired skills to the theatre.

Which is the future of surgical training?

We are living a huge technological advance in all social scopes and also in surgical training^[324]. In this context, the acquisition of knowledge is progressively moving to e-learning platforms that reduce classroom hours. This system includes interactive feedback with the instructor, assessment of the procedure and interaction with other participants. This system may also be combined with VR training^[325].

VR simulators for laparoscopic surgery have been importantly improved with haptic technologies. In the near future, it may even be possible to import real 3D images to VR software. This may allow the trainees to perform real operations in virtual surgical fields that look like the real ones. Modelling this imported images, the trainee may even be able to work in fields with anatomical variations^[326].

"Virtual cadavers" based on 3D images reconstructed from computerized tomographies will replace human cadaver and animal models. It will be possible to create huge libraries with this "virtual cadavers". The exposure to multiple scenarios during the same basic procedure will make easier the trainee progress from competency to expertise.

Tele-simulation will be possible thanks to this libraries allowing tele-training. Virtual environments as second life (SL) will be used to completely represent a training centre or meeting room. These environments are already available in the market and can make possible the interaction of scenarios, patients, VR simulators, lectures or videoclips. Surgeons will be able to build their own virtual clinic or whatever they may need to simulate according to the level of competency that is trained^[327].

Tele-mentoring^[328] using robots as RP-7 (RP-7, Intouch Health, Santa Barbara, California) makes possible active mentoring of the trainees with verbal instructions or changing position of the instruments/camera when needed. It also makes possible a passive mentoring just with verbal instructions. This tele-mentoring seems to be a valuable tool for training minimally invasive procedures.

Now is the moment when all this separate tools, laparoscopic surgery, tele-presence, VR, digital image, networking... join together making tele-surgery possible. A surgeon is able to be miles away from the theatre and assist a surgical procedure.

Robotic surgery has been progressively incorporated to advanced laparoscopic procedures and has made those procedures easier. Robotics will facilitate the training of those surgical procedures. Mixing VR or virtual libraries with the surgical console of the robotic

surgical systems will make it possible to train the procedure before doing it in the real world. It will make training a particular procedure in a particular patient possible.

In summary, we should imagine a surgeon being trained in his work environment in complex minimally invasive procedures by another surgeon that is "on-line". Robotic surgical systems will be present in daily work and training.

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